TTI-2-18-71-151-3

TEXAS A&M UNIVERSITY
1876

TEXAS
TRANSPORTATION
INSTITUTE

STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATIO

COOPERATIVE
RESEARCH

OPERATIONAL CHARACTERISTICS OF MAYS RIDE METER

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 151-3
STUDY 2-18-71-151
MAINTENANCE

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. TTI-2-18-71-151-3	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle OPERATIONAL CHARACTERISTICS OF MAYS RIDE METER	5. Report Date September 1976
	6. Performing Organization Code
7. Author(s) J. A. Epps, C. W. Shaw, G. G. Harvey, J. P. Mahoney, and W. W. Scott, Jr.	8. Performing Organization Report No. Research Report No. 151-3
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University College Station, Texas 77843	10. Work Unit No.
	11. Contract or Grant No. Study No. 2-18-71-151
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051; Austin, Texas 78763	13. Type of Report and Period Covered Interim - September 1973 September 1976
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Study Title: "Maintenance Quality, Methods and Ratings."

16. Abstract

A review of the literature together with field data obtained for the vehicle mounted Mays Ride Meter roughness measuring device is presented.

The operational characteristics of the Mays Ride Meter are presented by examining the type of vehicle in which it is used, changes in vehicles with time, and the effects of tire pressure, air temperature, passengers and luggage, wet or dry pavements, wind velocity, vehicle speed, and driver variability. Utilizing the above information, guidelines are recommended concerning operational control for the instrument.

Field data obtained in 1974 on statewide randomly located pavement sections is presented so that typical values for mean, standard deviation, and coefficient of variation may be observed.

17. Key Words Mays Ride Meter, roughness, performance, pavement evaluation, road meter.	18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 121	22. Price

Form DOT F 1700.7 (8-69)

OPERATIONAL CHARACTERISTICS OF MAYS RIDE METER

by

J. A. Epps, C. W. Shaw,

G. G. Harvey, J. P. Mahoney and W. W. Scott, Jr.

Research Report 151-3

Maintenance Quality, Methods and Ratings

2-18-71-151

Sponsored by

State Department of Highways
and Public Transportation

in Cooperation with

U.S. Department of Transportation

Federal Highway Administration

September 1976

Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

PREFACE

The information contained herein was developed on Research Study 2-18-71-151, titled "Maintenance Quality, Methods and Rating" in a cooperative study with the Texas State Department of Highways and Public Transportation.

The primary purpose of this report was to investigate certain operational features of the Mays Ride Meter roughness measuring device now being used by the SDHPT. Only the automobile mounted Mays Ride Meter was evaluated.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the Texas State Department of Highways and Public Transportation personnel in all districts as well as Divisions D-10 and D-18 for participating in field measurement activities. Particular thanks go to Messrs. S. G. Cox, Jr., R. P. Hudson, I. E. Larrimore, Jr., K. D. Hankins and A. B. Hubbard.

ABSTRACT

A review of the literature together with field data obtained for the vehicle mounted Mays Ride Meter roughness measuring device is presented.

The operational characteristics of the Mays Ride Meter are presented by examining the type of vehicle in which it is used, changes in vehicles with time, and the effects of tire pressure, air temperature, passengers and luggage, wet or dry pavements, wind velocity, vehicle speed, and driver variability. Utilizing the above information, guidelines are recommended concerning operational control for the instrument.

Field data obtained in 1974 on statewide randomly located pavement sections is presented so that typical values for mean, standard deviation, and coefficient of variation may be observed.

Key Words:

Mays Ride Meter, roughness, performance, pavement evaluation, road meter.

SUMMARY

A review of the literature together with field data obtained from the vehicle mounted Mays Ride Meter roughness measuring device is presented. Conclusions obtained from this study support the following operational guidelines:

1. Vehicles to be utilized as Mays Ride Meter test vehicles should have coil springs and standard suspension systems unless data are developed to demonstrate the adequacy of other types of vehicles.

2. Each test vehicle should be calibrated.

3. Control sections should be established as described in Appendix A and periodic check runs made to insure that the equipment remains in calibration.

4. Recalibration should be performed when the control sections indicate an out of calibration condition or after about 20,000 miles of operation. After 20,000 miles new standard shock absorbers and new tires should be installed and the front end aligned.

5. The tire pressure should be checked daily when the vehicle is in use and should be adjusted to the pressure used when the vehicle was last calibrated. For the TTI 1975 LTD, this pressure is currently 30 psi for the front and back tires. The tires should be checked after a minimum travel distance of five miles and no more than ten miles. This will allow the tires to heat to a somewhat standardized temperature.

6. Testing should be curtailed at temperatures below 25°F unless data are available for the test vehicle which will allow an appropriate temperature correction to be made.

7. Two operators and 100 pounds of luggage is all that should be allowed in the vehicle. The gasoline tank should be maintained above 1/4 full.

8. Testing can be allowed during light rainfall provided the pavement does not pond water.

9. Testing should be curtailed when cross winds exceed 15 mph.

10. The test speed should be maintained at 50 mph ± 3 mph.

11. Drivers should be familiar with the vehicle and understand the variation in Serviceability Index that can result from poor operational control.

IMPLEMENTATION STATEMENT

Information contained in this report supports the use of the Mays Ride Meter as a pavement roughness measuring device. The Mays Ride Meter is an integral part of the Maintenance Rating System and is utilized by some districts to determine pavement rehabilitation and maintenance needs. Adherence to operational guidelines for the Mays Ride Meter as outlined in this report will minimize errors associated with the determination of Serviceability Index from Mays Ride Meter roughness measurements.

TABLE OF CONTENTS

INTRODUCTION

The evaluation of the condition or quality of a roadway is an essential and continual job of the highway engineer. This assessment of quality usually involves a consideration for features both on and off the pavement which affect the ability of the roadway to carry traffic in a safe and economical manner. The evaluation of the pavement has received considerable attention in the last 20 years, and is most often undertaken for the purpose of assessing rehabilitation and maintenance needs. The pavement evaluation process has historically involved the following items (1);

1. Evaluation of physical deterioration such as cracking, deformation and disintegration,
2. Evaluation of structural or load carrying capacity,
3. Evaluation of user-related effects such as roughness, safety, noise and appearance and
4. Evaluation of user-related costs and benefits associated with varying serviceability and safety and with various rehabilitation measures.

User-oriented and mechanistic evaluation procedures can be utilized to assess the items listed above. Objective mechanistic evaluations have historically been concerned with measuring in quantitative terms items such as pavement cracking, road roughness and skid resistance. User-oriented evaluations are subjective and usually involve the utilization of a panel of highway users to define adequacy of a specific highway feature such as road roughness, signing, noise, etc.

The output from the subjective user evaluations and the objective mechanistic evaluations taken at any particular time is usually referred to as the level of service. The history of this level of service, or serviceability, with time is a measure of highway and/or pavement performance. Both the level of service and the serviceability of a pavement are important inputs for the determination of rehabilitation and maintenance needs of a highway network or for a particular project.

The purpose of this report is to investigate certain operational features of a mechanistic pavement roughness measuring device. This device, the Mays Ride Meter, is presently being utilized by the Texas State Department of Highways and Public Transportation as well as other agencies to evaluate road roughness. Both automobile and trailer mounted devices are presently utilized; however, this report concerns only the evaluation of the automobile mounted device.

A historical review of the development of methods to evaluate road roughness is presented. The major portion of the report will be devoted to defining the effects of operational variables on the performance of the Mays Ride Meter. Data will be presented to illustrate the effect of tire pressure, air temperature, passenger and luggage weight, wind velocity, vehicle speed, driver training and rainfall on recorded pavement roughness. Mays Ride Meter operational guidelines are contained in the report based in part upon the data presented in this report.

MEASUREMENT OF ROAD ROUGHNESS

Pavement roughness evaluation has received considerable attention from most highway and airport agencies as road roughness affects the safety of individuals using the highway, the riding quality of the roadway, the pavement loading (especially the impact loads from heavy vehicles and the remaining service life of the pavement) (2). The development of techniques to measure roughness have allowed engineers to make wide use of these data. Examples are; (3, 4, 5)

1. Construction quality-control
2. Allocation of maintenance and rehabilitation funds
3. Pavement research needs.

Specifications have been prepared requiring a certain pavement smoothness. Pavement roughness measurements are then utilized to furnish information for specification compliance. Additionally, areas of pavement can be identified which require corrective action by the contractor. In the case of portland cement concrete pavements, grinding has been used as a solution.

Allocation of maintenance and rehabilitation funds should be based in part upon roughness measurements. Roadway segments can be identified for maintenance or rehabilitation from a roadway network by establishing criteria and making measurements. A systematic and statewide or agency wide survey should be made on a periodic basis thus allowing the determination of pavement performance.

Pavement research efforts require that the performance of in-service pavements be defined. Pavement roughness from a user standpoint is one of, if not the most important, characteristic of performance; thus, it is important to the pavement design engineer to determine the performance of various pavement designs and to define the life of various maintenance and rehabilitation treatments for particular types of pavements. A wide variety of other uses can be made of pavement roughness information by the research engineer.

As indicated above, a major use of roughness measurements is for the establishment of pavement performance. Methods for measuring pavement performance and the associated definitions were first established at the AASHO Road Test (6). These definitions are utilized by most agencies in the United States and are reviewed below (6).

Present Serviceability - The ability of a specific section of pavement to serve high speed, high volume, mixed truck and automobile traffic in its existing condition.

Present Serviceability Rating (PSR) - The mean of the individual ratings made by the members of a specific panel of people selected for this purpose.

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

Performance - The serviceability trend of a section of pavement with increasing number of axle load applications (7).

At the AASHO Road Test a panel of raters traveled a roadway segment and evaluated that section in regard to its serviceability as defined above. In order to rate each section, a numerical rating from 0 to 5 was incorporated into the system. Table 1 lists the numerical rating and range of general pavement conditions which each represents.

Each rater would, in effect, ask himself: "How well would I

TABLE 1. Present Serviceability Numerical Index

4.0 - 5.0	Very good
3.0 - 4.0	Good
2.0 - 3.0	Fair
1.0 - 2.0	Poor
0.0 - 1.0	Very poor

TABLE 2. Number of Raters Per Panel Required for Minimum Permissable Errors

	No. of Raters Required	
Permissable Error	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

(after reference 8)

like to drive over roads just like this section all day long?" Having done this, he would then assign a number, within a range of one-tenth of a point, to which rated the pavement section's existing condition. If the pavement was considered to be "good" and approaching "very good", it might be given a rating of 3.8 or 3.9.

Reliability became a problem since a PSR is based on the average of the several individual ratings given a particular section. How many ratings were enough to evaluate the pavement? Investigations at Purdue University (8) resulted in a determination of the number of raters required within various permissible errors of the "true" PSR. Results with 90 and 95 percent probability levels are shown in Table 2.

From Table 2, a panel of three raters will have deviations from the "true" PSR of magnitude which are definitely unacceptable from a reliability standpoint. Hughes (9) states that the rideability as determined by rating panels encounters too wide a range of deviations to have any reliable accuracy. He also states that for an effective means of determining pavement conditions, the differences between any two rating teams on a given section should, in general, be within ± 0.3 for a 90 percent probability. This would require a panel rating system of twenty-one raters, which was not practical for use at the AASHO Road Test nor is it practical for most applications today.

More reliable and faster methods of determining pavement performances were needed. Thus the AASHO Road Test staff established correlations between panel ratings and objective mechanistic evaluation tools (7). This correlation involved measurements of longitudinal profile variations, the amount of cracking and patching and in the case of flexible pavements, transverse profile variations (rutting). For both rigid and flexible pavements a formula was obtained allowing the computation of a Present Serviceability Index which closely approximated the mean rating of the panel derived Pavement Serviceability Rating. Additional research (10) has indicated that Present Serviceability Rating can adequately be represented by road roughness measurements. Correlation of the roughness measurements with panel ratings result in a Present Serviceability Index often referred to as Serviceability Index or SI.

With the apparent need for roughness measuring instruments well defined at the AASHO Road Test, a number of devices were developed. For convenience these devices can be grouped according to the following categories.

1. Profilometer
2. Mechanical vibrometer and
3. Precise leveling.

Speed of operation, advantages, disadvantages, research needs and agencies that utilize these various roughness measuring devices grouped according to the above format are shown in Table 3. It should be noted that not all of these devices were developed after the AASHO Road Test thereby indicating that the importance of roadway roughness existed long before formalized definitions were established. A brief discussion of roughness measuring devices follows (3).

Profilometer

Rolling straight edge measuring equipment was used in the United States as early as 1900. Since that time, numerious profile measuring devices identified by such names as Viagraphs, profilograph, and profilometers have been developed and utilized by highway and airport agencies.

TABLE 3. Pavement mechanistic evaluation-roughness evaluation.

CATEGORY	METHOD	QUANTITY MEASURED	SPEED OF OPERATION	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION	RESEARCH NEEDS
Profilometer	Rolling Straight Edge (Calif. U of Michigan, Illinois, French, Others)	Vertical Movement	Slow	*Repeatability	*Operating Speeds *Measurement of Certain Wave Lengths	*California Division of Highways *University of Michigan *Other Agencies (3)	*Increase Speed of Operation and Measurement of Certain Wave Lengths
	CHLOE Profilometer	Slope Variance	Slow	*Repeatability	*Slow Operating Speed *Measurement of Long and Short Wave Lengths *Movement of Towing Vehicle	*AASHO Road Test *General States (3)	*Increase Speed of Operation and Measurement of Certain Wave Lengths
	British - RRL	Vertical Movement (Inches Per Mile)	Slow	*Repeatability *Calibrations of Other Roughness Measuring Devices	*Slow Operating Speed *Measurement of Long Wave Lengths	*Several Canadian Provinces *Canadian Ministry of Transport *British - R.R.L. (3)	*Speed of Operation and Measurement of Long Wave Lengths
	Surface Dynamics Profilometer	Aptitude and Length of all Waves	Moderate	*Repeatability *Calibration of Other Roughness Measuring Devices *Measurement of Long Wave Length	*High Capital and Operating Costs *Highly Skilled Operating Personnel ReQuired for Operation *Data Reduction Costs *Complexity of System *Not a Direct Measure of Vehicle Ride Characteristics	*General Motors *Texas *Michigan (3)	*Transfer Function for Roadway Wave Length and Frequency to User Opinion
Mechanical Vibrometer	VIA-Log	Relative Vertical Movement Between Rear Axle and Mass (Body of Car)	Traffic Speed	——	——	*Developed in 1926 and Utilized in New York State (2)	
	PCA	Relative Vertical Movement Between Rear Axle and Mass (Body of Car)	Traffic Speed or 50 MPH	*Low Cost *Simplicity and Ease of Operation *Speed of Operation *Mass Inventory Possible *Portability of Equipment	*Repeatability *Affected by Environment *Does Not Measure True Amplitude or Length of Waves	*Wisconsin *Washington *California (3)	
	Mays Ride Meter	Relative Vertical Movement Between Rear Axle and Mass (Body of Car)	Traffic Speed or 50 MPH	*Low Cost *Simplicity and Ease of Operation *Speed of Operation *Mass Inventory Possible *Portability of Equipment *Continuous Record	*Repeatability *Affected by Environment *Does Not Measure True Amplitude or Length of Waves	*Texas (3)	*Improve Repeatability of Results *Identify Significant Vehicle and Environmental Factors Affecting Roughness Measurement *Improve Data Handling Technique
	Cox and Son	Relative Vertical Movement Between Rear Axle and Mass (Body of Car)		*Low Cost *Simplicity and Ease of Operation *Speed of Operation *Mass Inventory Possible *Portability of Equipment *Continuous Record	*Repeatability *Affected by Environment *Does Not Measure True Amplitude or Length of Waves	*Research Activities (2)	
	BPR Roughometer	Relative Vertical Movement Between Wheel and Mass (Trailer)	20 MPH	*History of Use	*Low Operating Speed *Attenuation of Wave Lengths in the Ride Frequency Range *Repeatability and Constancy Related to Calibration	*Several States (3)	
Precise Leveling	Rod and Level	Amplitude and Length of All Waves	Slow	*Precise Measurement *History of Use	*Slow Operating Speeds *Safety *"Down Time" of Facility *Not a Direct Measure of Vehicle Ride Characteristics	*Agencies Associated with Airfields (3)	*Increase Speed of Operation *Transfer Function for Roadway Wave Length and Frequency to User Opinion
	Traveling Rod and Laser Beam	Amplitude and Length of All Waves	Slow	*Precise Measurement	*Slow Operating Speed *"Down Time" of Facility *Not a Direct Measure of Vehicle Ride Characteristics	*Under Development (2)	

After reference (3).

Correlation of user-oriented performance evaluation with roughness measurements was formalized at the AASHO Road Test. The Chloe profilometer was utilized, in part, for this correlation.

Surface dynamic profilometers have received increased use in the last 10 years as research tools and for calibration of other roughness measuring equipment. Surface dynamics profilometer equipment promises to be the most desirable method of this category of equipment to measure road profile characteristics. Its major advantages are

1. Determination of actual profiles,
2. Capability of handling large amounts of data by automated means,
3. Operating speeds sufficient to cover reasonable amounts of pavement in a reasonable time,
4. Capability of detecting and analyzing longer wave lengths in the pavement,
5. Excellent repeatability, and
6. Capability of use for calibration of car road meters.

Mechanical Vibrometer

This category of equipment measures vertical movement between the axle of an automobile or a wheel in the case of trailer devices and the mass automobile or wheel supports. The State of New York developed a device called a Via-Log prior to 1926. This device measured the vertical movement between the front axle and the body of the car. Similar devices commonly referred to as the PCA road meter, the Mays Ride Meter and the Cox and Son road meter have been developed by using many of the same principles. The major advantages offered by this newer equipment are in terms of improved measuring and recording equipment, thus allowing higher speeds of operation.

Limited work has been performed on measuring runway and taxiway roughness with instrumented aircraft. Certainly this is an area that deserves further consideration from both a vehicle operational standpoint and a passenger standpoint.

In 1941 the Bureau of Public Roads reported the development of a trailer unit capable of measuring road roughness. This device, known as the BRP roughometer, has been widely used and correlated with performance evaluations. Excellent repeatability and possible use as a calibrator for other roughness measuring devices make its use attractive.

This category of roughness measuring devices does not give a reliable measure of roughness wave length.

Precise Leveling

The precise leveling method has been utilized for a number of years. A survey rod and level have been widely used on airfields and some highways. Research on the application of laser beams together with a traveling rod have been reported that will offer a faster and perhaps more reliable method.

From the above discussion it is apparent that several different types of pavement roughness measurement devices have been developed and utilized. The mechanical vibrometer types of instruments and in particular the PCA and Mays Ride Meters have been utilized extensively by highway agencies primarily for mass inventory purposes (Table 4). Highway Research Board Special Report 133, "Pavement Evaluation Using Road Meters," (11) contains the proceedings of a workshop held to identify the uses of and problems associated with road meters. The

TABLE 4. Areas of Applicability for Various Types of Roughness Measuring Equipment

Type of Facility	Construction Monitoring	Mass Inventory
Expressway or Primary Highway	BPR Roughometer Car Ride Meters Surface Dynamics Profilometer Rolling Straight Edge (British Road Research Laboratory) (CHLOE Profilometer)	Car Ride Meters Surface Dynamics Profilometer (British Road Research Laboratory) (CHLOE Profilometer)
Secondary (Rural) Highway	BPR Roughometer Car Ride Meter Rolling Straight Edge (Surface Dynamics Profilometer) (British Road Research Laboratory) (CHLOE Profilometer)	Car Ride Meters (Surface Dynamics Profilometer) (British Road Research Laboratory) (CHLOE Profilometer)
Country or Local Rural Highways	BPR Roughometer Car Ride Meter Rolling Straight Edge (Surface Dynamics Profilometer)	Car Ride Meters
Airfields	Car Ride Meters Surface Dynamics Profilometer British Road Research Laboratory (Precise Level)	Car Ride Meters Surface Dynamics Profilometer British Road Research Laboratory (Precise Level)

1. Brackets denote applicability primarily for special purposes of control sections.

majority of the papers presented at this conference were concerned with the PCA road meter. This report will be concerned with the Mays Ride Meter; which, like the PCA road meter, provides the following:

1. A reasonable estimate of Pavement Serviceability Rating,
2. Provides satisfactory uniformity of rating on a statewide basis,
3. Reproducible within acceptable limits,
4. Requires minimal manpower,
5. Economical to operate and
6. Easily transported.

An additional advantage of the Mays Ride Meter is its ability to provide graphical depiction of road roughness on chart paper and keyed to some location along the highway.

DESCRIPTION OF MAYS RIDE METER

The Mays Ride Meter was developed by Ivan K. Mays in 1967 and first utilized in an automobile. Several improvements have been made in both the measuring system and data display system since 1967. Additionally, the Texas State Department of Highways and Public Transportation has installed several Mays Ride Meters in trailers in the last year. Details of the changes in the Mays Ride Meter can be obtained from conferences 12 and 13 or from the Rainhart Company, manufacturers of the Mays Ride Meter unit or File D-10R of the Texas State Department of Highways and Public Transportation.

The basic reasons for developing a trailer to house the Mays Ride Meter sending unit were to reduce cost in that an automobile would not be "tied-up" solely as a roughness measuring unit and to allow for the measuring unit to be easily transferred from district to district. Additional benefits that may be obtained include control of some of the variables affecting roughness measurements such as vehicle weight, variations in suspension systems and vehicle alignment.

Data contained in this study were obtained from Mays Ride Meters installed in automobiles since the majority of Mays Ride Meter units throughout the country are installed in automobiles and because of the late development of the trailer units. A description of the unit as installed in an automobile is given below.

The two main components of the Mays Ride Meter system are both contained within the vehicle. The transmitter is conveniently mounted out-of-the-way in the trunk directly over the center of the differential housing. A cable extending directly from the digital transmitter is attached to the center of the differential housing. This creates a solid drive mechanism for the transmitter and thus gives more nearly accurate input to the recorder. The recorder is self-contained within an aluminum housing and is connected to the transmitter by its umbilical cord. Power for the unit is obtained from the 12-volt DC negative-ground system of the vehicle (12).

As the vehicle travels over the road surface, the transmitter detects both the direction and magnitude of relative vertical motion between the automobile and the axle housing with 0.1 inch resolution. The recorder and its associated systems employ electrically transmitted data in providing a continuous record of the road surface roughness. The variable-rate chart-feed drives the chart in increments of 1/64 inch for each 0.1 inch of rear axle/body excursion. A distance trace (top, Figure 1) automatically (from a separate odometer) records distance information in increments of 0.05 miles. An event marker or landmarks

ROAD ROUGHNESS MEASUREMENT (Inches/Miles)

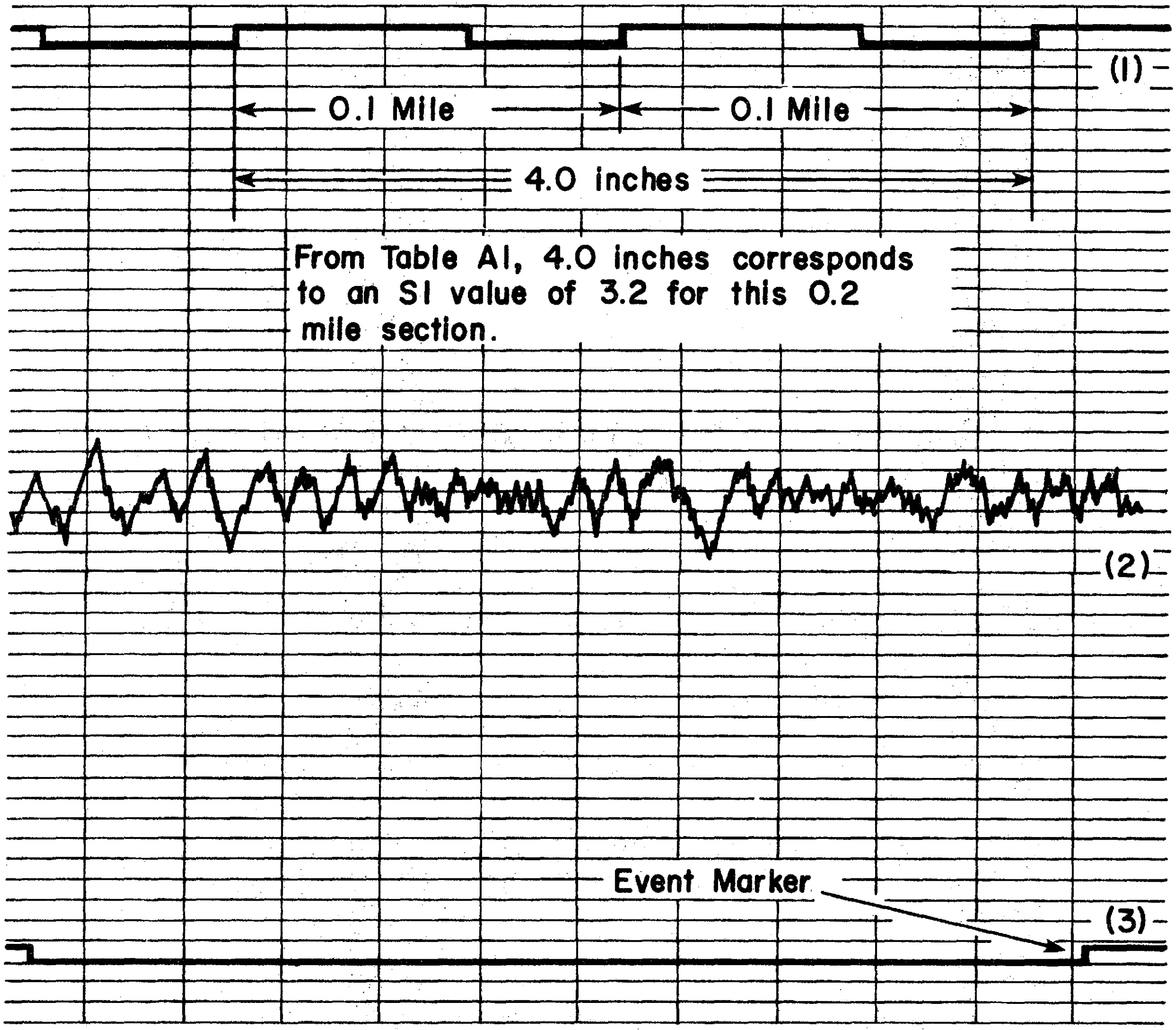


FIGURE 1. TYPICAL MRM ROAD ROUGHNESS MEASUREMENTS.

trace (bottom, Figure 1) is activated by a pushbutton switch which moves laterally to mark the beginning or ending of a section, bridge or overlay, or the locations of surface imperfections, highway intersections, etc. Field notes can be written directly on the chart thus avoiding expense, delay, or possible errors in transcribing them later. Within the housing, an illuminated desk is provided for making such field notes directly.

The profile trace (center, Figure 1) plots, at half the magnitude the rear axle excursions (plotting them in the same direction) thus displaying, directly, any surface imperfections.

Description of Test Vehicle

The design of the Mays Ride Meter is such as to require an ideal vehicle which closely relates the actual roughness excursions (without initiating or cancelling any). The ideal vehicle, as described by the Mays Ride Meter manufacturer, would have the following characteristics.

1. A full size body,
2. Front engine,
3. Solid rear axle,
4. Coil springs (front and rear),
5. Drag links (to keep the axle from wandering fore and aft),
6. Rear sway bar (to prevent the axle from wandering laterally),
7. Firm shock absorbers (the suspension must be hard enough to not bottom out readily but soft enough to generate adequate transmitter action),
8. Round tires (preferably ground, since cyclic out-of-roundness will appear as surface roughness),

9. Dynamically balanced tires,
10. A sufficiently accurate original equipment odometer and speedometer (automobile dealers can furnish a variety of transmission/speedometer take-off gears--one tooth difference is about 5 percent),
11. An automatic speed control device and
12. Air conditioning (this is highly desirable for driver comfort in hot climates and for the reliability of the electronic components. All solid state circuitry operates more reliably in a cool, dry environment; stepper motors and large resistors dissipate heat more readily).

Description of the Crew

Based on experience gained by the Texas Transportation Institute and the Texas State Department of Highways and Public Transportation, a two man crew should be utilized for obtaining mass roadway inventory data with the Mays Ride Meter. The driver must maintain a constant speed in a precise wheel path in order to obtain a reproducible measure of the pavement roughness. When accelerating, the vehicle will tend to squat; when braking, the vehicle will lift (dip forward); thus pitching is generated. The vehicle will roll when blanketed by a passing truck or traveling in a strong crosswind; and likewise the vehicle yaws when changing lanes or traveling out of the wheel paths. All of these extraneous motions will change the vehicle's attitude and will be recorded as roughness. The full attention of the driver is normally needed to reduce these factors to a minimum.

The second member of the roughness measuring team is required for navigation and recording pertinent information such as field notes and landmarks on the recording chart (Figure 1).

Correlation of Roughness and Present Serviceability Index

A correlation procedure developed by Walker and Hudson (14) allows the Present Serviceability Index to be determined from Mays Ride Meter roughness measurements. The procedure involves the use of the Surface Dynamics Profilometer as a basis to obtain a relationship between a Present Serviceability Rating obtained by a panel and Present Serviceability Index. The Mays Ride Meter output is then correlated with Surface Dynamics Profilometer output to obtain Serviceability Index (SI). The Surface Dynamics Profilometer provides an extremely accurate measure of roadway roughness as opposed to the Mays Ride Meter; however, operational costs are about 10 times that of the Mays Ride Meter (13). Thus, it was decided to use the Surface Dynamics Profilometer primarily as a standard roughness measuring instrument and for special research activities while the Mays Ride Meter units are used for inventory purposes.

The general relationship utilized to relate Serviceability Index and Mays Ride Meter roughness is shown below:

$$SI = 5e^{-\left(\frac{\ln M}{\beta}\right)^{\alpha}}$$

where:

SI = Serviceability Index

M = Mays Ride Meter roughness measurement, inches per mile

α and β = nonlinear regression coefficients

Usual values of α are in the range of 3 to 8 with the majority of vehicles in the range of 5 to 7. Some of the original equations were developed with linear regression techniques with α assigned a value of 5. Values of β are typically in the range of 5 to 6 (14) (Table 5).

TABLE 5. Statistical Regression Information Obtained by Surface Dynamics Profilometer Correlations with Mays Ride Meter

Mays Meter Vehicle	Calibration Date	Alpha	Beta	R^2	Standard Error for Regression	Mean Coefficient of Variation	Maximum SI Residual
1972 Ford Custom	15 Aug.,1973	7.24	5.54	0.999	0.162	0.237	0.52
	23 Aug.,1973	5.69	5.61	0.999	0.173	0.259	0.55
	5 Feb.,1974	6.96	5.25	0.998	0.222	0.255	1.00
	5 Mar.,1974	5.43	5.38	0.996	0.292	0.268	1.14
1975 Ford LTD	31 Mar.,1975	5.18	5.48	0.997	0.277	0.323	1.26
	13 May, 1975	5.24	5.52				
	23 Sept.,1975	7.37	5.40	0.998	0.220	0.251	1.47
	25 Sept.,1975	6.52	5.37	0.998	0.245	0.265	1.49
	10 Mar.,1976	8.40	5.27	0.998	0.223	0.257	1.41
	17 June,1976	8.88	5.28	0.996	0.318	0.253	1.88

Control of Serviceability Index Measurements

Accurate Serviceability Index values depend on proper use and operation of the Mays Ride Meter. Proper operation of the equipment can be insured by development of a set of control procedures in which Mays Ride Meter results are continually monitored. Control procedures have been developed by Walker and Hudson (14) and are further defined in Appendix A.

These procedures basically involve the establishment of pavement control sections over which the Mays Ride Meter travels immediately after calibration and at periodic intervals. Based on results from readings obtained on these control sections, two control charts are developed which are utilized for monitoring Mays Ride Meter validity. One chart referred to as the Mean Control Chart is utilized for checking the mean or average for repeated Serviceability Index values on a given section. The second control chart, called the Range Control Chart, is utilized for checking the variation among replicate values obtained on a given section. Typical mean and range control limits are shown on Table 6. These data indicate that the mean SI values for any given control sections should not vary more than ± 0.10 to ± 0.20 from its original mean value without an out of calibration condition being suspected. Likewise, the range of SI values obtained from measurements on a given section should not exceed 0.4 to 0.7 without suspecting an out of calibration condition.

OPERATIONAL FEATURES OF MAYS RIDE METER

In order to obtain a reliable Serviceability Index for a given roadway segment or values for a roadway network, the above calibration

TABLE 6. Typical Mean and Range Control Limits for Mays Meter Vehicle

		Control Limits for	
Vehicle	Date	Mean	Range
TTI - 69 Plymouth	Dec., 1971	±0.16	0.57
	June, 1972	±0.14	0.53
TTI - 72 Ford	Aug., 1972	±0.11	0.38
	Aug., 1973	±0.15	0.55
	Mar., 1974	±0.12	0.44
	May, 1974	±0.16	0.57
TTI - 75 Ford	Oct., 1975	±0.19	0.70
	July, 1976	±0.20	0.72
District 21 - Ford	April, 1972	±0.17	0.61
	Jan., 1973	±0.14	0.53
D-10R	Nov., 1974	+0.21	0.74

procedures must be utilized together with certain operational procedures. Initially, the operational procedures utilized were based on those used for the PCA ride meter since both instruments measure road roughness in a similar manner, i.e. record the deviation between the body of the vehicle and its axle. The study described below investigated the effect of operational variables on Mays Ride Meter output. These operational variables are those variables which can be controlled, to a large degree, by the agency operating the vehicle. Operational variables considered in the study include:

1. Type of vehicle,
2. Changes in vehicles,
3. Tire pressure,
4. Air temperature,
5. Vehicle weight,
6. Wind velocity
7. Speed of operation,
8. Driver of vehicle and
9. Wet or dry pavement.

Type of Vehicle

The selection of the type of vehicle for installation of the Mays Ride Meter may be important although each vehicle should be calibrated with a rating panel or other suitable method to determine Serviceability Index. General requirements for the vehicle have been described above. A review of vehicles utilized in 1972 for road roughness measurements indicate that the Ford Custom (11)* with

---

*The Ford Custom line of automobiles is no longer available. The Texas Transportation Institute is presently utilizing a Ford LTD.

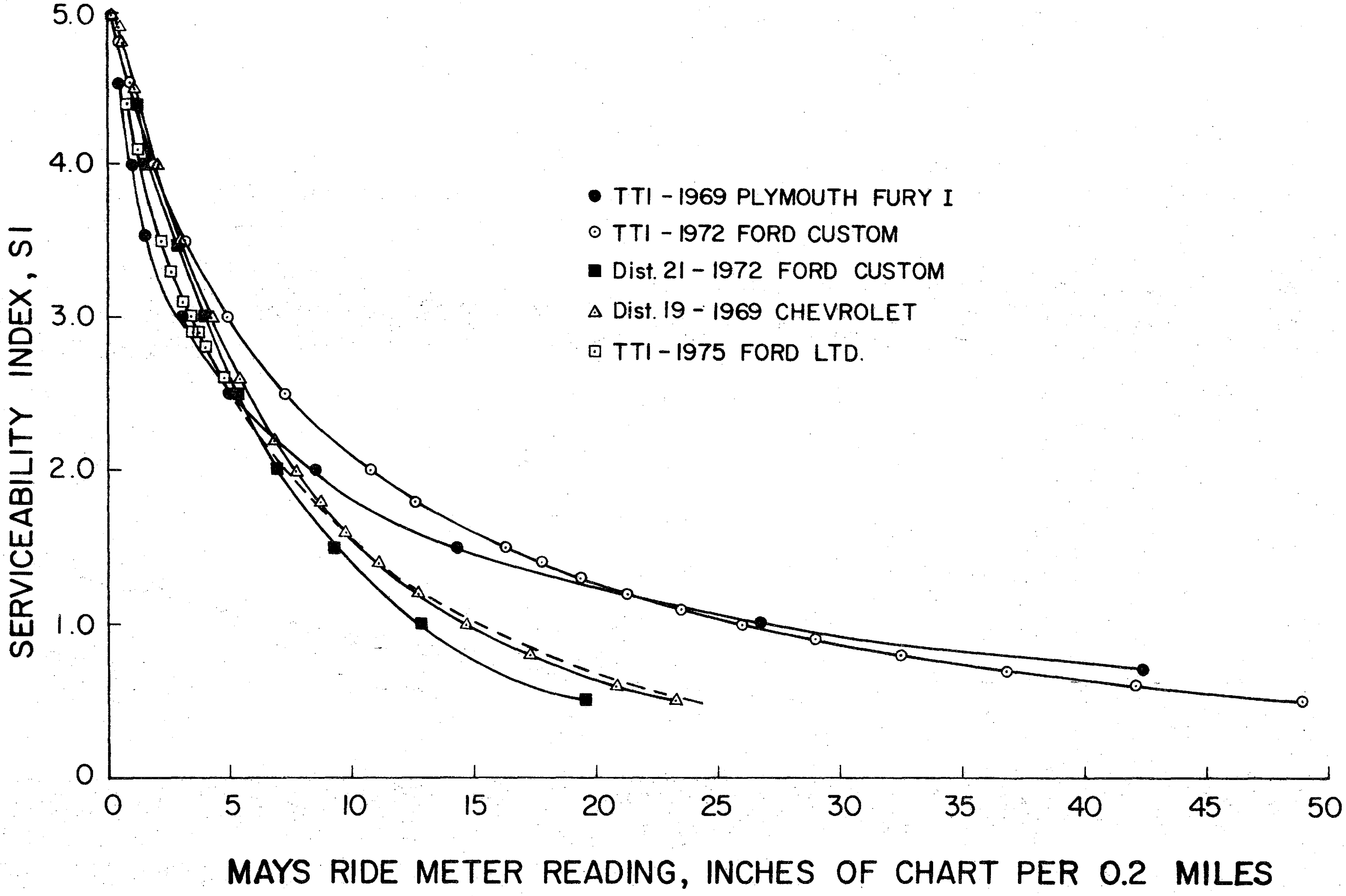


FIGURE 2. COMPARISON OF CALIBRATION CURVES FOR MAYS METERS.

standard suspension and coil-springs is popular. Calibration curves for five vehicles utilized in Texas are shown on Figure 2. The 1969 Plymouth Fury I utilized by the Texas Transportation Institute utilizes a torsion bar, leaf spring design while the 1972 Ford Custom and 1975 Ford LTD utilize coil spring suspension systems.

A comparison of Serviceability Index values obtained over roadway sections in District 19 with the District 19 Mays Meter Vehicle and a Texas Transportation Institute Vehicle are shown in Table 7.

A comparison of the response of vehicles with PCA ride meters can be found in reference 11 and in particular reference 15. Hughes (15) has presented data describing calibration curves obtained on similar model vehicles. Calibrations performed on ten 1966 Fords and six 1969 Fords of identical model and suspension system indicated that each vehicle should be calibrated to obtain the desired Present Serviceability Index accuracy. Argue's (16) data reinforce the observed need for calibrations to be performed on each vehicle to be used with ride meters.

Changes in Vehicles

Vehicles response to road roughness will change with time. Shock absorber wear, tire condition and loss of wheel alignment have been the most troublesome problems associated with the testing vehicle. Changes in calibration of the 1972 Ford Custom and 1975 Ford LTD are shown in Tables 8 and 9, respectively. A record of maintenance activities for these vehicles associated with the calibration runs is shown on Tables 10 and 11.

The 1972 Ford Custom was first calibrated with a mileage of 4,345 miles. After a year's use and at 41,565 miles, new heavy duty front

TABLE 7. TTI - District 19 Mays Ride Meter Correlation
October 1972 - Texarkana

Section	Highway Number	District 19 chart inches/ 0.2 mile	Dist 19 SI	TTI SI	Begin Point	End Point
945-1	FM 1397	3.1	3.1	3.1	.35 mi. past I-30	.55 mi. past I-30
1231-2	FM 1397	3.1	3.1	3.0	county road route	cross road
2879-2	FM 2240	4.7	3.0	2.7	0.8 mi. past FM 1397	1.0 mi. past FM 1397
2878-1	FM 2878	3.4	3.5	2.9	county road	0.2 mi. north county road
1020-1	FM 559	2.2	2.8	3.2	mile post #2	following culvert
2048-1	FM 2253	4.0	2.9	2.7	0.1 mi. past mile post #2	0.3 mi. past mile post #2
2050-1	FM 2148	3.5	3.3	3.3	0.2 mi. north of county road Lt	0.4 mi. north of county road
1231-1	FM 989	2.6	3.0	3.4	mile post #2 2.0 mi. past FM 2878	2.2 mi. past FM 2878
945-2	FM 558	3.4	2.9	3.2	1.15 mi. from begin .1 mi. past crossroad	.3 mi. past crossroad
2422-1	FM 2516	3.7	4.1	2.9	FM 989	0.2 mi. past FM 989
218-3	US 59	1.2	4.4	3.5	0.1 mi. south of county road crossing	0.3 mi. south of county road crossing
218-1	US 59	0.8		4.1	Robinson Road	0.2 mi. south of Robinson Road

TABLE 8. Comparison of Mays Ride Meter Calibrations - 1972 Ford Custom

Date	Inches of Mays Ride Meter Chart per 0.2-mile of Roadway					
PSI	16 Aug. 1972	15 Aug. 1973	23 Aug. 1973	5 Feb. 1974	5 Mar. 1974	22 May, 1974
0.5	48.9	15.7	20.6	11.6	16.5	15.9
1.0	26.0	11.6	13.9	8.7	11.1	11.0
1.5	16.3	9.2	10.3	6.9	8.1	8.3
2.0	10.8	7.5	7.8	5.6	6.2	6.4
2.5	7.3	6.1	6.0	4.6	4.8	5.0
3.0	4.9	4.9	4.6	3.7	3.6	3.9
3.5	3.2	3.8	3.4	2.9	2.7	2.9
4.0	1.9	2.8	2.3	2.2	1.8	2.0
4.5	0.9	1.8	1.4	1.4	1.1	1.2
5.0	0.0	0.1	0.0	0.1	0.0	0.0

TABLE 9. Comparison of Mays Ride Meter Calibrations - 1975 Ford LTD

Date	Inches of Mays Ride Meter Chart per 0.2-mile of Roadway					
PSI	31 Mar. 1975	13 May, 1975	23 Sept. 1975	25 Sept. 1975	10 Mar. 1976	17 June 1976
0.5	19.5	20.3	13.2	14.0	10.5	10.4
1.0	12.7	13.2	9.9	10.1	8.2	8.2
1.5	9.2	9.6	7.9	7.9	6.8	6.9
2.0	6.8	7.1	6.5	6.3	5.7	5.8
2.5	5.2	5.4	5.3	5.0	4.8	5.0
3.0	3.9	4.0	4.3	4.0	4.0	4.2
3.5	2.8	2.9	3.4	3.1	3.3	3.5
4.0	1.9	2.0	2.6	2.2	2.6	2.7
4.5	1.1	1.1	1.7	1.4	1.8	1.9
5.0	0.0	0.0	0.1	0.1	0.1	0.1

shock absorbers were installed and the vehicle calibrated. As expected, considerable difference in calibration existed between the first and second calibrations (Figure 3 and Table 8). Prior to the August 23, 1973 calibration, new rear shock absorbers were installed, the front end was aligned, the tires were replaced and the brakes were relined. As noted on Table 8 and Figure 3, a change in the calibration occurred; however, the maximum change in Serviceability Index numbers occurs only on the very rough roadways.

Brokaw (17, 18) does not recommend the use of heavy-duty shock absorbers as this type of shock absorber deteriorates at a faster rate than standard shock absorbers. An out of calibration condition existed after about 6 months of use of heavy duty shock absorbers on the 1972 Ford Custom. The calibration of February 5, 1974 was performed prior to the installation of standard shock absorbers. A comparison of these calibrations with that of August 23, 1973 indicates vehicle suspension changes that occur over about 22,000 miles of operation (Table 8 and Figure 3). Significant changes occurred during this period. Prior to the March 5, 1974 calibration, new standard front and rear shock absorbers were installed. The change from the older heavy duty shock absorbers to the new standard shock absorbers should be considered significant.

Calibration curves for the 1975 Ford LTD do not indicate large changes between calibrations as observed with the 1972 Ford Custom (Tables 8 and 9). However, it should be noted that the last available calibration was performed at 28,000 miles. A comparison of calibration curves obtained on September 23, 1975 and September 25, 1975 and curves obtained on March 10, 1976 and June 17, 1976 indicate that only slight differences in calibration occurred when new shocks and tires were

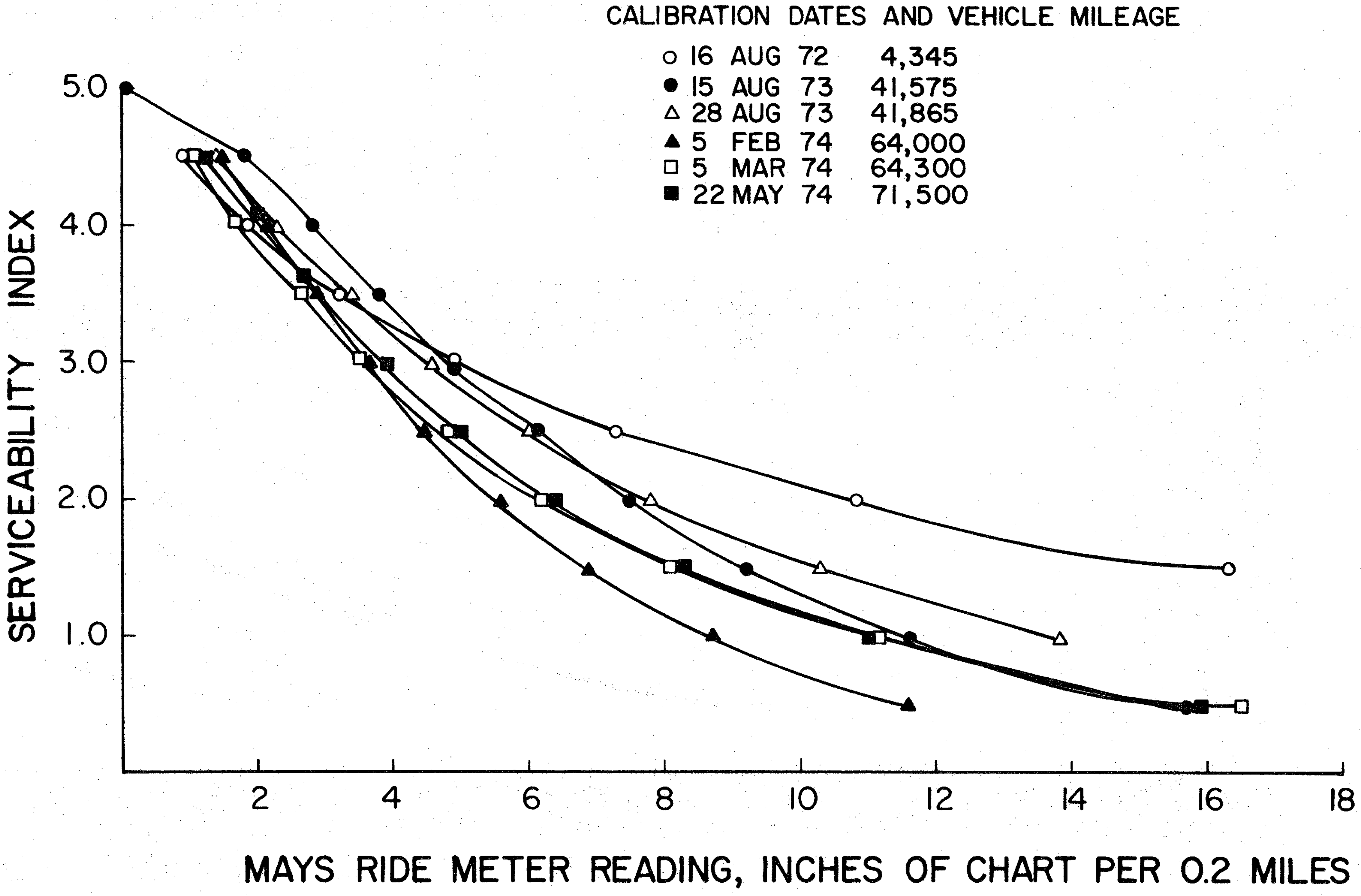


FIGURE 3. CALIBRATION CURVES FOR MAYS RIDE METER INSTALLED IN 1972 FORD CUSTOM.

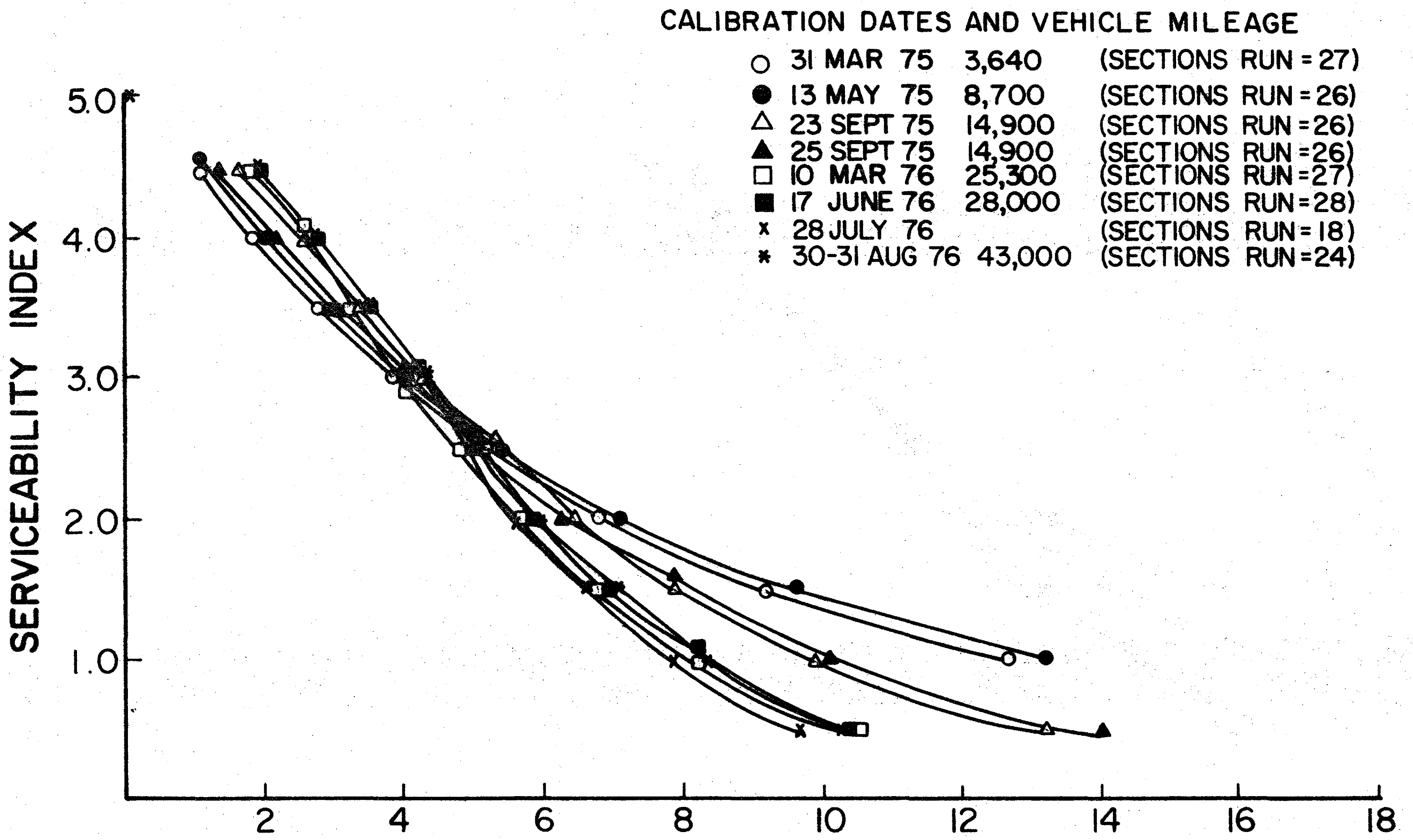


FIGURE 4. CALIBRATION CURVES FOR MAYS RIDE METER INSTALLED IN 1975 FORD LTD.

installed on this vehicle (Table 9 and Figure 4). It will be interesting to note the changes in calibration as vehicle mileage increases. Changes in vehicle calibration with shock absorber replacement has also been noted by LeClerc, Marshall and Anderson (19), Argue (16), Chong and Phang (20), and Hughes (15). These calibration changes are considered significant and recalibration is suggested.

Heavy-duty suspension systems have been evaluated by Hughes (15). These suspension systems reduced the movement between the rear-axle housing and the vehicle body, especially on smooth roads. Although heavy-duty suspension systems can be used on road meter vehicles, it is preferable to use standard suspension systems (15).

Based on these data it appears appropriate to recalibrate when shock absorbers are changed. Data are not available to adequately describe calibration changes when only tires and/or front end alignment is changed. Records such as those contained on Tables 8 to 11 should be kept for all Mays Ride Meters.

Tire Pressure

In order to determine if variations in tire pressure on the Mays Ride Meter vehicle affect the Serviceability Index, a series of tests was conducted with tire pressure as the only variable. A minimum of five runs were made over eight test sections at each of three different tire pressures--25 psi, 31 psi, and 35 psi. For some highway test section-tire pressure combinations one or two additional series of five measurements were made.

The range of 25 to 35 psi pressures was chosen because that is the range that is normally encountered in-service for vehicles of this type. An intermediate tire pressure of 31 psi was used in an attempt to determine if the relationship between Serviceability Index and tire

TABLE 10. Calibration and Maintenance Schedule for 1972 Custom Ford

Calibration Date	Mileage, Miles	Maintenance Work Performed on Vehicle Prior to Calibration
16 Aug. 1972	4,345	First calibration
15 Aug. 1973	41,575	New heavy-duty front shock absorbers installed
23 Aug. 1973	41,865	New heavy-duty rear shock absorbers installed, front end alignment, 4 new tires, brakes installed, and motor tune-up
5 Feb. 1974	64,000	
5 Mar. 1974	64,300	New standard front and rear shock absorbers installed
21 May, 1974	71,500	

TABLE 11. Comparison of Mays Ride Meter Calibration - 1975 Ford LTD

Calibration Date	Mileage, Miles	Maintenance Work Performed on Vehicle Prior to Calibration
31 Mar. 1975	3,640	First calibration
13 May 1975	8,700	No maintenance
23 Sept. 1975	14,900	Front end alignment
25 Sept. 1975	14,900	Four new tires and shocks
10 Mar. 1976	25,300	No maintenance
17 June 1976	28,000	Four new tires and shocks and front end alignment

pressure was linear or nonlinear. Thirty-one psi is the normal operating tire pressure for the TTI test vehicles.

The data as presented in Table 12 were analyzed in two ways. First, graphical "pictures" of the data were studied to determine whether any particular trend could be seen. The resulting graphical relationships are shown in Figures 5-12.

Analysis of these figures yielded only a somewhat vague "frequency distribution" of three types of plots. Figures 6, 7, 8, 9, and 12 seem to be similar in that the general trend exhibited is that as the tire pressure increases, the Serviceability Index value decreases. (This was the expected effect of varying the tire pressure; however, the significance of the magnitude of the Serviceability Index variation remained to be determined.)

Figure 5 is unique in that the average Serviceability Index values for both 31 and 35 psi tire pressure tests are higher than the average Serviceability Index at 25 psi. Figures 10 and 11 are similar to each other as the average Serviceability Index decreases as the tire pressure is increased from 25 to 31 psi, but it then increases slightly as the tire pressure is increased to 35 psi.

The effects noted in Figures 5, 10, and 11 are puzzling, but the differences from the expected trend are attributed to other uncontrollable test variables, such as wind, temperature, vehicle suspension, nature of pavement roughness, etc. The test program called for all of these variables to remain constant for all tests, but some variation could be expected if several of the variables introduced small additive changes simultaneously.

The second method of analysis was statistical. The results of an analysis of variance indicate that differences in the Serviceability

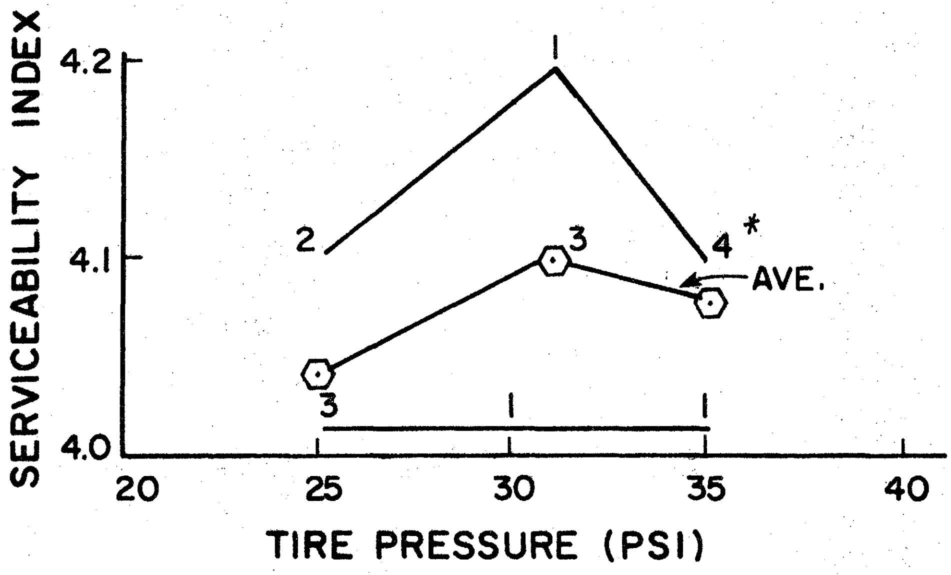


FIGURE 5. Tire Pressure Vs. S.I.~ FM 60

*Numbers Show Numberof Data Points With Indicated Values; Typical.

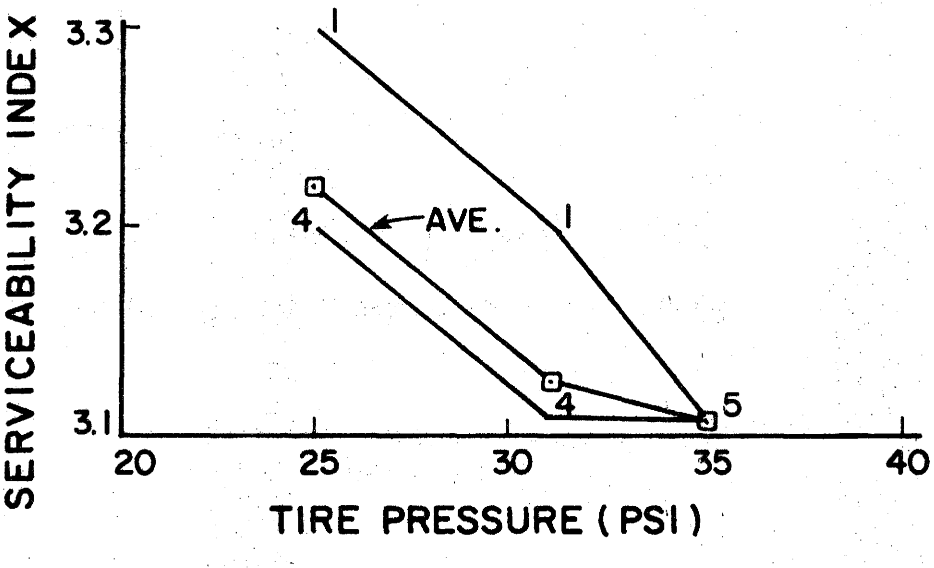


FIGURE 6. Tire Pressure Vs. S.I.~ FM 50-N

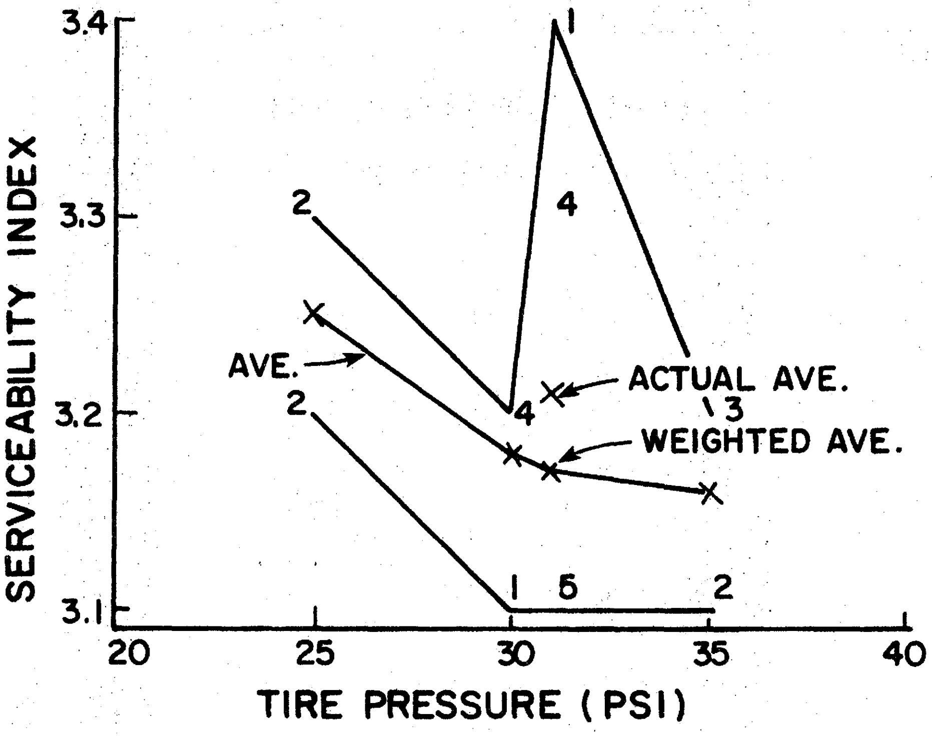


FIGURE 7. Tire Pressure Vs. S.I.~FM 2347

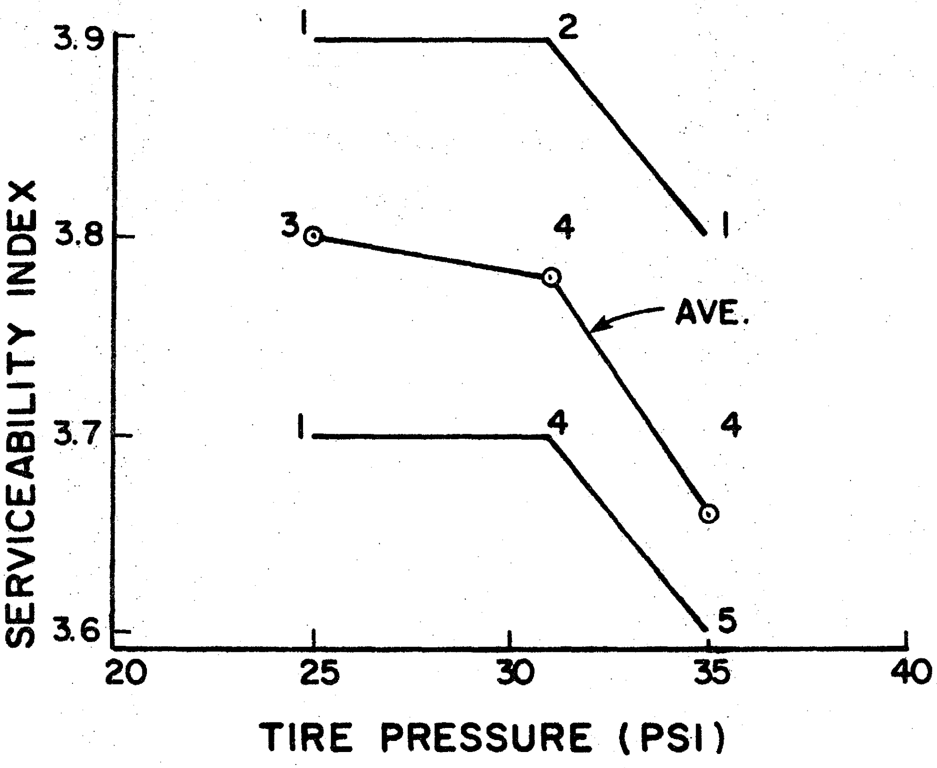


FIGURE 8. Tire Pressure Vs. S.I.~FM 50-S

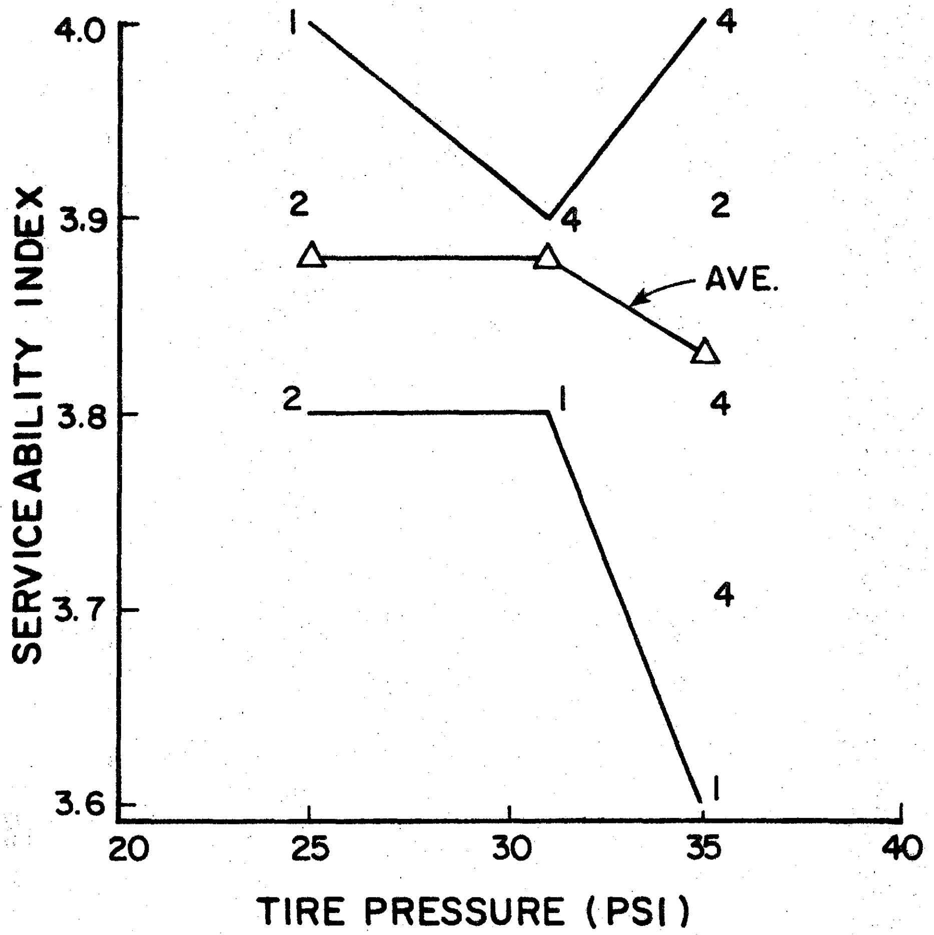


FIGURE 9. Tire Pressure Vs. S.I.~East By-Pass (S.H.6 SBTL)

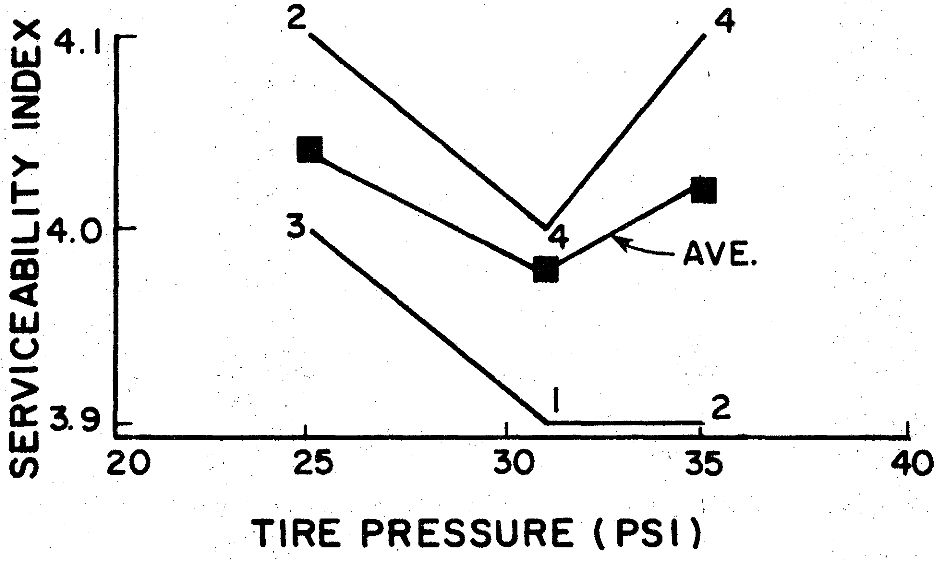


FIGURE 10. Tire Pressure Vs. S.I.~S.H.6B

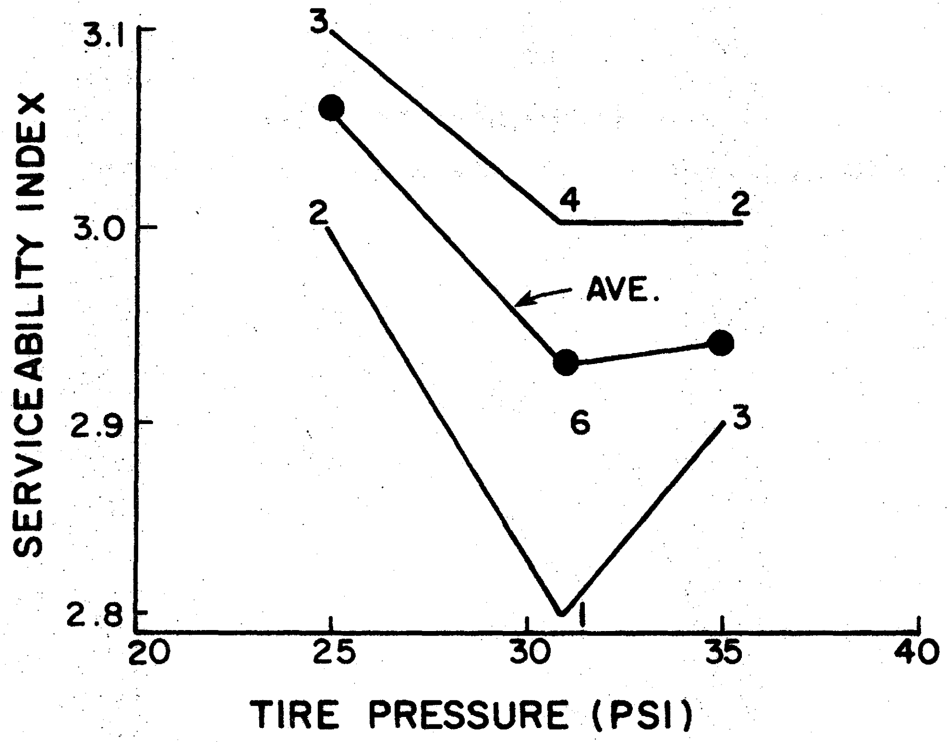


FIGURE 11. Tire Pressure Vs. S.I. ~ Unmarked Road.

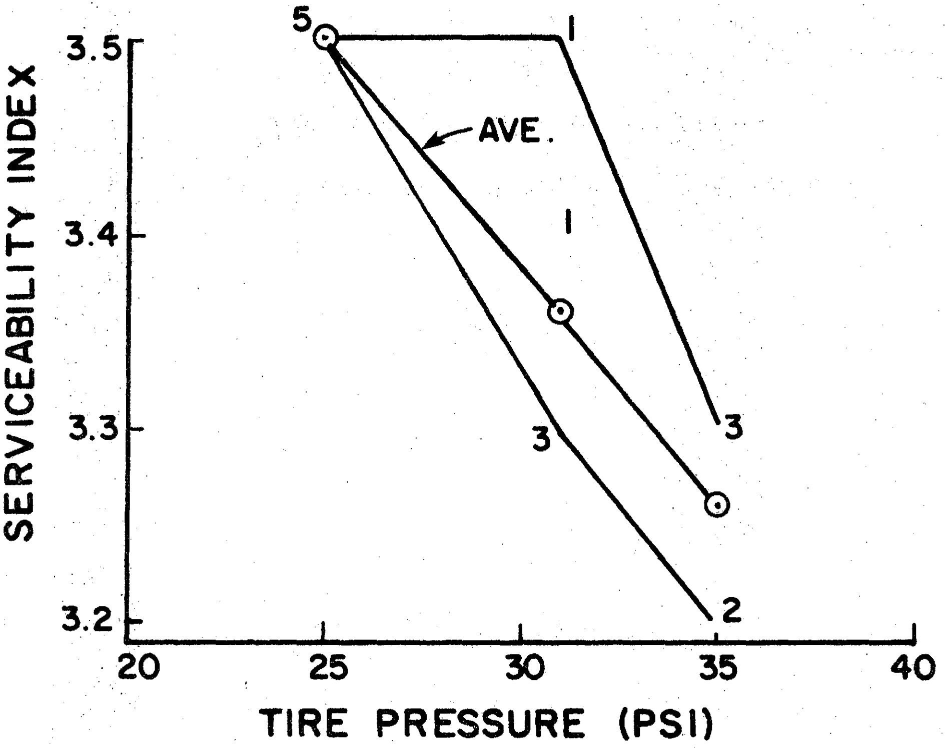


FIGURE 12. Tire Pressure Vs. S.I. ~ FM 2154.

Index means for different tire pressures are statistically significant at least to the 2.5 percent Level of Significance (they are not significant at the 1 percent level); however, the differences caused by tire pressure variation are probably <u>not</u> significant from a practical viewpoint.

The analysis recognizes the fact that the sets of five Serviceability Index measurements were separate entities; that is, for a test section-tire pressure combination with more than one set of 5 observations, the measurements were not a continuous set but the second and/or third set was made at a later time(s) than the first. Under this condition, the variation of the means for the sets of measurements within a test section-tire pressure combination is a valid measure of the random variation expected from set to set under identical conditions. The analysis of variance table for the analysis (Table 13) indicates that the variation in mean Serviceability Index caused by varying the test section is quite significant (at least to 2.5 percent). It also indicates that the variation of Serviceability Index means due to the interaction between the test section and the tire pressure is not significant; i.e., when compared to the variation of sets within test section-tire pressure combinations, the effect of changing tire pressure is essentially the same on each and every test section (21).

The statistical significance may be misleading, however. Examination of the means of the Serviceability Index (rounded to the nearest tenth) for each tire pressure for a particular test section reveals that approximately 88 percent of the means are within 0.1 of each other, which is about the same precision with which the single measurements are made. Also, approximately 96 percent of the test Serviceability

Table 12. Serviceability Index - Tire Pressure Data

	Test Section																							
	FM 60			FM 50N			FM 50S			FM 2347			East By-Pass (SH 6)			Unmarked Road (Old FM)			SH 6B			FM 2154		
	Tire Pressure (psi)																							
Run Number	25	31	35	25	31	35	25	31	35	25	31	35	25	31	35	25	31	35	25	31	35	25	31	35
1	4.1	4.1	4.1	3.2	3.1	3.1	3.7	3.7	3.6	3.2	3.1	3.1	3.8	3.8	3.9	3.0	3.0	2.9	4.0	4.0	4.1	3.5	3.3	3.3
2	4.0	4.2	4.0	3.2	3.1	3.1	3.8	3.7	3.6	3.2	3.1	3.1	3.8	3.9	4.0	3.0	3.0	2.9	4.0	4.0	4.1	3.5	3.3	3.2
3	4.0	4.1	4.1	3.2	3.1	3.1	3.8	3.7	3.7	3.3	3.1	3.2	3.9	3.9	4.0	3.1	2.9	2.9	4.0	4.0	4.0	3.5	3.4	3.3
4	4.1	4.0	4.1	3.2	3.1	3.1	3.8	3.7	3.7	3.3	3.1	3.2	3.9	3.9	4.0	3.1	2.9	3.0	4.1	4.0	4.1	3.5	3.3	3.2
5	4.0	4.1	4.1	3.3	3.2	3.1	3.9	3.8	3.7		3.1	3.2	4.0	3.9	4.0	3.1	2.8	3.0	4.1	3.9	3.9	3.5	3.5	3.3
1								3.8	3.6		3.2				3.7		2.9				3.9			
2								3.8	3.6		3.2				3.7		3.0				4.0			
3								3.8	3.6		3.2				3.8		2.9				4.0			
4								3.9	3.7		3.2				3.8		3.0				4.0			
5								3.9	3.8		3.1				3.9		2.9				4.1			
1															3.7									
2															3.7									
3															3.8									
4															3.8									
5															3.6									
Mean PSI	4.04	4.10	4.08	3.22	3.12	3.10	3.80	3.78	3.66	3.25	3.21	3.16	3.88	3.88	3.83	3.06	2.93	2.94	4.04	3.98	4.02	3.50	3.36	3.26
Range	0.1	0.2	0.1	0.1	0.1	0.0	0.2	0.2	0.2	0.1	0.3	0.1	0.2	0.1	0.4	0.1	0.2	0.1	0.1	0.1	0.2	0.0	0.2	0.1
Stnd. Dev.	.055	.071	.045	.045	.045	.000	.071	.079	.070	.058	.120	.055	.084	.045	.133	.055	.067	.055	.055	.045	.079	.000	.089	.055
Pooled Stnd Dev. (Sp)	0.058			0.036			0.074			0.097			0.114			0.062			0.067			0.061		
Average of the Means (M)	4.07			3.15			3.75			3.21			3.86			2.98			4.01			3.37		
Coef of Var (Pooled) (C_V=Sp÷$\overline{M}$)	1.43 percent			1.14 percent			1.97 percent			3.02 percent			2.95 percent			2.08 percent			1.67 percent			1.81 percent		

TABLE 13. Analysis of Variance, Tire Pressure (considering data sets as separate entities).

Source of Variance	d.f.	Mean Squares	F		$F_{.025}$
Test Section, TS	7	3.1041	89.71.	>>	4.99
Tire Press., TP	2	0.0963	6.21	>	4.86
Test Section X Tire Press., TS X TP	14	0.0155	0.45	<<	4.60
Sets, (TS X TP)	7	0.0346			
Residual	123	0.0037			

Index means are within ± 0.14 of the calibration control initial Serviceability Index means (see reference 14 for control definitions and procedures). This, coupled with the fact that 100 percent of the test sets had ranges well below the maximum allowable range control value of 0.36, says that the variation in measured Serviceability Index due to tire pressure variation between 25 and 35 psi is not sufficiently great to cause the control limits to be exceeded.

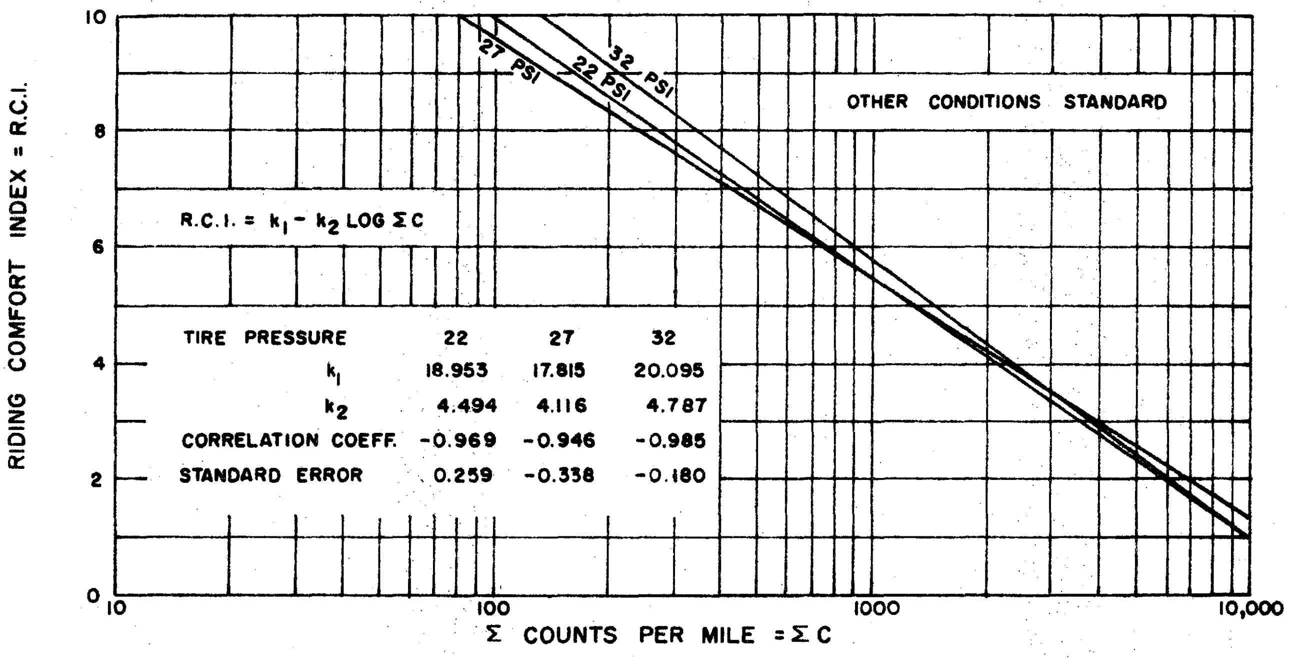
In summary, these results indicate that although there is a statistically significant difference in the average Serviceability Index value obtained at each of the three different tire pressures, this difference may be considered to be insignificant in a practical sense, because the Serviceability Index values are determined to only the nearest 0.1, and because the measured Serviceability Indexes remain within the control limits set according to the procedure outlined in Appendix A.

A review of literature associated with the effect of tire pressure on road meter roughness determinations confirms the conclusions reached above. Brokaw (17) has indicated that for standard tires, tire pressures within the range of 24 to 26 psi have no significant effect on present Serviceability Index determinations. Clark (22) varied tire pressure ± 5 psi from his standard operating pressure of 27 psi and found variations in Riding Comfort Index* which ranged up to 1.0 units of the Index (Figure 13). This is equivalent to about 0.5 units of the Serviceability Index Scale.

Studies conducted in South Africa by Curtayne (23) indicate

---

*A Canadian measure of Serviceability Index with the base scale ranging from 0 to 10 rather than 0 to 5 as used in the United States.



TIRE PRESSURE	22	27	32
k_1	18.953	17.815	20.095
k_2	4.494	4.116	4.787
CORRELATION COEFF.	-0.969	-0.946	-0.985
STANDARD ERROR	0.259	-0.338	-0.180

after Clark (22)

FIGURE 13. EFFECT OF TIRE PRESSURE ON ESTIMATING RIDING COMFORT INDEX.

that for practical purposes determinations are insensitive to variation in tire pressures within the range normally found during vehicle operation.

The type of tire utilized on the test vehicle has been investigated by Hughes (15). Standard 2-ply tires and winter 4-ply snow tires were evaluated. The data obtained indicated that there is no significant difference in vehicle response.

Air Temperature

Data were obtained for this portion of the study by recording temperature when a test section was utilized for a set of 5 Mays Ride Meter calibration control runs. Therefore, the analysis of the data consists of correlating the resultant mean Serviceability Index value of each set of Mays Ride Meter runs on a particular test section with the temperature at which it was run; then determining whether there is any significant difference between Serviceability means that can be attributed to temperature variation.

Table 14 is a tabulation of the mean Serviceability Index values for sets of runs related to both temperature and test section. Although some data points were collected for each existing calibration control test section, sufficient data for a detailed analysis were collected for only the 5 sections shown on Table 14.

The total range of temperature covered was from 51°F to 92°F. This temperature was the ambient area temperature as obtained from the local radio stations; the Flight Service Station at Easterwood Airport, College Station, Texas; or from a thermometer carried by the Mays Ride Meter operator.

The temperature-dependent repeatability of the Serviceability values obtained on the 5 test sections is shown on Figures 14-20.

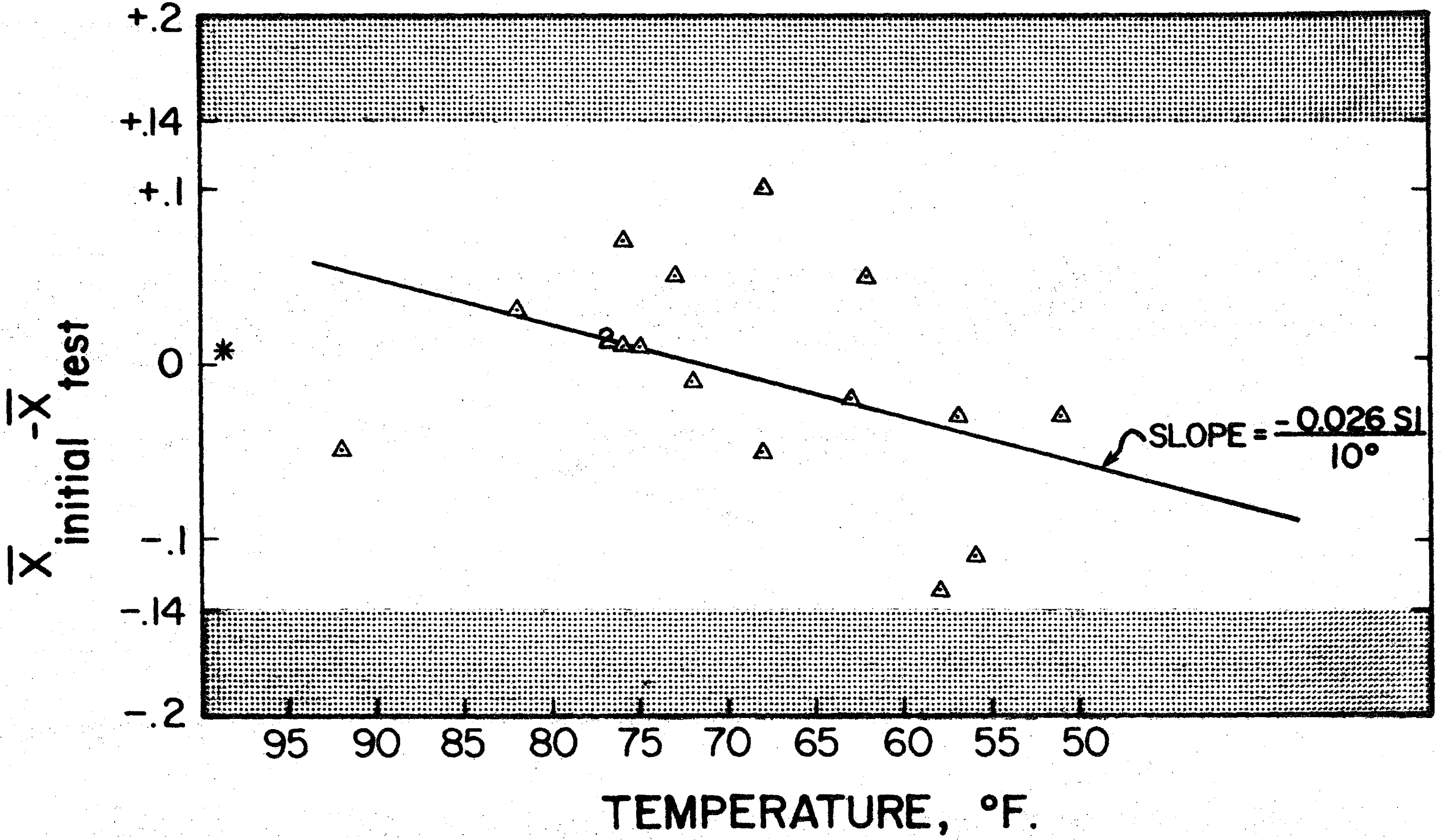
TABLE 14. Mean Serviceability Index Values Vs. Temperature

Temperature (°F)	FM 2347	FM 50S	SH 6B	EBP (SH 6)	Elmo Weedon Road
51	3.28				
53		3.64	4.06	3.78	
55					2.36
56	3.36	3.70			
57	3.28	3.62	4.10	3.80	
58	3.38			3.90 3.92	
59					2.43
60			4.10	3.78	
62	3.20	3.70	4.00	3.80	2.49
63	3.27				
68	3.15 3.30	3.70 3.70	4.10	3.70	2.54
71			3.90	3.80	2.29
72	3.26				
73	3.20	3.54			
75	3.24	3.62		3.78	2.50
76	3.24 3.18 3.24				
77			4.06		
81				3.84	
82	3.22				
89					2.37
91			4.00		
92	3.30	3.58			

The Mean Control Limits existing at the time that the test runs were made was ± 0.14. Even though there is considerable scatter in the data, it can be seen that all of the points remain inside the control band. Figure 19 is a composite plot of all the data resulting from the subtraction of the mean Serviceability Index values in Table 14 from the respective initial mean Serviceability Index ($\bar{X}$ in the figures); and Figure 20 is a plot of the total range of mean Serviceability Index values for each of the 5 test sections. These ranges are all below the Upper Range Control Limit of 0.36.

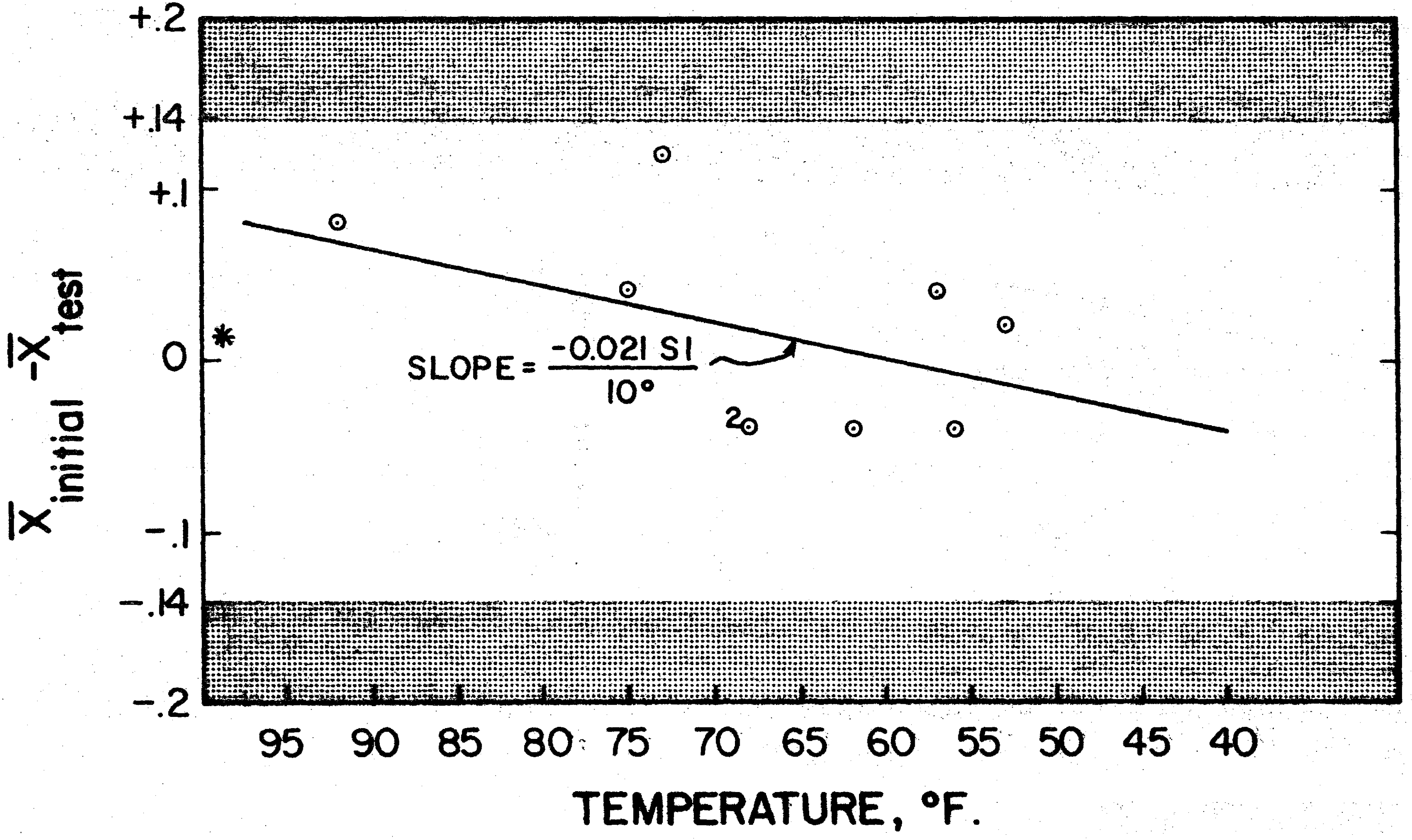
If one assumes that a linear relationship exists between temperature and Serviceability Index, then a least-squares regression line can be used to determine the rate of change of Serviceability Index with temperature differences. This type of line has been plotted on each of Figures 14-18. Using the composite plot (Fig. 19) the slope of the line for all of the data is about $\frac{-0.022 \text{ SI}}{10°\text{F}}$. This indicates that for an <u>increase</u> of 10° from one set of Mays Ride Meter runs to the next, a corresponding <u>decrease</u> of 0.022 can be expected for the mean Serviceability Index. Or, stated another way, for a difference in test temperatures of approximately 45°, the Serviceability Index will be changed about 0.1 point.

A second approach to evaluation of the temperature data was also taken. Given that the linear relationship exists, and has the indicated slope, the line may conceivably be extrapolated through decreasing temperatures below 51° (thought to be more critical than temperatures above 92°) until it intersects the Lower Mean Control Limit. This was done, and the temperature below which the Serviceability Index means would be outside the control band was found to be approximately 11°F. Although such extrapolations have risk, it agrees favorably with the low



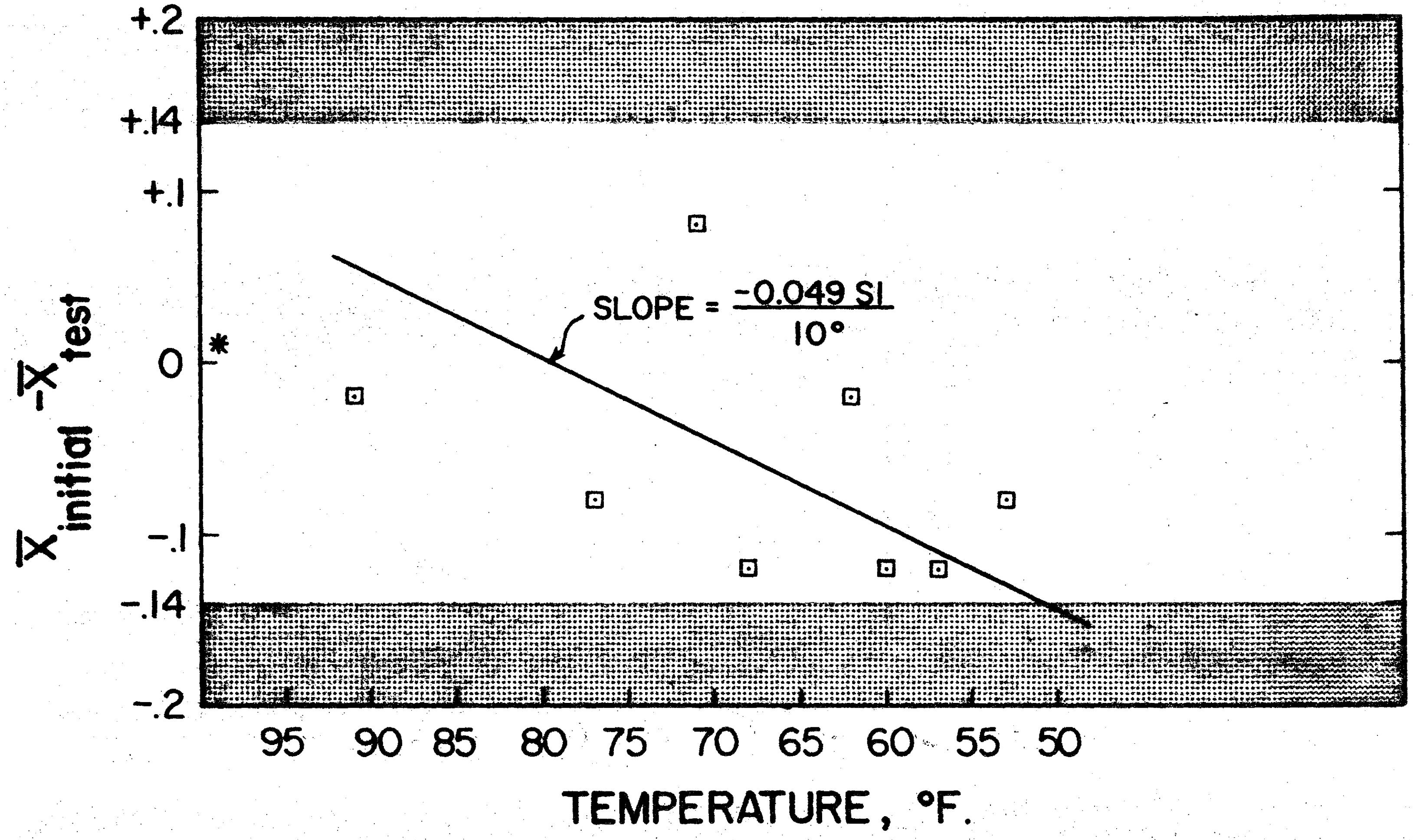
* INITIAL MEAN S.I. = 3.25

FIGURE 14. TEMPERATURE VS. DIFFERENCES FROM MEAN SERVICEABILITY INDEX. FM 2347.



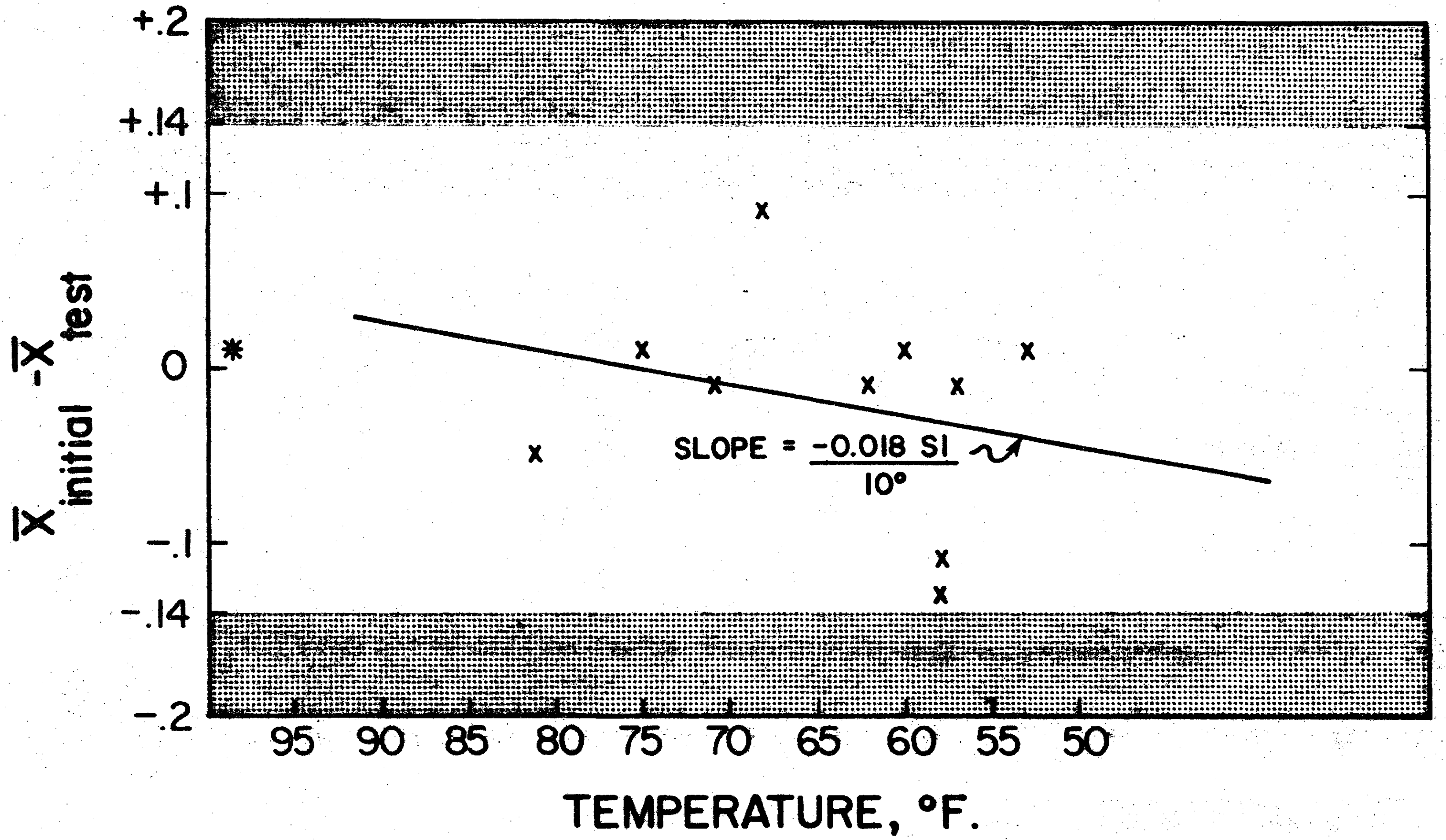
* INITIAL MEAN S.I. = 3.66

FIGURE 15. TEMPERATURE VS. DIFFERENCES FROM MEAN SERVICEABILITY INDEX. FM 505.



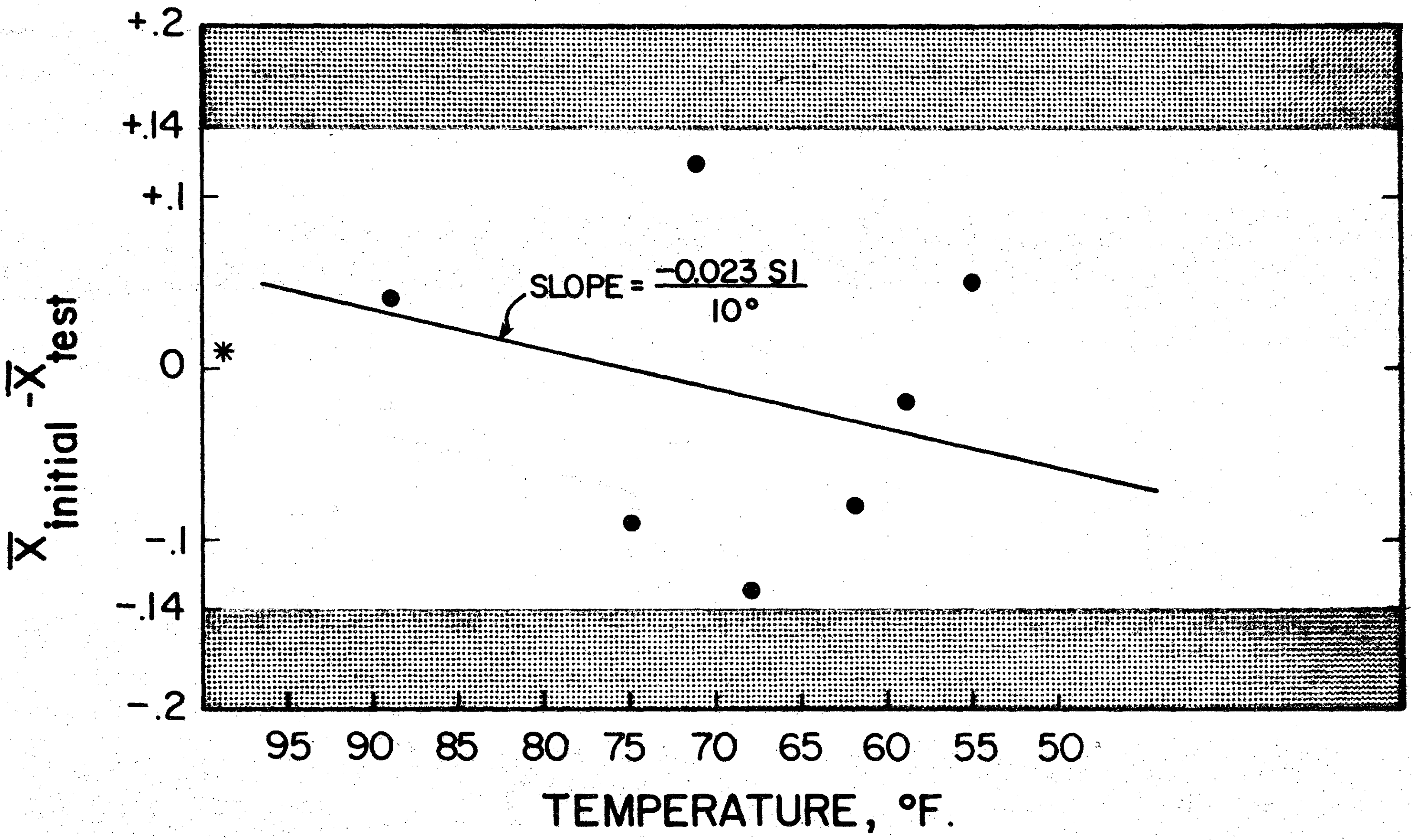
* INITIAL MEAN S.I. = 3.98

FIGURE 16. TEMPERATURE VS. DIFFERENCES FROM MEAN SERVICEABILITY INDEX. S.H. 6B.



* INITIAL MEAN S.I. = 3.79

FIGURE 17. TEMPERATURE VS. DIFFERENCES FROM MEAN SERVICEABILITY INDEX. EAST BYPASS S.H.6.



* INITIAL MEAN S.I. = 2.41

FIGURE 18. TEMPERATURE VS. DIFFERENCES FROM MEAN SERVICEABILITY INDEX. ELMO WEEDON ROAD.

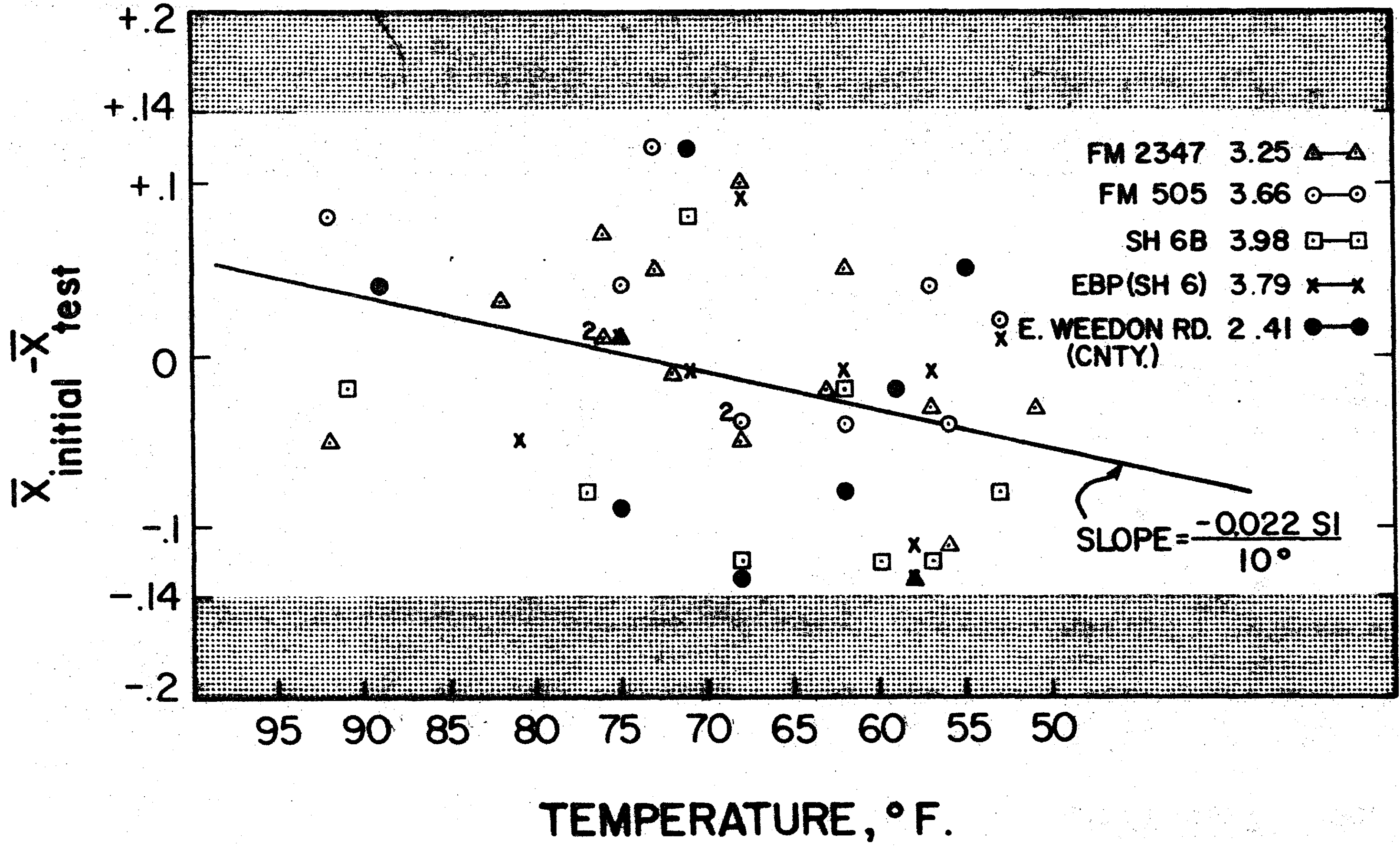


FIGURE 19. TEMPERATURE VS. DIFFERENCES FROM MEAN S.I. COMPOSITE PLOT.

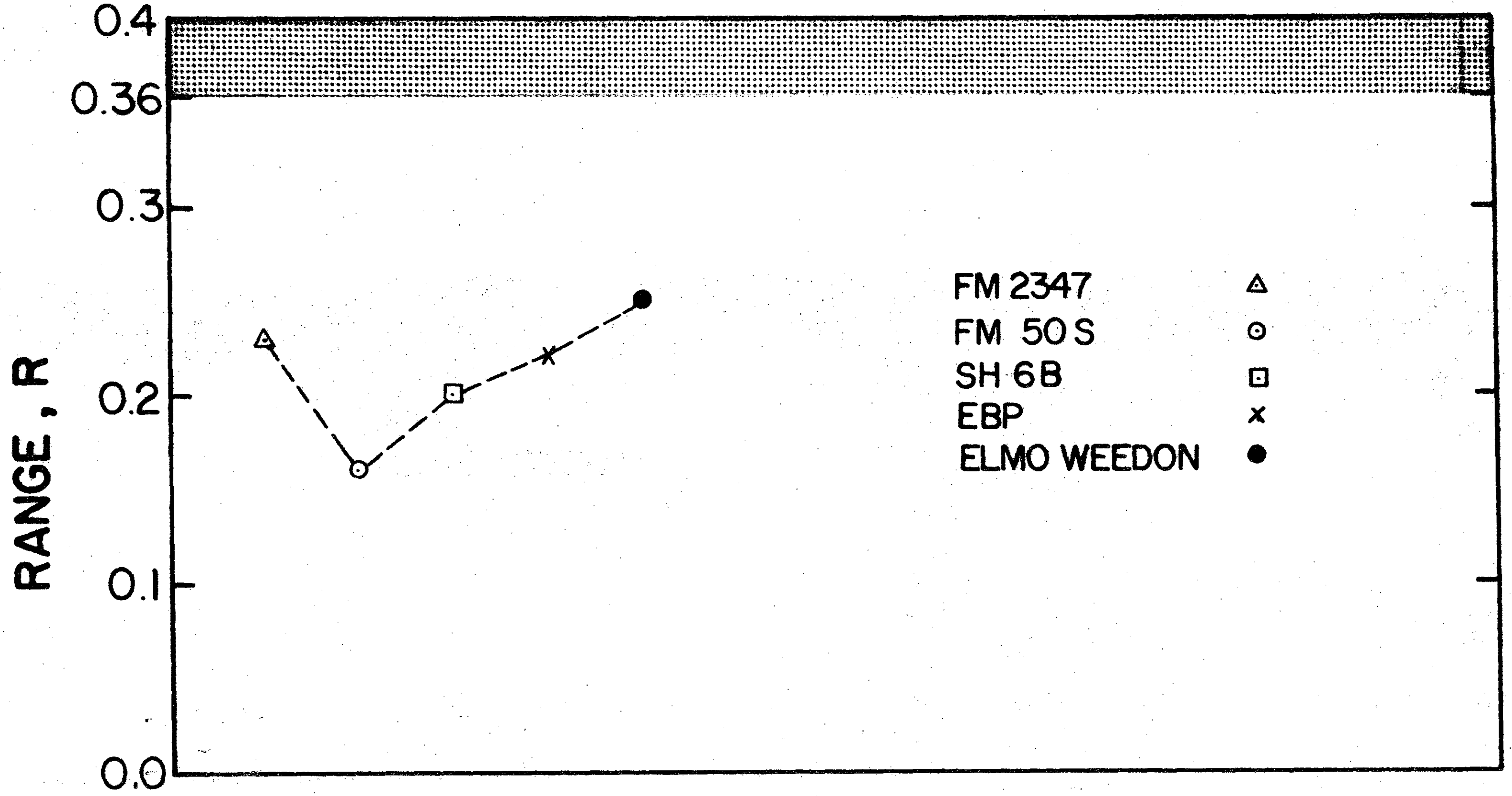


FIGURE 20. RANGE FOR S.I. READINGS FROM FIVE TEST SECTION OVER TEMPERATURE RANGE OF 51° TO 92° F.

temperature limit of 10°F indicated by Brokaw (17).

Other studies have been conducted to determine the effect of temperature or road meter response (11). Clark's (22) work defined correlation curves for tests performed at +35°F and -33°F. A stiffening of the suspension system was noted at the lower temperature. Dunn's and Schultz's (24) work indicates that the road meter is affected by extremely low temperature probably due to stiffening of the vehicle suspension system (Figure 21).

Temperature correction equations have been suggested by Law and Burt (25) for both the PCA road meter and the Mays Ride Meter. The equation for the Mays Ride Meter is given below;

$$M_C = M_B + 0.5(70 - T)$$

where;

M_C = Corrected Mays Ride Meter Roughness, inches per mile

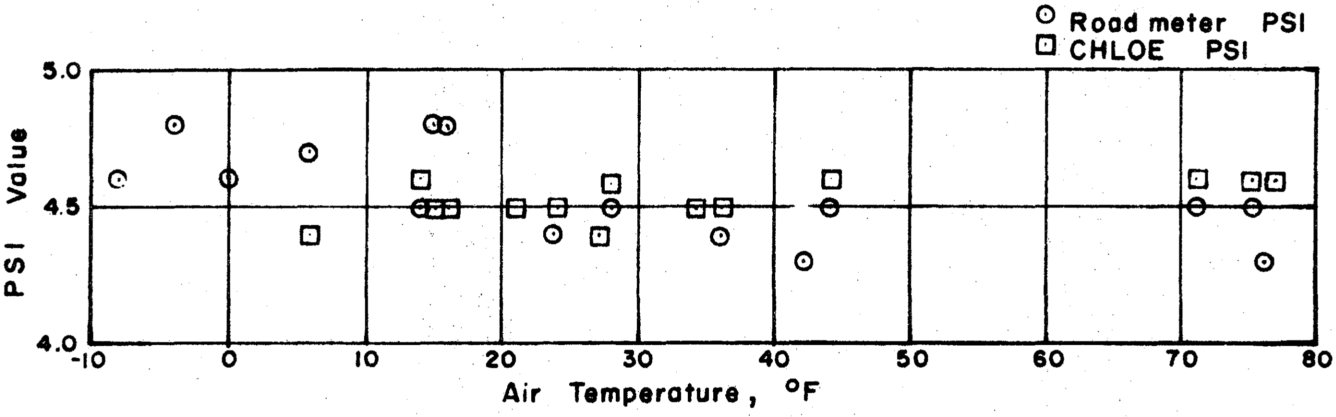
M_B = Basic Mays Ride Meter Roughness, inches per mile

T = temperature, °F.

The study temperatures ranged from 38 to 74°F. (Figure 22).

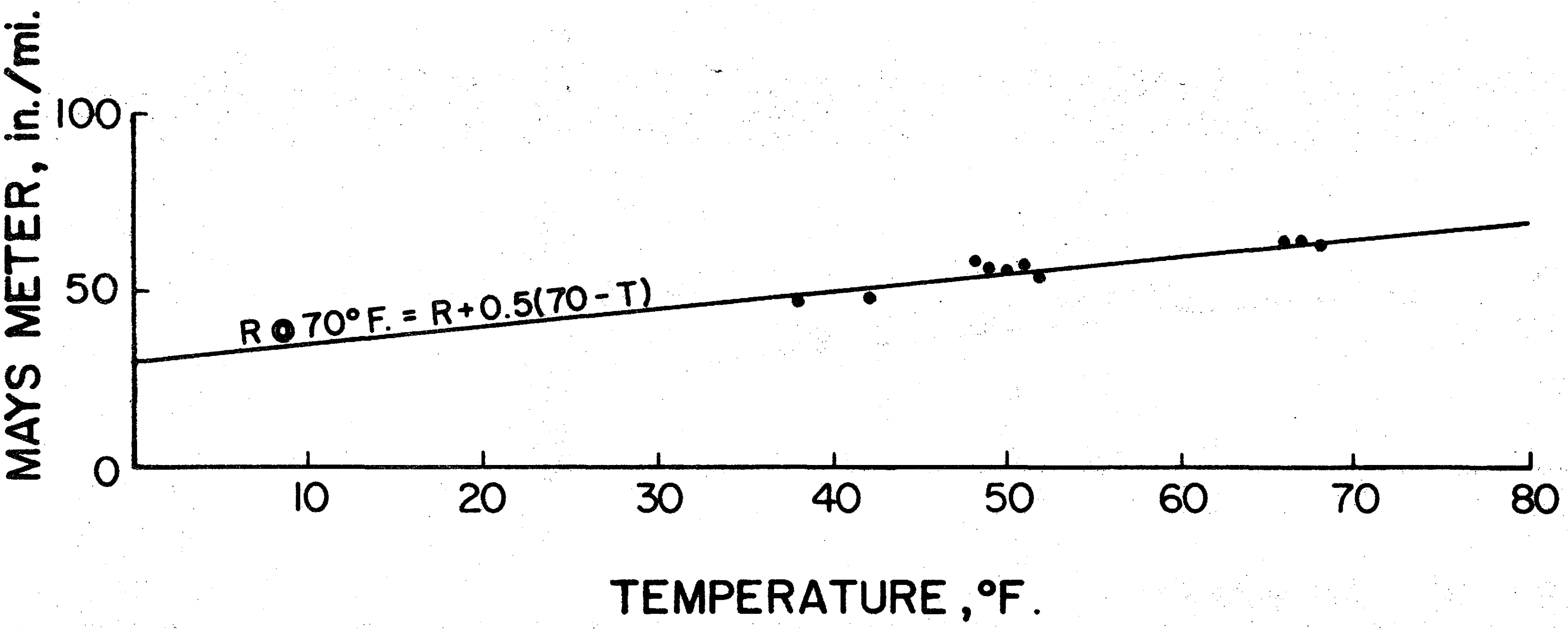
Passengers and Luggage

As discussed previously the Mays Ride Meter is normally operated by two individuals. A test program was established to determine the effect of operating the Mays Ride Meter with one or more passengers in the back seat and with luggage in the trunk. For demonstration and training purposes, it is often desirable to carry one or two additional passengers in the back seat. In addition, for research purposes involving the measurement of roadways throughout the state, it is necessary to carry luggage in the trunk or back seat as the crew will likely spend several nights away from the home office.



after Dunn and Schultz (24)

FIGURE 21. RELATION BETWEEN TEMPERATURE OUTPUT OF ROAD METER VERSUS CHLOE PROFILOMETER.



after Law and Burt (25)

FIGURE 22. TEMPERATURE CORRECTION CURVES AND EQUATIONS.

The test procedure consisted of the standard sets of five repeated runs of the Mays Ride Meter on a particular control section. Different weight and different distribution of weights were placed in the vehicle in an effort to determine the effect of added passengers and luggage on the observed Serviceability Index values.

Figure 23 shows the plotted results of the tests conducted on the FM 60 test section. The first set of runs is typical of standard operating conditions; i. e., driver and operator in an unloaded car. Then, two cases that can exist with one passenger in the back seat were evaluated. These points are labeled ② and ③ on the Mean Control Chart in Figure 23. The fourth set of runs on FM 60 was run with 200 pounds of "luggage" in the center of the trunk. It is evident from the figure that all of the $\Delta\overline{X}$ points are within the control band, but a general trend is apparent. The plotted points indicate that as more weight is added and as the weight is moved toward the rear of the car, the mean Servicability Index value decreases and $\Delta\overline{X}$ approaches the Upper Mean Control Limit.

The second type of test procedure held the load condition constant and sets of Mays Ride Meter runs were made on 8 different test sections. The constant load condition was 150 pounds in each of the rear seats, simulating two passengers. The resultant set of $\Delta\overline{X}$ points is plotted on Figure 24. In this case, 4 of the points show that the Upper Mean Control Limit has been exceeded. Noteworthy, too, is the fact that the points for the other 4 test sections are <u>above</u> the $\Delta\overline{X} = 0$ line, indicating that the Serviceability Index means corresponding to the points are all <u>below</u> the control mean for that section. Again, this suggests that more weight toward the rear of the car causes the Serviceability Index to decrease. Thus, as the passenger and/or luggage weight increases in the vehicle, the measured roughness increases as expected.

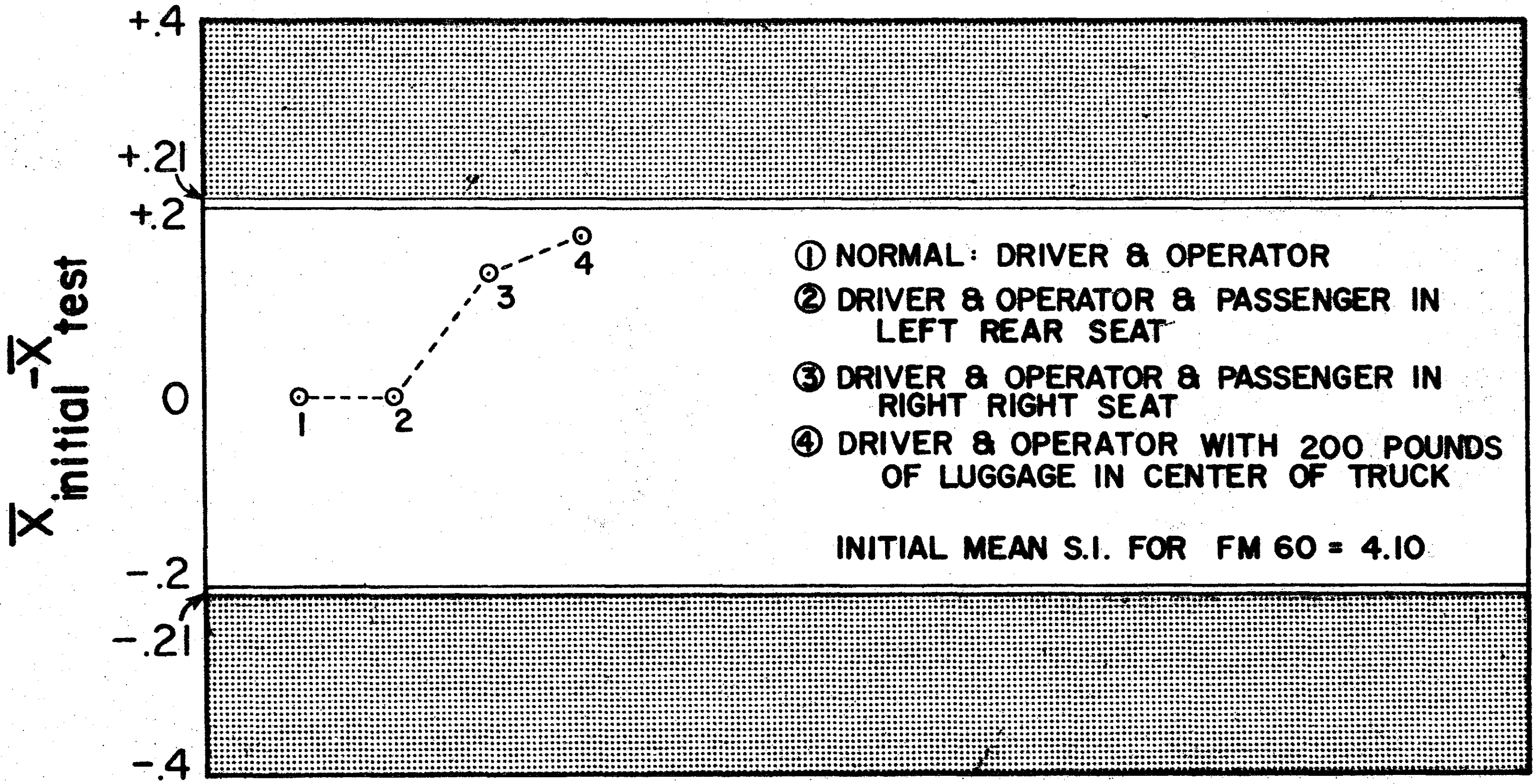


FIGURE 23. LOAD CONDITION VS. RESULTANT DIFFERENCES FROM INITIAL MEAN S.I.

These results are in general agreement with those obtained by Hughes (15), Clark (22). Hughes (15) presents data indicating that a passenger in the back seat of the test vehicle has more effect on measured roughness than a full gas tank (approximately 140 pounds), a passenger in the front seat or a 100-pound weight in the truck. Data obtained by Clark (22) illustrate the influence of the number of men and the effect of gas tank level on Riding Comfort Index. Variations up to about 1 unit of Riding Comfort Index or 0.5 Serviceability Index units were obtained (Figure 25).

It should be noted that the difference between a full tank of gasoline and 1/4 tank can represent a weight difference of about 100 pounds for a standard size automobile.

Wet or Dry Pavements

Six sets of Mays Ride Meter runs were made on four of the control sections while it was raining and the results were compared with the values of the Serviceability Index determined on dry pavements. It was hoped that the results of the comparison would determine whether Mays Ride Meter measurements could be performed in wet as well as dry weather.

As can be seen in Figure 26, the deviation from the dry-pavement Serviceability Index due to wet pavement is very slight except in one of the two sets ran on Unmarked Road. Even this point remains inside the mean control band. Thus, 83 percent of the tests deviated from the dry mean by 0.05 point or less; while 100 percent were within the ± 0.14 allowable control deviation band.

Water film depths were not measured. Visual observations indicated that similar water depths existed for the test runs on all sections. Water was ponded in depressions and the pavement was slightly "wet" in high places. Rutting is not a problem on any of the sections tested, so water was not a continuous thick film nor was the water depth excessive for a substantial length of pavement.

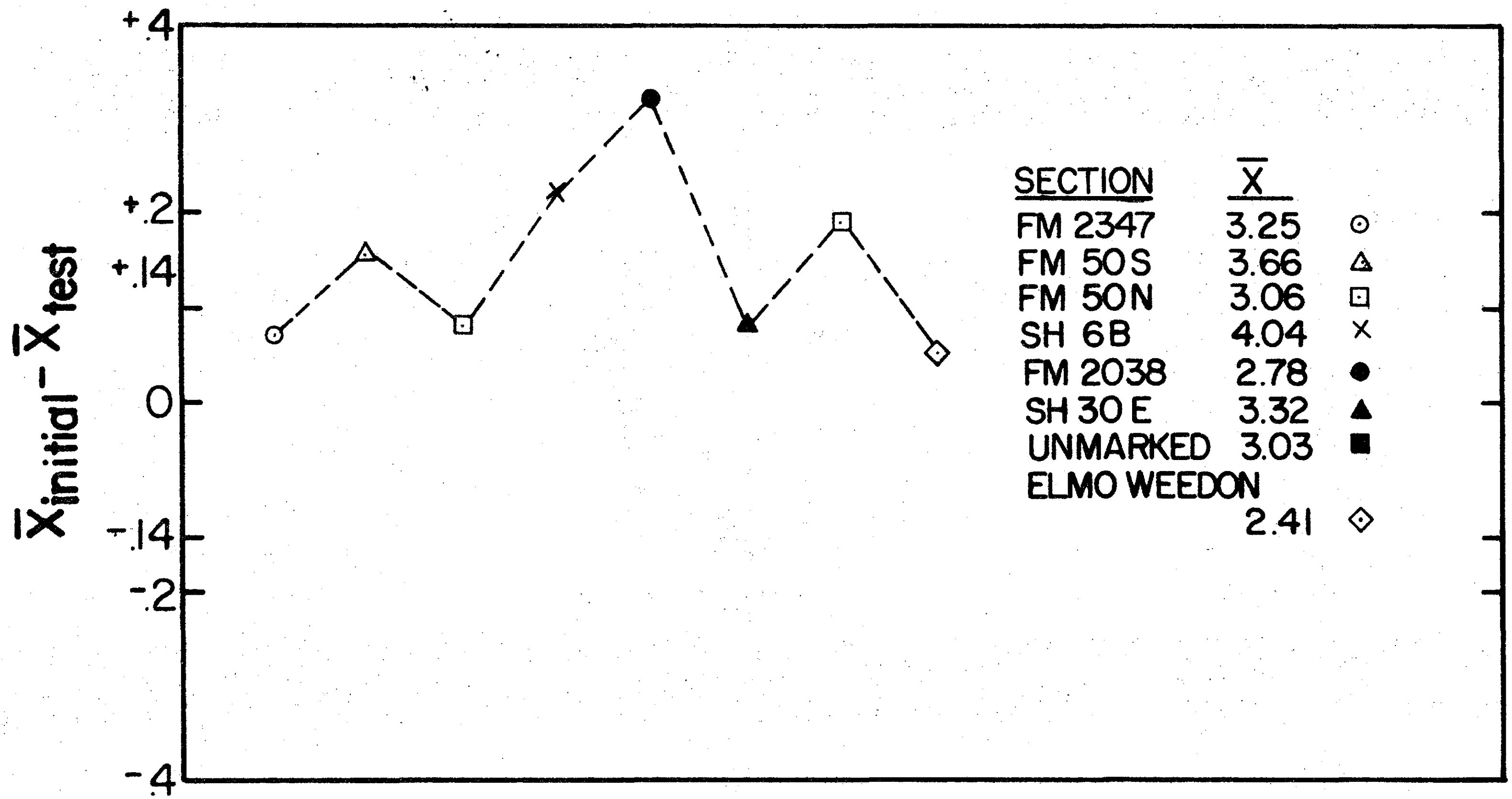
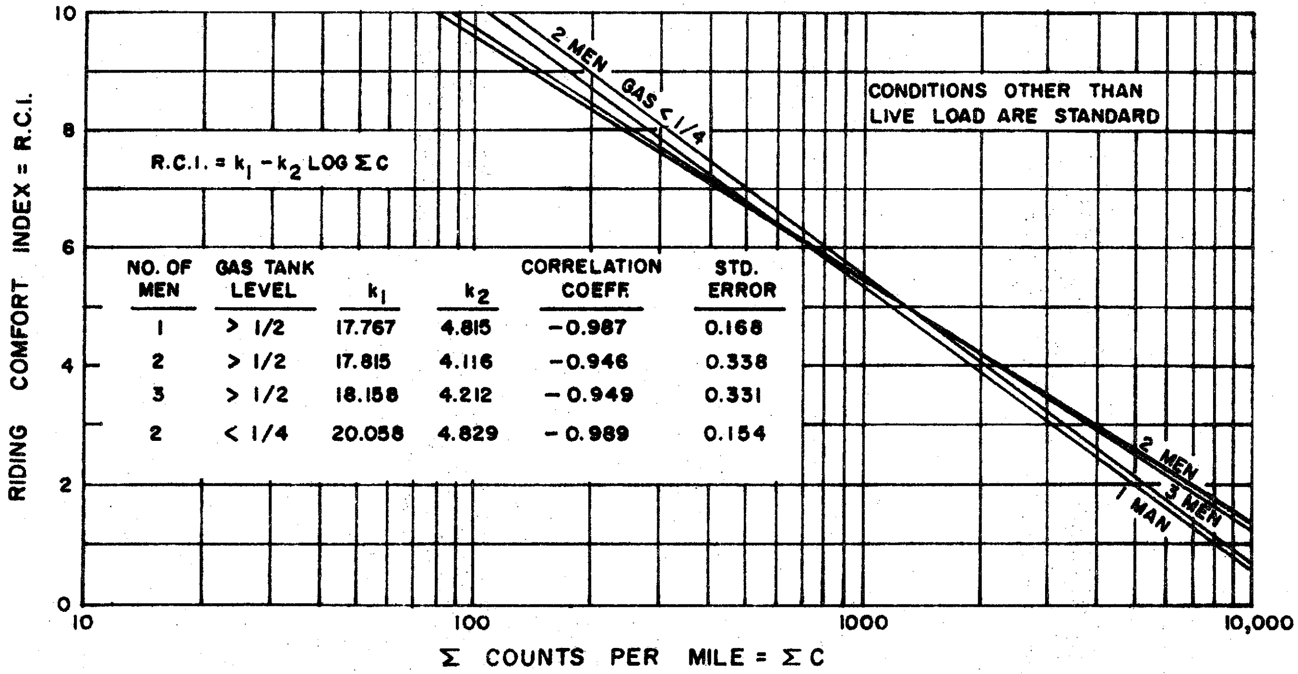


FIGURE 24. LOAD CONDITION VS. RESULTANT DIFFERENCES FROM INITIAL MEAN S.I.

All sets run with driver and operator and two passengers in back seat.



NO. OF MEN	GAS TANK LEVEL	k_1	k_2	CORRELATION COEFF.	STD. ERROR
1	> 1/2	17.767	4.815	−0.987	0.168
2	> 1/2	17.815	4.116	−0.946	0.338
3	> 1/2	18.158	4.212	− 0.949	0.331
2	< 1/4	20.058	4.829	− 0.989	0.154

after Clark (22)

FIGURE 25. EFFECT OF NUMBER OF VEHICLE OCCUPANTS AND GAS TANK LEVEL ON RIDING COMFORT INDEX.

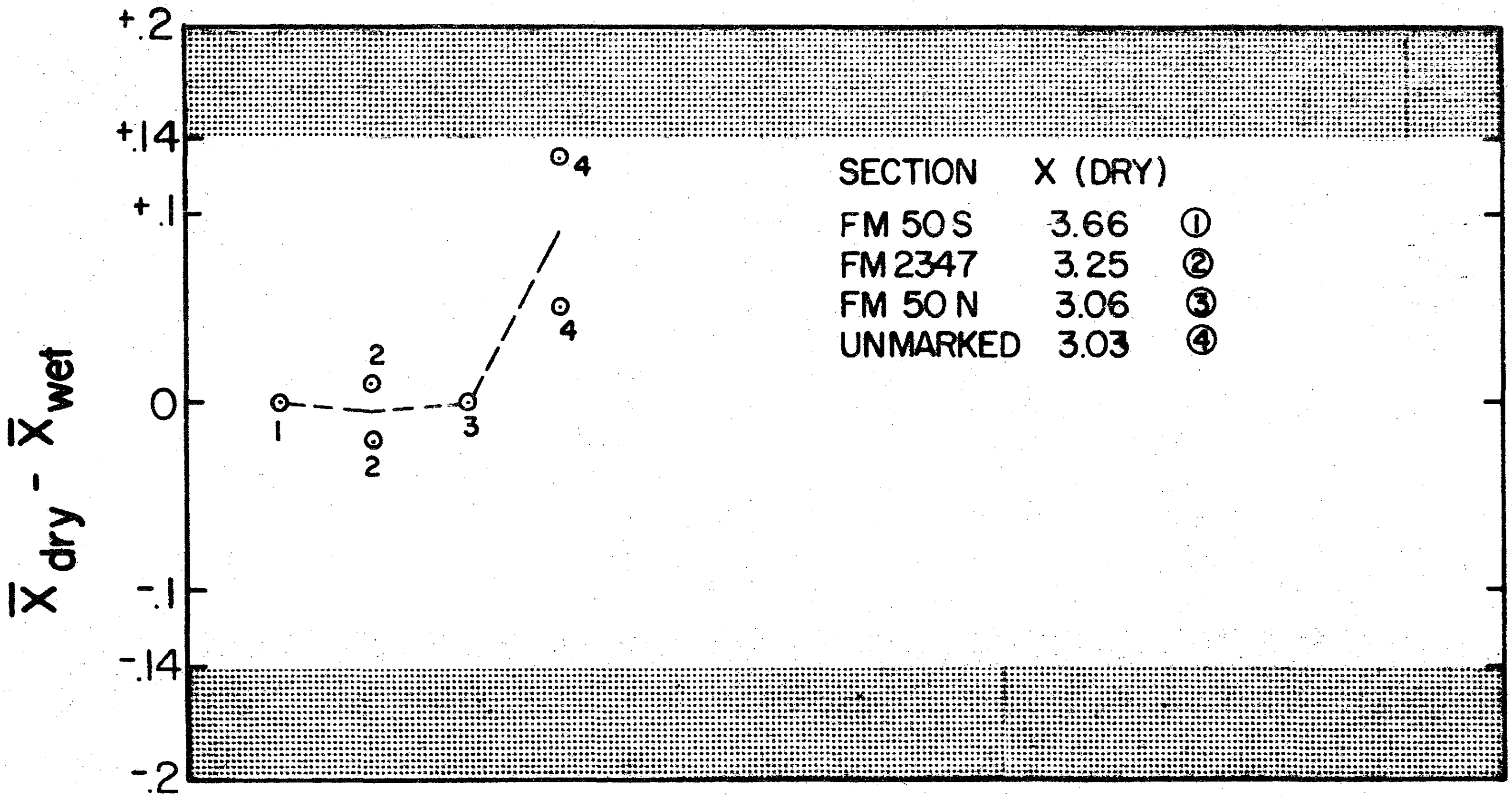


FIGURE 26. DIFFERENCES FROM DRY MEAN S.I. CAUSED BY WET PAVEMENT FOR FOUR TEST SECTIONS.

Wind Velocity

Brokaw (17, 18) has indicated that cross wind velocities above about 15 miles per hour affect roughness measurements made with automobile mounted road meters. An abbreviated test program was undertaken to investigate the effect of wind velocity on Mays Ride Meter Serviceability Index determinations in this study. Unfortunately, little data could be obtained involving cross winds in excess of 15 mph. This was partially due to the location of the test sections in and around the Bryan, Texas area. Recorded winds from the Farm Serivce (Texas A&M University) weather data indicated that winds greater than 15 miles per hour occurred only 0.8 percent of the time from 1967 to 1971. There were no recorded sustained winds greater than 15 miles per hour during 1971 (26).

Further study of the climatological data throughout Texas showed that there were significant winds (greater than 15 mph) occurring during 1970 and 1971. Figures 27 and 28 show the percentage of days in which the wind recorded was greater than 10 mph throughout 1970 and 1971. In contrast to the 10 mph and 15 mph wind study, Figures 29 and 30 show the percentage of days in which the winds were calm (0-4 mph) throughout the state (except for the High Plains area) for 1970 and 1971. Table 15 is a list of the stations utilized for the recorded wind study.

Two sets of Mays Ride Meter runs in winds greater than or equal to 15 mph were obtained. One set of runs were obtained in wet weather and at a temperature significantly lower than the temperature at which the initial control Serviceability Index mean was established; thus, deviations could be attributed to both temperature and wind.

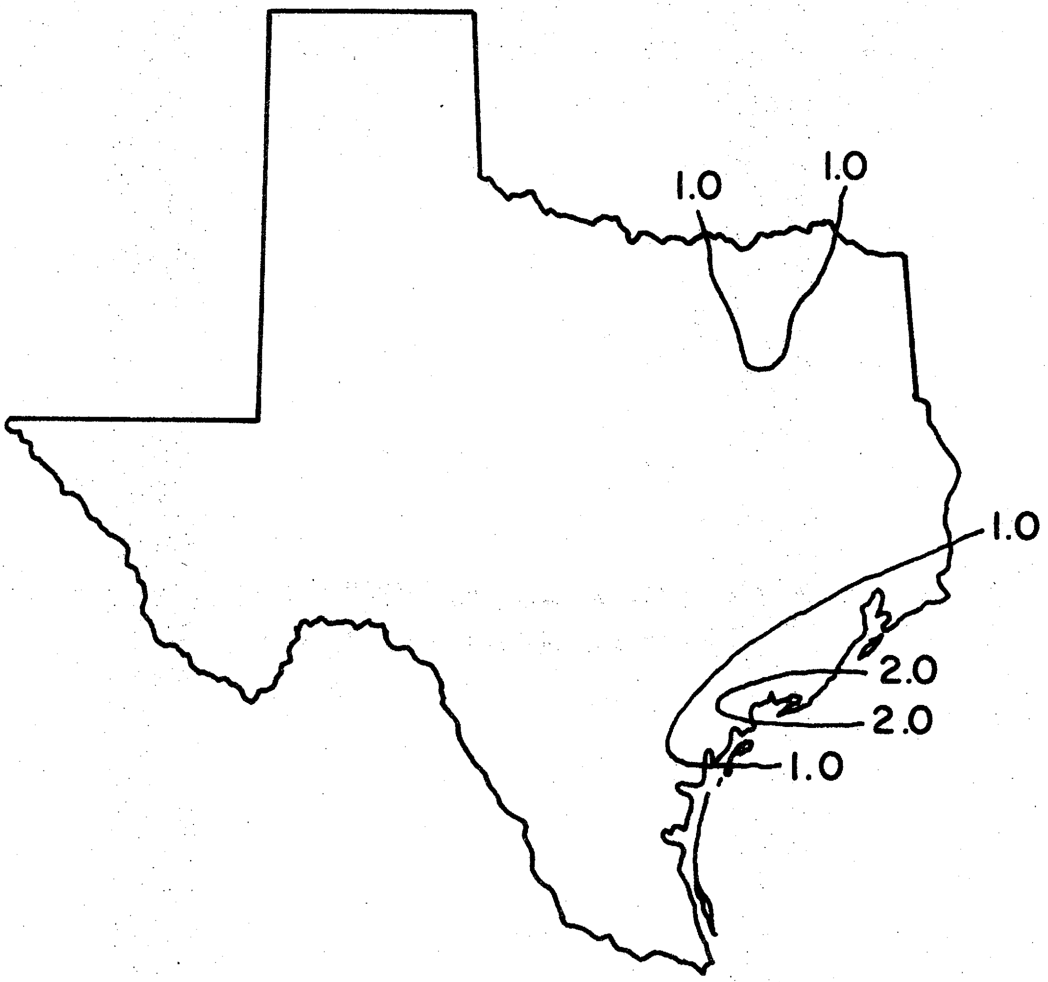


FIGURE 27. PERCENTAGE OF DAYS IN 1970 WITH WINDS GREATER THAN 10 MPH.

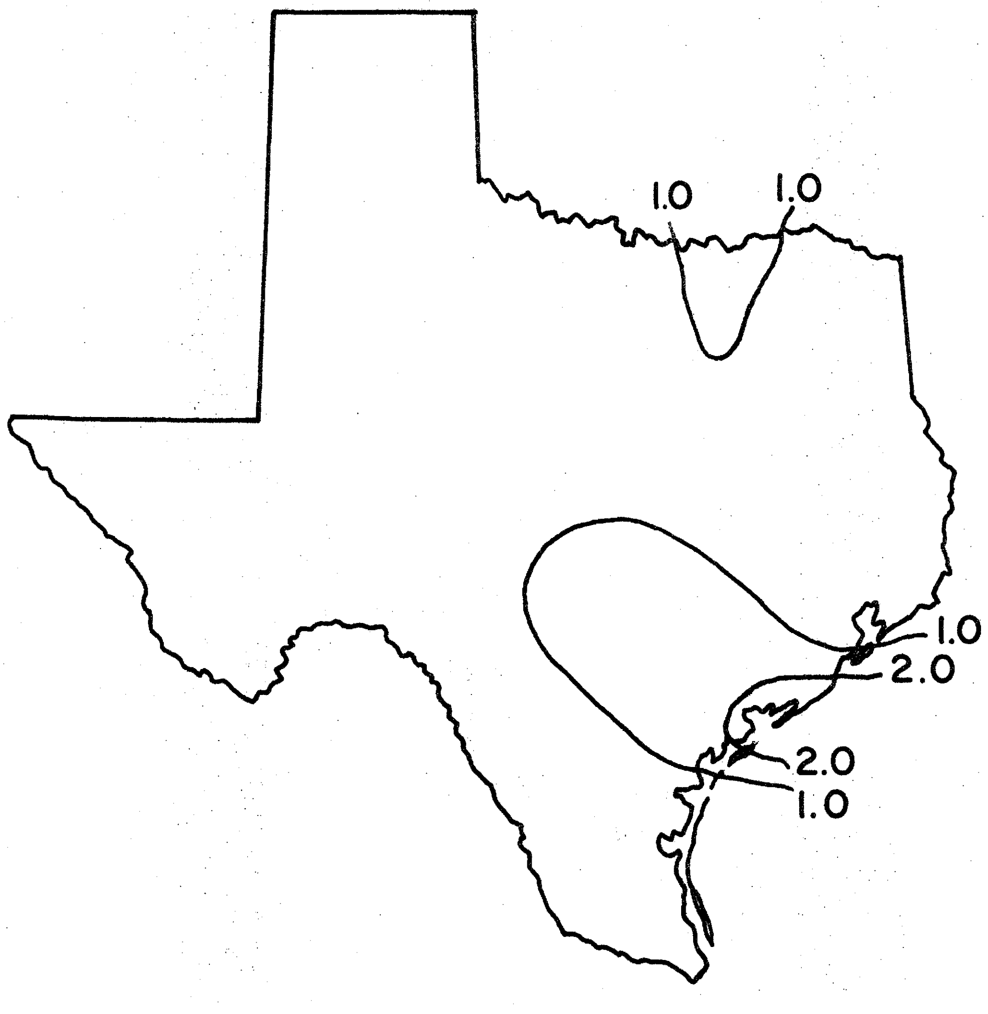


FIGURE 28. PERCENTAGE OF DAYS IN 1971 WITH WINDS GREATER THAN 10 MPH.

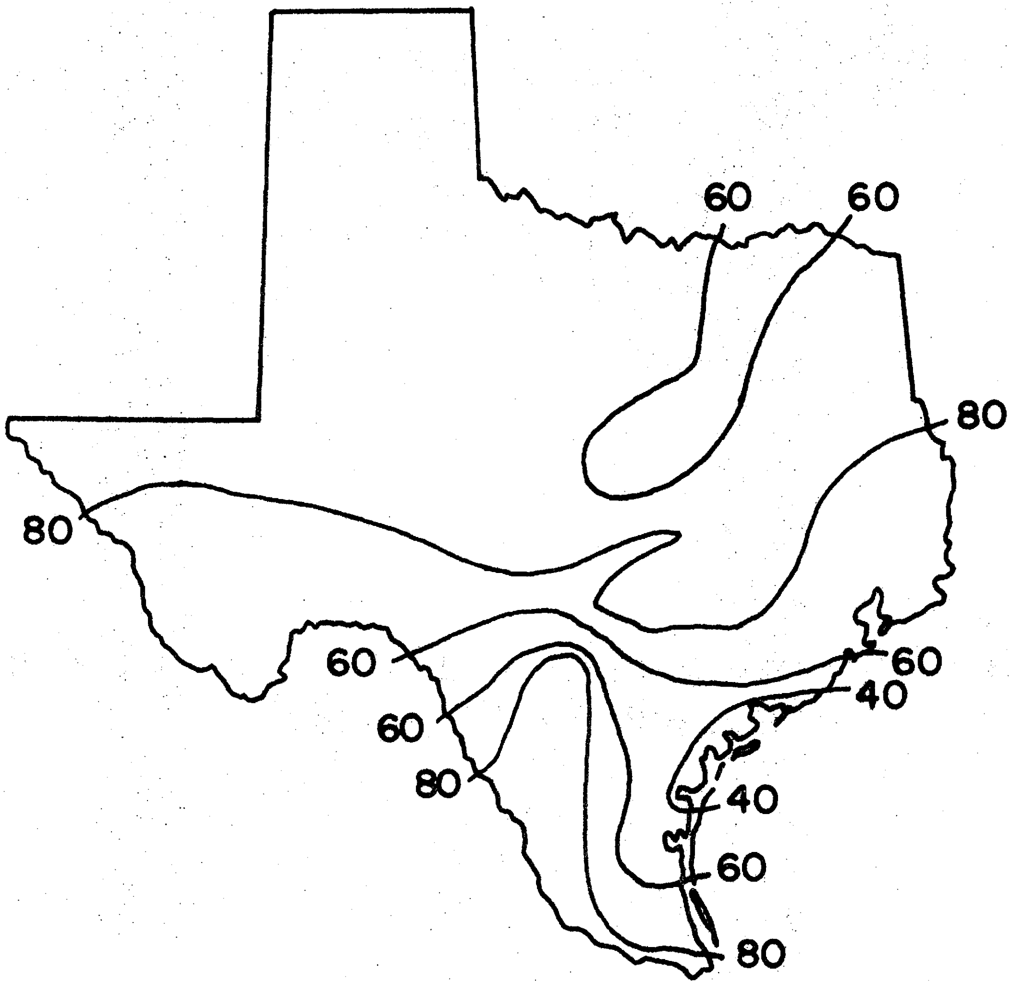


FIGURE 29. PERCENTAGE OF DAYS IN 1970 WITH WINDS LESS THAN 4.0 MPH (CALM).

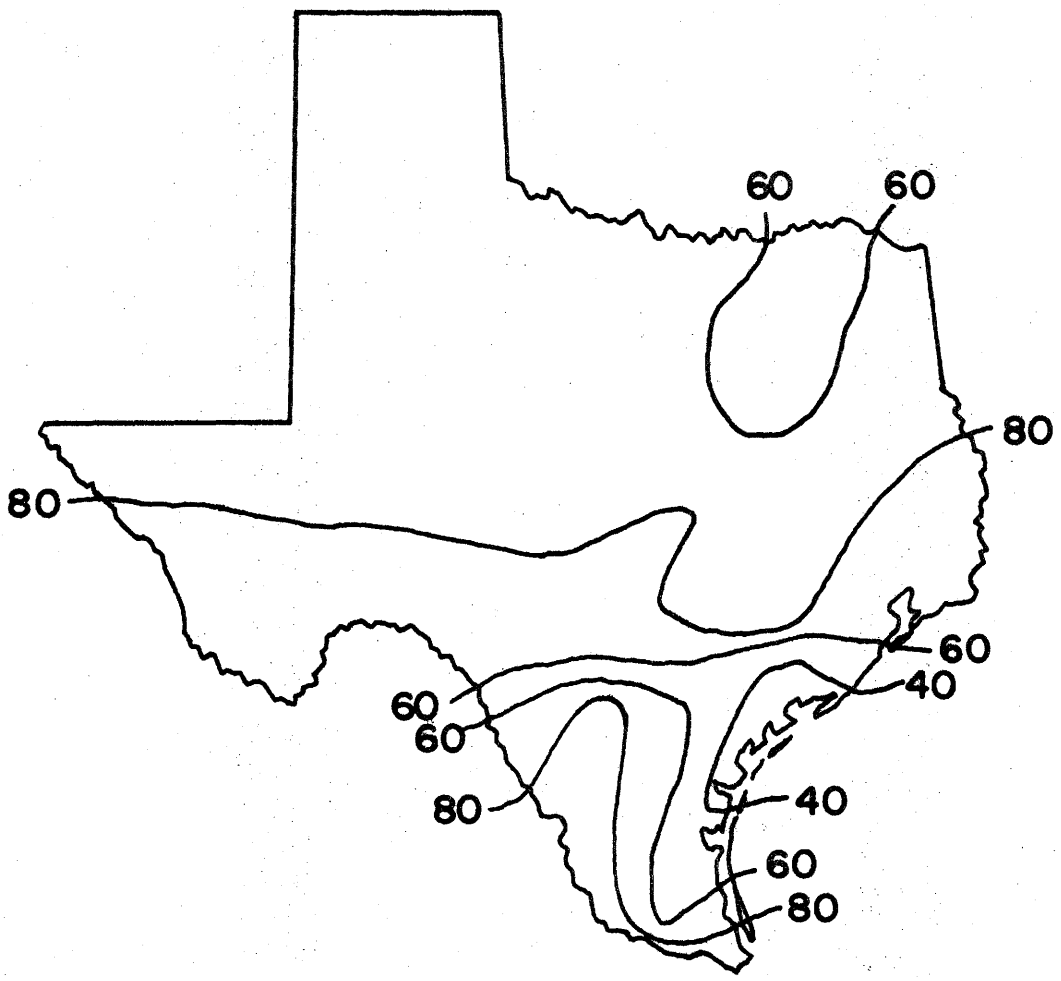


FIGURE 30. PERCENTAGE OF DAYS IN 1971 WITH WINDS LESS THAN 4.0 MPH (CALM).

TABLE 15. Station Locations for Wind Study

- Low Rolling Plains
  - Hords Creek Dam
- North Central
  - Bardwell Dam
  - Belton Dam
  - Benbrook Dam
  - Denison Dam
  - Grapevine Dam
  - Lavon Dam
  - Navarro Mills Dam
  - Proctor Reservoir
  - Stillhouse Hollow Dam
  - Waco Dam
  - Whitney Dam
- East Texas
  - Daingerfield
  - Sam Rayburn Dam
  - Town Bluff Dam
- Trans Pecos
  - Mount Locke
  - Ysleta
- Edwards Plateau
  - Amistad Dam
  - San Angelo Dam
- South Central
  - Austin Airport
  - Beeville
  - Canyon Dam
  - Somerville Dam
- Upper Coast
  - Point Comfort
  - Thompsons
- Southern
  - Dilley
  - Rio Grande City
- Lower Valley
  - McCook
  - Weslaco

A second set of runs was obtained with winds in excess of 15 mph on FM 2818 test section. The mean value for this set of runs was 3.86 while the initial control mean was 3.84. The difference between the mean value is negligible. The mean control band for the Mays Ride Meter was ± 0.21 at the time of testing.

Vehicle Speed

A speed of 50 mph is the specified operating speed of the Mays Ride Meter. The correlation between the Surface Dynamics Profilometer and the Mays Ride Meter as well as the correlation between the panel derived Present Serviceability Rating and Surface Dynamics Profilometer are based in part upon 50 mph speeds. Thus, for road roughness measurements or for determining out of calibration conditions, a speed of 50 mph is utilized. However, not all roads which require testing will be safe to test at 50 mph because of traffic and/or geometric conditions.

For these reasons a study was undertaken to evaluate the reliability of a calibrated Mays Ride Meter in producing a standard relationship between pavement roughness and the relative speed of the vehicle at which the measurement was taken. Two approaches were utilized for the study. The first approach involved the determination of roughness at different speeds on sections of pavements near the Bryan-College Station, Texas area that are utilized to determine the adequacy of Mays Ride Meter calibration (Appendix A). These pavement sections ranged in pavement roughness from 10 to 300 inches per mile and in Serviceability Index values from 2.58 to 4.63.

Each section was run under standard operating procedures except for the variation in vehicle speeds. With all else constant, the testing incorporated vehicle speeds from 20 mph to 70 mph in increments

TABLE 16. Speed Calibration Study*

SI	Inches of Mays Ride Meter Chart per 0.2 mile of Roadway		
	30 mph	40 mph	50 mph
0.5	19.5	21.2	20.3
1.0	12.7	13.4	13.2
1.5	9.2	9.4	9.6
2.0	6.9	6.9	7.1
2.5	5.2	5.1	5.4
3.0	3.9	3.8	4.0
3.5	2.8	2.7	2.9
4.0	1.9	1.8	2.0
4.5	1.1	1.0	1.1
5.0	0.0	0.0	0.0

* 1975 Ford LTD.

of 10 mph. Throughout this speed range roadway roughness summations were measured and recorded. The chart output was converted to roughness summation by the following equation:

Roughness Summation (in/mile) = 6.4 x 5 x Chart Output (inches)

A plot was then prepared of the roughness summation versus the vehicle speed for each pavement section tested (Figures 31 to 38).

Three general relationships evolved from the study and will be discussed below. Figure 31 shows a tendency for the roughness to increase and become asymptotic with speed. Perhaps this behavior is related to the suspension system of the vehicle. That is, the suspension system is designed so that the springs work independently of the shock absorbers up to a certain displacement and then beyond this particular displacement both work together to control the relative roughness communicated by the vehicle. This would then account for the increase in roughness and the asymptotic relationship with speed, if it is assumed that vehicle displacment increases with speed.

The second relationship is that as shown in Figures 32, 33, and 34. As the speed increased, the roughness increased to a maximum and then began to decrease. The actual pavement roughness may be of such magnitude and frequency that it is not totally recorded at any speeds other than 50 mph for the test vehicle. This seems to indicate that more than one speed could be used.

The third general relationship was that of roughness increasing or decreasing with increasing speed without ever reaching an asymptote before the legal vehicle operation speed of 70 mph. Figures 35 through 38 depict such a relationship which may be related to the first general tendency discussed above (relative to design characteristics of vehicle).

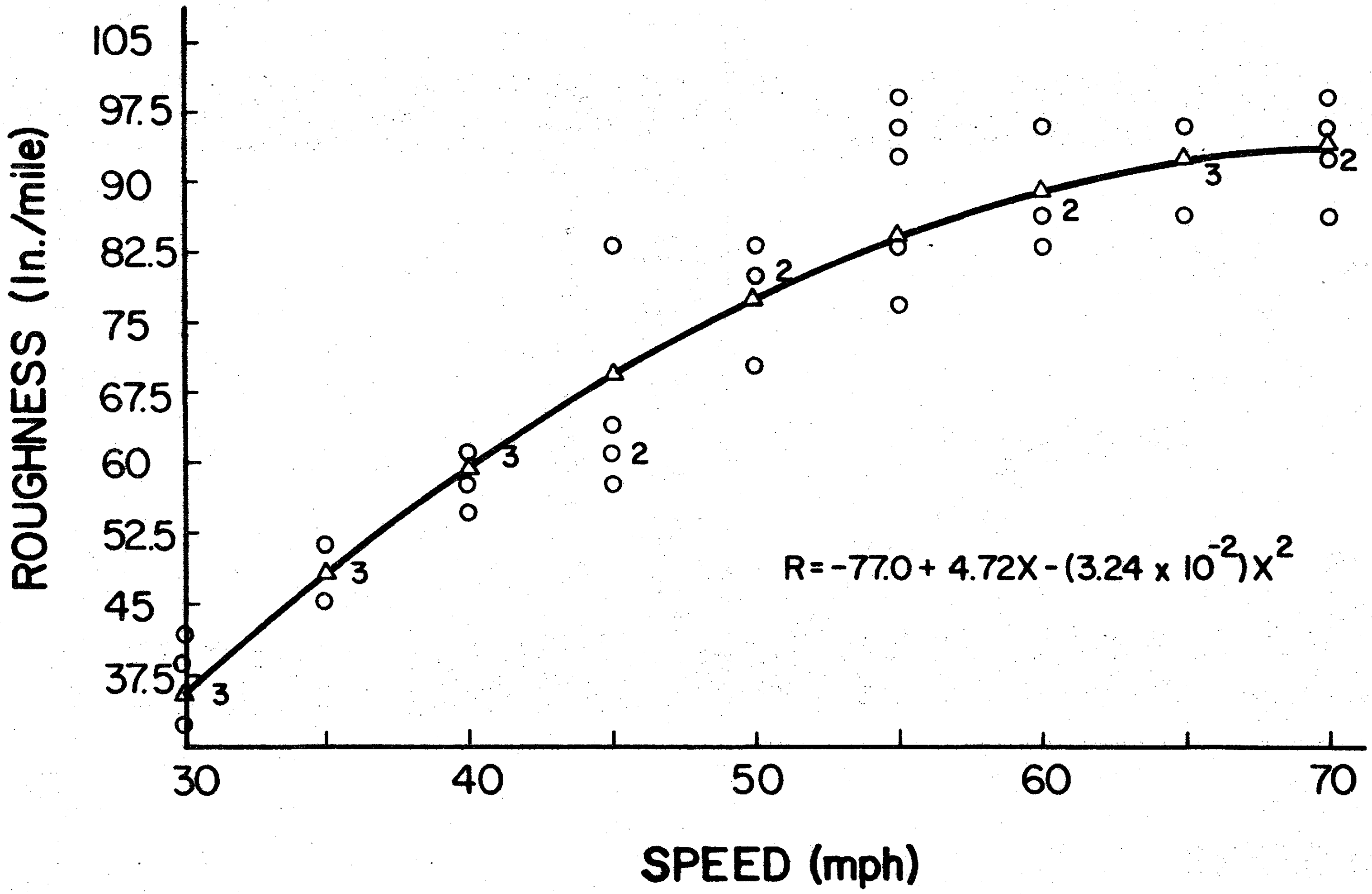


FIGURE 31. VEHICLE SPEED STUDY, F.M. 2347, MRM NO. 1.

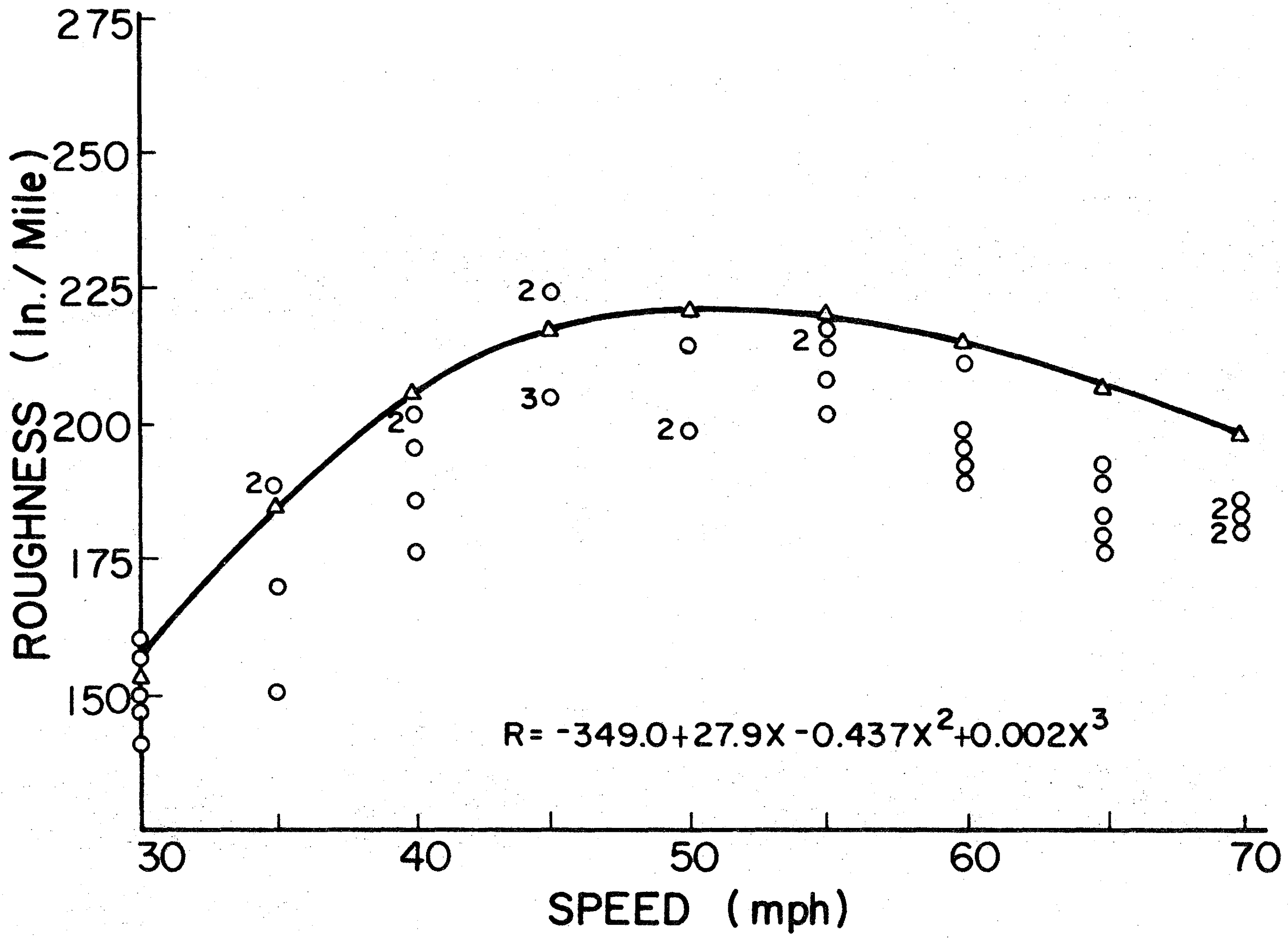


FIGURE 32. VEHICLE SPEED STUDY, O.S.R., MRM NO. 1.

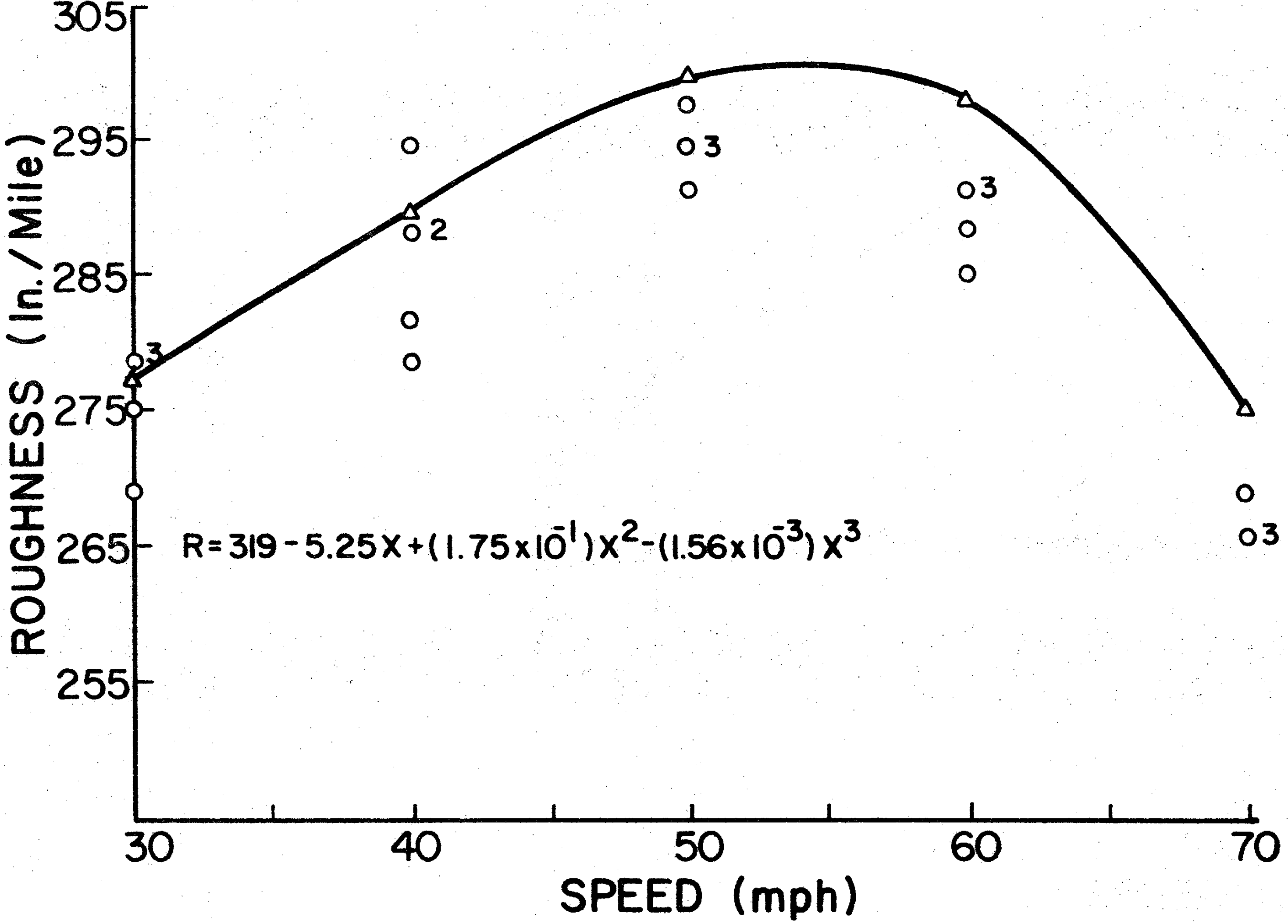


FIGURE 33. VEHICLE SPEED STUDY, O.S.R., MRM NO. 2.

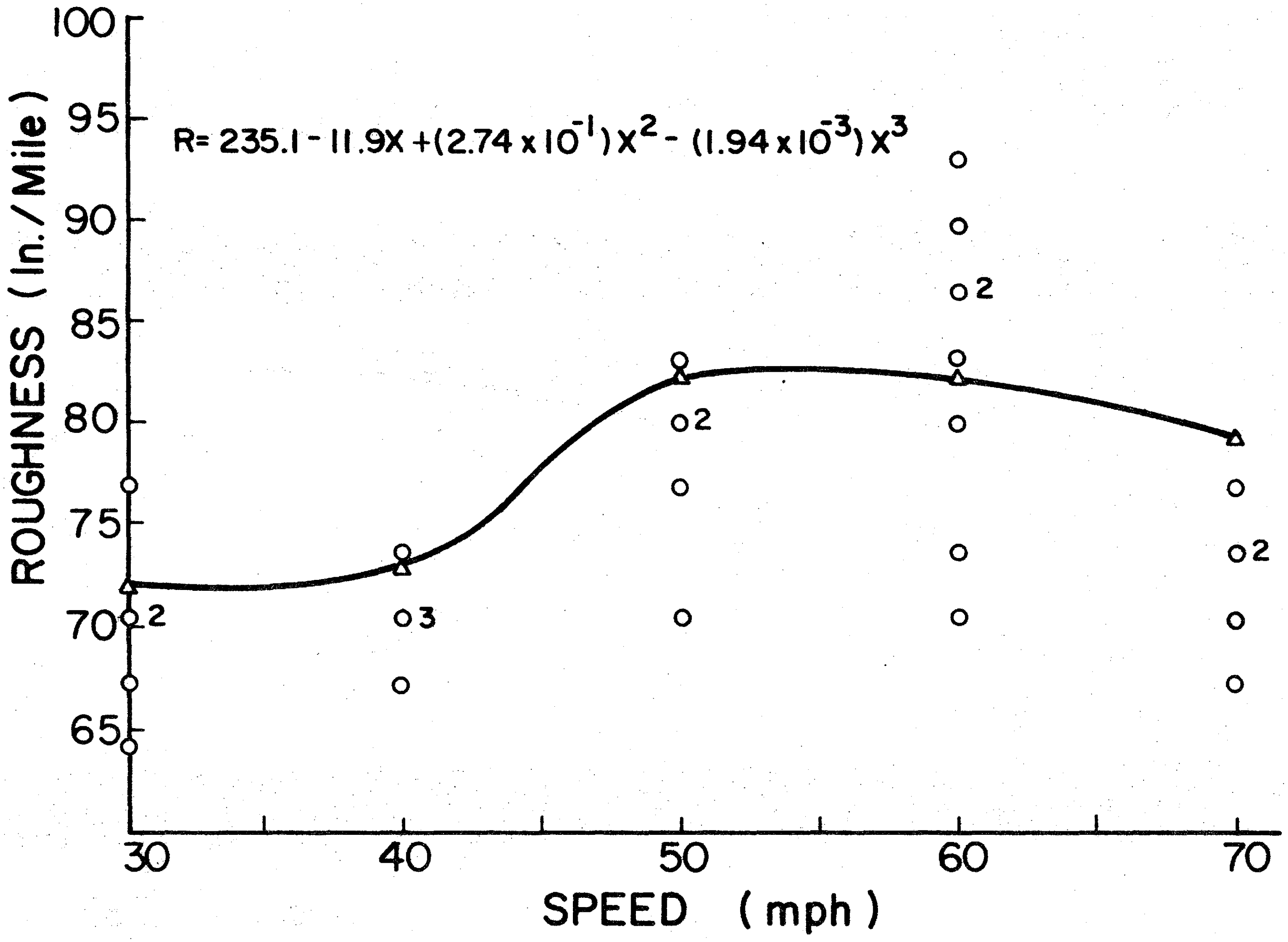


FIGURE 34. VEHICLE SPEED STUDY, EAST BY-PASS, MRM NO. 2.

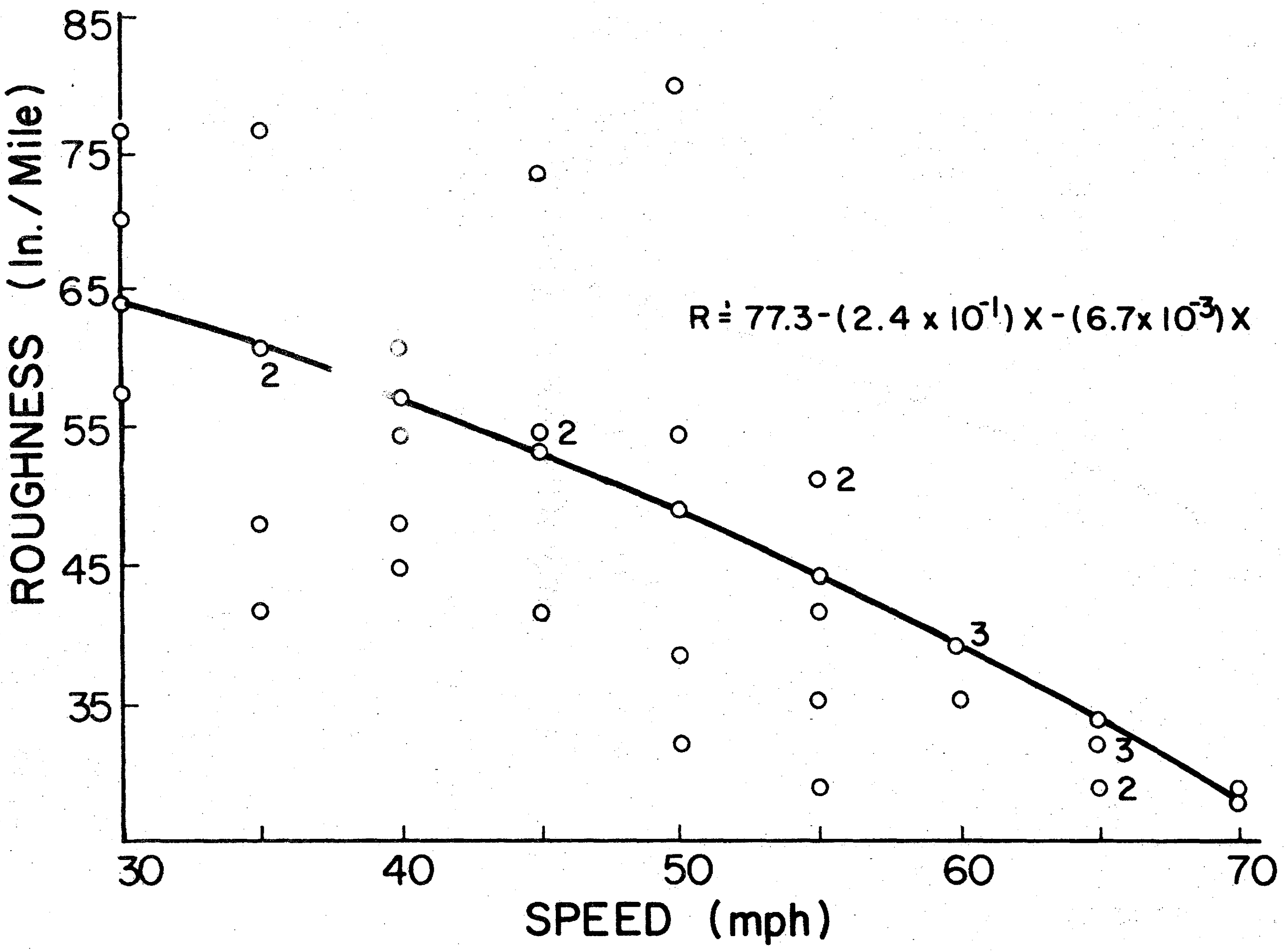


FIGURE 35. VEHICLE SPEED STUDY, F.M. 50 S, MRM NO. 1.

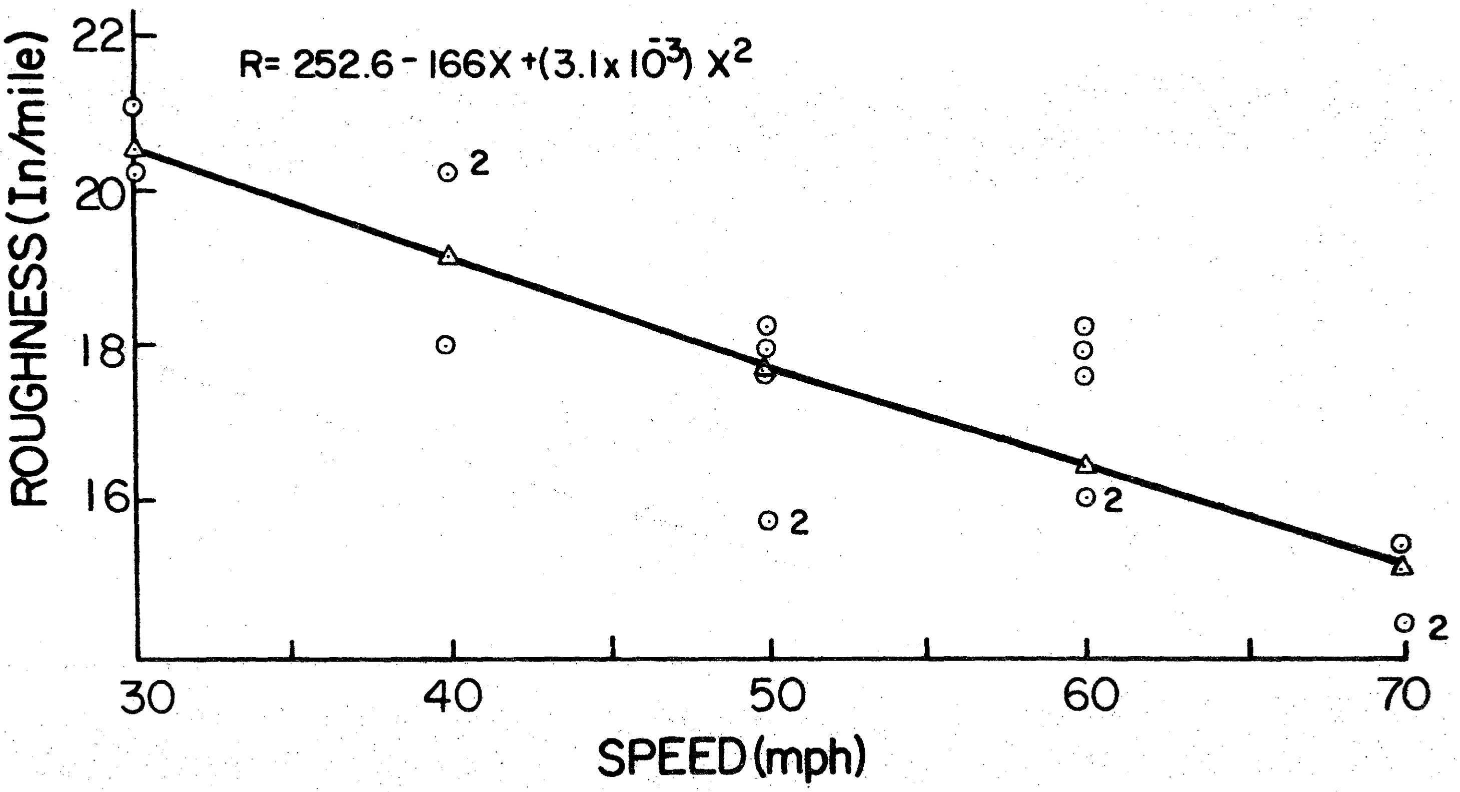


FIGURE 36. VEHICLE SPEED STUDY, F.M. 50N, MRM NO. 2.

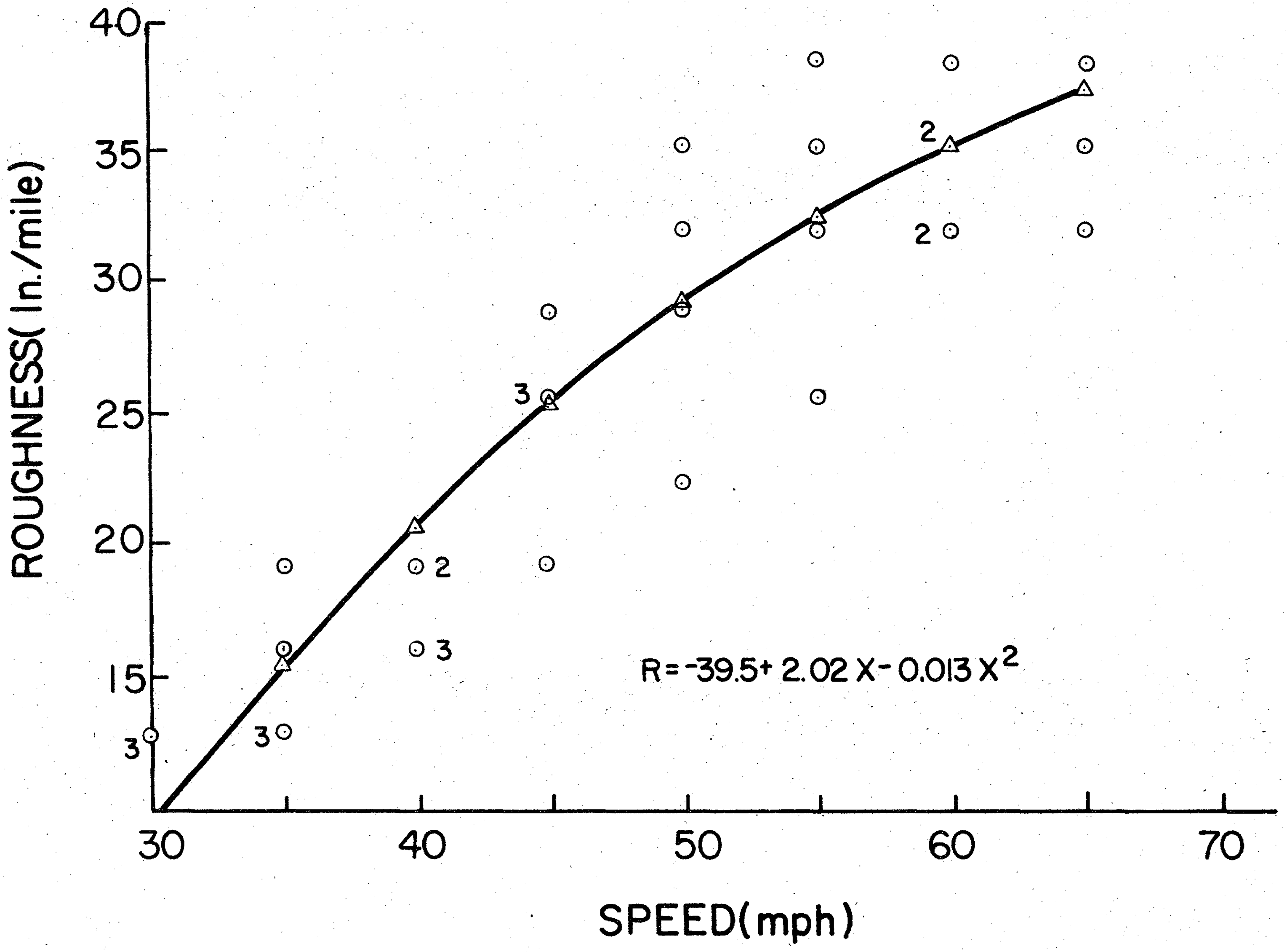


FIGURE 37. VEHICLE SPEED STUDY, S.H.6 NBTL, MRM NO. 1.

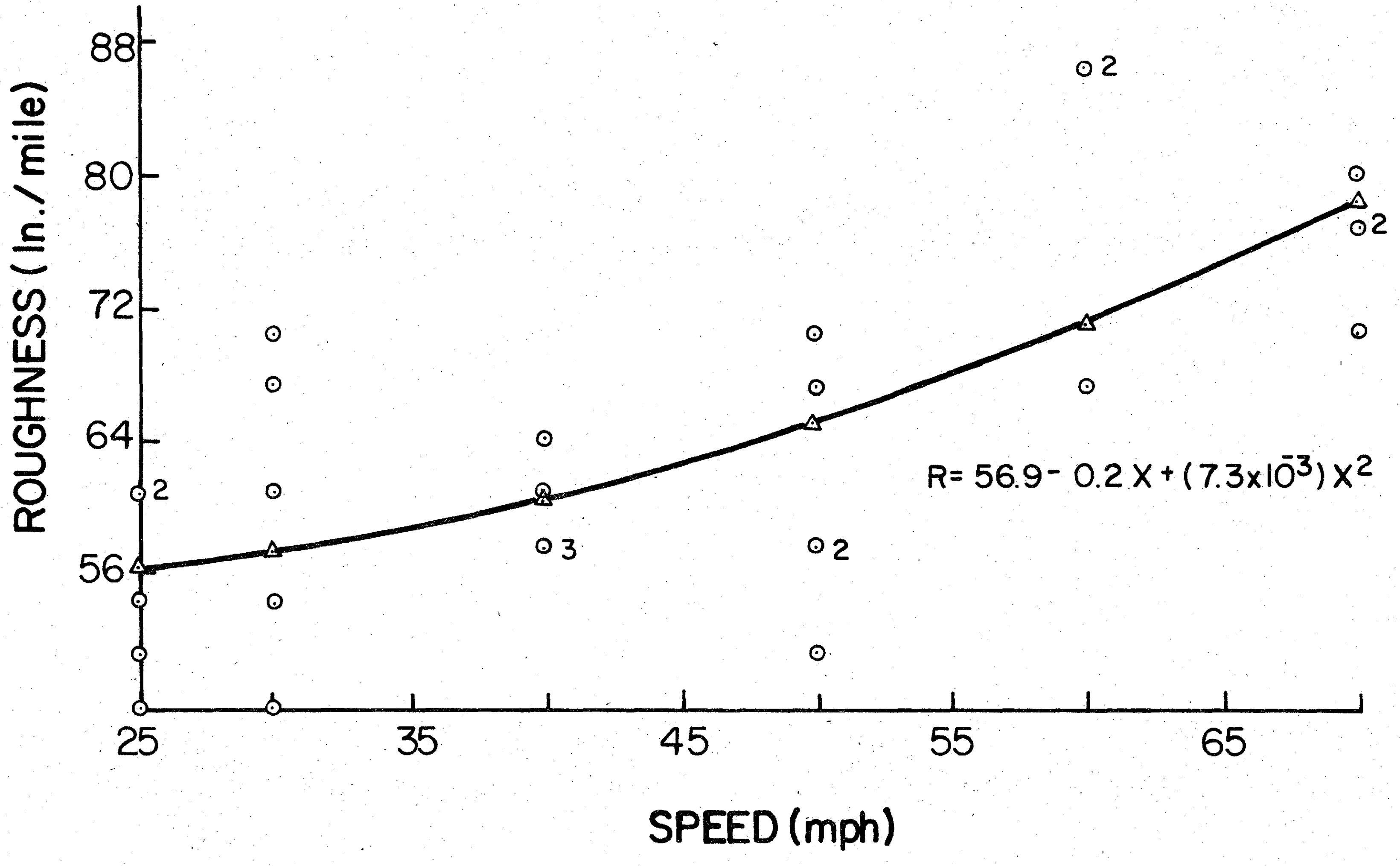
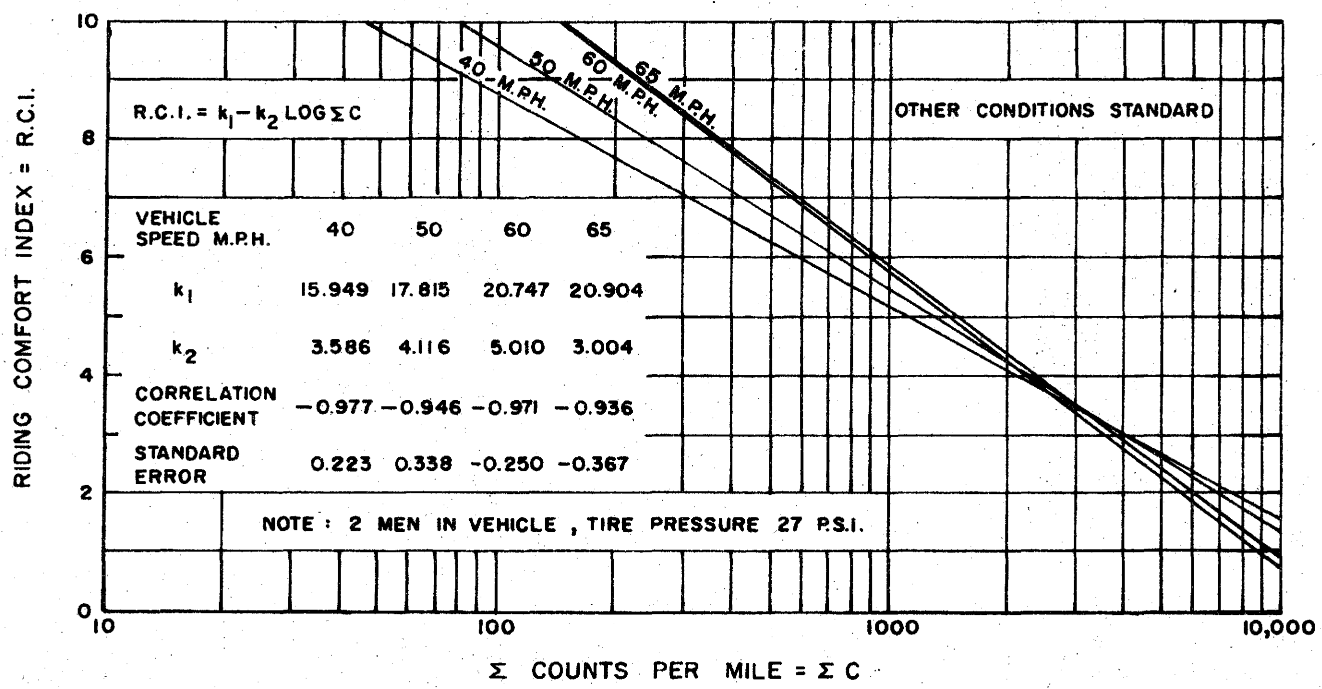


FIGURE 38. VEHICLE SPEED STUDY, S.H. 6 NBTL, MRM NO. 2.

With these general relationships evolving, an attempt was made to assign each to a particular range of roughness values. This proved to be to no avail since within a range of roughness from 10 to 85 inches per mile, the three types of the relationships existed. In fact, no general relationship repeated itself through any range of roughness throughout all of the reference sections tested. The repeatability of relationships occurred only on the same reference section as measured by both Texas Transportation Institute Mays Ride Meter Vehicles. In other words, if a particular control section had roughness which tended to increase as vehicle speed increased, this tendency would repeat in every measurement by either the 1969 Plymouth or 1972 Ford Custom Mays Ride Meter Vehicle (Mays Ride Meter No. 1 and No 2, respectively).

The second approach utilized in this study was to relate speed and measured roughness on the calibration pavement section in Austin. The 1975 Ford LTD was run on the test sections at speeds of 30, 40 and 50 mph. The resulting calibrations between roughness and Serviceability Index for the various operating speeds are shown in Table 16. Little difference is noted in these calibrations for the various speeds of operation.

Speed studies have been conducted by other researchers. Hughes (15) has concluded that operating speed varied over the range of 15 mph significantly affects serviceability measurements. Argue (16) and Clark (22) concluded that errors in predicting Riding Comfort Index are of the same order of magnitude for vehicle calibrations at 40 and 50 mph. Variations due to speed on the Riding Comfort Index as developed by Clark are shown on Figure 39. In general the slope of the curves become steeper as the vehicle speed increases.



VEHICLE SPEED M.P.H.	40	50	60	65
k_1	15.949	17.815	20.747	20.904
k_2	3.586	4.116	5.010	3.004
CORRELATION COEFFICIENT	−0.977	−0.946	−0.971	−0.936
STANDARD ERROR	0.223	0.338	-0.250	-0.367

after Clark (22)

FIGURE 39. EFFECT OF VEHICLE SPEED ON ESTIMATING RIDING COMFORT INDEX.

Research performed by Law and Burt (25) resulted in equations to define the effect of speed on PCA and Mays Ride Meter outputs. The equations proposed for use with the Mays Ride Meter is shown below.

$$M_{CS} = M_B + 1.5\ (50 - S)$$

where;

M_{CS} = Corrected Mays Ride Meter Roughness, inches per mile

M_B = Basic Mays Ride Meter Roughness, inches per mile

S = Test speed miles per hour.

This equation is based on data collected at 30, 40, 50 and 60 mph.

Driver Variability

In November of 1973 the 1972 Ford Custom was utilized to determine the variability in Serviceability Index that could result from different drivers operating the vehicle. Drivers 1 and 2 were familiar with the driving skills required by Mays Ride Meter operators as they were regular Mays Ride Meter operators. Drivers 3, 4 and 5 were selected from the secretarial staff at the Texas Transportation Institute and given one-half hour of instruction and driving experience prior to running the test section. The test section was run at the standard operating speed of 50 mph in both the northbound and southbound lane. The roadway (FM 158 between SH 30 and FM 179) was rough and contained several horizontal and vertical curves. Driver concentration was required to maintain the vehicle in the wheel paths on this particular roadway.

Serviceability Index values for each driver and for each 0.2 mile increment of the test section are shown in Tables 17 and 18 for the northbound and southbound lanes, respectively. Average values for each driver together with other statistics are shown on Table 19 for the entire 2.8 mile section. Mean values for the entire 2.8 mile section for the various drivers show a maximum range among means of 0.11 (southbound lane, Table 19) which from a road network survey standpoint is acceptable. The range of readings for individual 0.2 mile sections (Tables 17 and 18) were within 0.5, 85 percent of the time. Range control limits as determined according to the procedure described in Appendix A and shown in Table 6 are often in excess of 0.5.

A second series of tests were performed in September 1976 to define the effect of the driver on Serviceability Index. The data were obtained on seven 0.2 mile pavement sections in the Bryan-College Station area. These sections are the ones currently used to periodically check the calibration of the TTI Mays Ride Meter vehicle. As can be seen in Table 20, the pavements selected have Serviceability Indices ranging from about 2.0 to 4.5.

Each of the pavement sections were run twenty times to provide an adequate sample on which to examine experimental error. The runs for each pavement section were conducted within approximately one hour, utilizing to the extent possible the same driver, air temperature, gasoline amount, vehicle weight distribution, etc. In this case, experimental error is considered to be primarily driver error induced by the driver's inability to steer the automobile in the same wheel path. Although other potential errors can influence such data, it is felt the driver is the primary source of error, all other factors being held constant as possible.

Both the digital counter (added to the TTI Ford LTD in 1975) and paper chart data were obtained on each run through the sections. The summary

TABLE 17. Serviceability Index for Various Drivers - North Bound Lane of FM 158

Location, Mile Marker	Driver Number					Ranges of Reading For 0.2 Mile Increments
	1	2	3	4	5	
0.2	2.5	2.7	2.1	2.2	2.3	0.6
0.4	2.4	2.1	2.3	2.4	2.3	0.3
0.6	2.9	2.4	2.7	2.7	2.6	0.5
0.8	3.0	2.6	2.8	2.7	2.7	0.4
1.0	2.8	2.6	2.6	2.7	2.6	0.2
1.2	2.7	2.7	2.7	2.6	2.6	0.1
1.4	2.1	2.4	2.1	2.1	2.3	0.3
1.6	2.2	2.4	2.7	2.7	2.6	0.3
1.8	2.9	3.2	2.8	2.8	2.7	0.5
2.0	3.2	2.8	3.3	3.2	3.0	0.5
2.2	3.2	3.1	3.3	3.2	3.2	0.2
2.4	2.8	3.1	2.5	3.2	3.0	0.6
2.6	1.9	2.9	3.2	2.3	3.2	1.3
2.8	2.5	2.3	2.1		2.3	0.4

TABLE 18. Serviceability Index for Various Drivers - South Bound Lane of FM 158

Location, Mile Marker	Driver Number 1	2	3	4	5	Ranges of Readings For 0.2 Mile Increments
.2	2.0	2.0	2.2	2.1	2.0	.2
.4	1.8	1.9	1.9	2.2	1.9	.4
.6	2.7	2.9	2.7	2.8	2.5	.4
.8	2.4	2.3	2.2	2.5	2.2	.3
1.0	2.5	2.6	2.6	2.5	2.5	.1
1.2	2.6	2.9	2.4	2.7	2.6	.5
1.4	3.0	3.0	2.6	2.9	3.0	.4
1.6	2.2	2.6	2.6	2.4	2.3	.4
1.8	2.5	2.5	2.7	2.4	2.5	.3
2.0	2.5	2.3	2.5	2.5	2.4	.2
2.2	2.2	2.3	2.4	2.4	2.2	.2
2.4	2.1	2.1	2.0	1.9	1.7	.4
2.6	2.0	2.5	1.9	2.3	2.1	.6
2.8	1.9	1.9	2.1	2.1	2.1	.2

TABLE 19. Serviceability Index for Various Drivers--Statistical Data.

Lane	Driver Number	Statistic				
		Mean	Standard Deviation	Coefficient of Variation	Range	Number of Data Points
North Bound	1	2.66	0.41	0.15	1.3	14
	2	2.66	0.37	0.14	1.1	14
	3	2.67	0.38	0.14	1.2	14
	4	2.68	0.37	0.14	1.1	13
	5	2.70	0.32	0.12	0.9	14
South Bound	1	2.34	0.34	0.15	1.1	14
	2	2.46	0.35	0.14	1.1	14
	3	2.35	0.30	0.13	0.8	14
	4	2.43	0.28	0.11	1.0	14
	5	2.31	0.33	0.14	1.3	14

of means and standard deviations is shown in Table 20. Only slight differences were observed to occur between the two means for a given pavement section. Section 4 (FM 2347), the roughest section measured, did show a difference of 0.2 between means.

For either method of obtaining the Mays Ride Meter data, the standard deviation represents the (±) range within which the mean should fall approximately 68 percent of the time. For example, the Section 1 (FM 50 So) mean obtained from the digital counter should fall within the values of 3.24 to 3.56 approximately 68% of the time if values for the pavement were repeatedly obtained. A small standard deviation could indicate the driver's ability to duplicate his route through the pavement section repeatedly and/or that the pavement section has little variability across the wheel paths.

Table 21 shows the coefficient of variation (CV) for these data examined four ways. They are as follows: (1) CV for raw data from the digital counter, (2) CV for raw data from the paper chart, (3) CV for Serviceability Index (after reduction) as obtained from the digital counter, and (4) CV for Serviceability Index (after reduction) as obtained from the paper chart. The coefficient of variation is a dimensionless number shown as a percentage in this case. The coefficient of variation is a way in which the standard deviation can be related to the mean and represents the percentage the standard deviation is of the mean. In other words, a high CV value, say 50%, represents a standard deviation which is half of the mean. This would represent a process with high variability.

Referring to Table 21, the coefficients of variation for the raw data are higher than those for the reduced data for 5 of the 7 pavement

TABLE 20. Serviceability Index Means and Standard Deviations for MRM Digital Counter and Paper Chart Systems as Measured on 0.2 Mile Pavement Sections

	Digital Counter		Paper Chart	
Section	Mean	Std Dev	Mean	Std Dev
1 (FM 50 So)	3.4	.15	3.5	.15
2 (SH 6 Front Rd)	3.0	.12	3.0	.12
3 (FM 2818	3.5	.17	3.6	.18
4 (FM 2347)	2.0	.09	2.2	.09
5 (SH 6 By-Pass)	3.2	.11	3.3	.10
6 (FM 50 No)	2.5	.19	2.6	.17
7 (SH 30)	4.4	.13	4.5	.13

TABLE 21. Coefficients of Variation for the TTI 1975 LTD Mays Ride Meter Vehicle as Measured on 0.2 Mile Pavement Sections

Section	CV Raw Data Digital Counter (%)	CV Raw Data Paper Chart (%)	SI (Digital) CV (%)	SI (Paper Chart) CV (%)
1 (FM 50 So)	6.2	6.1	4.3	4.4
2 (SH 6 Front Rd)	4.0	4.2	3.8	4.2
3 (FM 2818)	7.2	7.6	4.9	5.1
4 (FM 2347)	3.0	3.0	4.6	4.3
5 (SH 6 By-Pass)	4.1	3.8	3.5	2.9
6 (FM 50 No)	5.9	5.8	7.7	6.7
7 (SH 30)	12.3	11.8	2.9	2.8

sections measured. This may be due to the smoothing effect caused by converting raw data to Serviceability Index values. In any case based on this small sample, it appears driver error can cause approximately a 4 percent variation in obtaining Serviceability Index data for any given pavement section. This potentially could cause some difficulties in obtaining reliable Serviceability Indices for pavement sections being measured periodically and could have had an unknown impact on some of the previously mentioned studies.

The difference in coefficients of variation as produced by the digital counter and the paper chart do not appear to be of a significant nature.

SERVICEABILITY INDEX MEASUREMENT ACCURACY

The accuracy required for Serviceability Index measurements is dependent upon the end use of the measurements. If the data are to be utilized to determine the Serviceability Index of a particular short highway section, a different degree of accuracy may be required than that required to obtain average values for a statewide highway system. Accuracy required for research and inventory purposes is also different.

Mean Serviceability Index values obtained in 1974 for randomly selected 2-mile pavement sections throughout the state of Texas are shown in Figure 40 and on Table 22. The average Serviceability Index standard deviation for the two-mile section on which 10 - two tenths of a mile measurements are made is of the order of 0.3 with about 95 percent of the data between 0.1 and 0.7. Thus, one can expect a coefficient of variation of about 10 to 15 percent as a 2-mile section of pavement is transversed. On very rough roads much higher variability can be expected as an examination of the data contained in Figure 40 and Table 22 reveals.

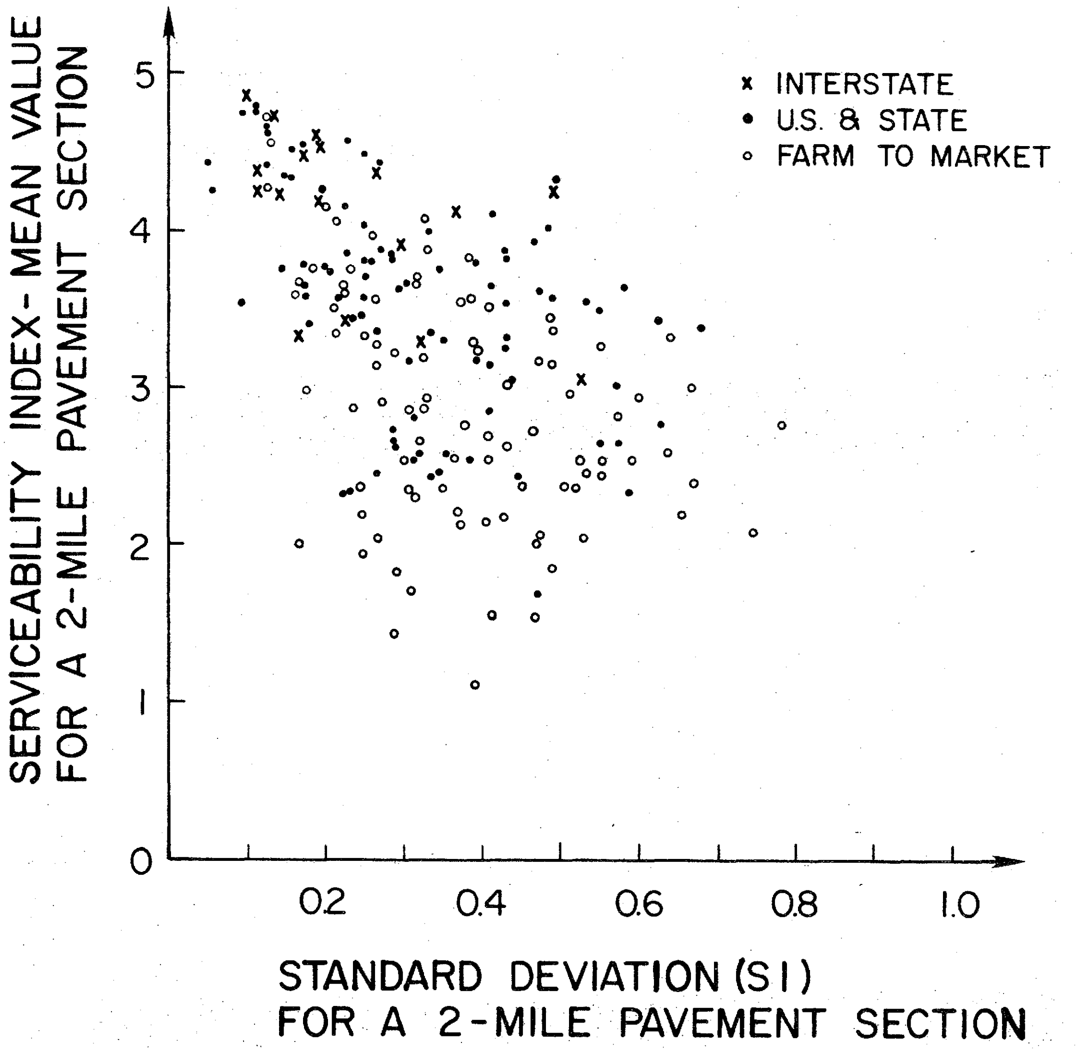


FIGURE 40. SERVICEABILITY INDEX MEAN AND STANDARD DEVIATIONS FOR RANDOMLY SELECTED 2 MILE SECTIONS OF PAVEMENT IN TEXAS - 1974.

TABLE 22. 1974 Mays Ride Meter Data Summary for Randomly Located Pavement Sections

District	County	Highway	Control-Section	Location	Date	N	$\overline{X}$	S	CV (%)	LV	HV	R
1	Grayson	US 82	45-4	P22/P24	8/27/74	10	3.38	.266	7.86	3.0	3.8	0.8
1	Grayson	FM 2729	2798-3	P4/P6	8/27/74	4	3.58	.263	7.36	3.2	3.8	0.6
1	Hunt	IH 30	9-13	P107/H-HCL	10/26/74	9	3.44	.230	6.67	2.9	3.6	0.7
1	Hunt	SH 34	173-6	CASH/P30	10/26/74	10	3.93	.464	11.82	3.1	4.4	1.3
1	Hunt	FM 1566	1495-1	P4/P2	10/26/74	9	2.18	.429	19.72	1.2	2.6	1.4
1	Hunt	FM 2736	2732-1	P0/P2	10/26/74	9	2.03	.527	25.91	1.4	2.8	1.4
1	Lamar	US 271	136-8	P6/P8	8/27/74	9	3.58	.176	4.91	3.2	3.8	0.6
1	Lamar	FM 905	730-3	P14/FM 1497	8/27/74	8	2.54	.526	20.74	1.9	3.4	1.5
1	Lamar	FM 79	688-2	P16/P14	8/27/74	10	2.40	.673	28.05	1.1	3.5	2.4
1	Rains	US 69	203-3	P6/P8	10/25/74	10	3.55	.217	6.12	3.3	3.9	0.6
2	Erath	SH 6	258-1	P8/P10	8/29/74	10	3.81	.251	6.60	3.4	4.1	0.7
2	Erath	FM 2157	1990-1	P4/P6	8/29/74	10	2.38	.457	19.18	1.8	3.2	1.4
2	Jack	US 281	249-7	P38/P36	8/28/74	10	3.43	.236	6.88	3.1	3.8	0.7
2	Jack	FM 206	391-7	P6/P4	8/28/74	9	2.96	.517	17.51	2.1	3.8	1.7
2	Johnson	US 67	259-4	P28/P30	11/23/74	9	4.00	.332	8.29	3.7	4.5	0.8
2	Johnson	FM 917	1181-2	P2/P4	11/23/74	10	2.03	.263	12.94	1.7	2.4	0.7
2	Tarrant	FM 1709	1603-3	P2/P4	8/28/74	9	2.51	.362	14.43	2.1	3.1	1.0
2	Johnson	IH 35W	14-4	P19/P21	10/27/74	9	3.06	.527	17.25	2.4	3.8	1.4
3	Clay	SH 79	282-2	P6/P4	8/27/74	9	4.01	.481	11.99	2.9	4.5	1.6
3	Clay	FM 1197	1350-1	P10/P12	8/27/74	9	2.78	.784	28.22	1.6	4.0	2.4
3	Montague	SH 59	239-2	P22/P20	8/27/74	7	4.03	.250	6.20	3.6	4.4	0.8
3	Montague	FM 455	845-1	P6/P8	8/27/74	4	3.30	.245	7.42	3.0	3.6	0.6
3	Throckmorton	US 183	404-1	P36/P34	8/28/74	10	2.65	.574	21.66	2.1	3.7	1.6
3	Throckmorton	FM 2651	2645-1	P2/US 380	8/28/74	8	2.55	.588	23.06	1.7	3.4	1.7
3	Wilbarger	US 183	147-1	P29.4/P28	8/26/74	7	3.14	.412	13.10	2.7	3.8	1.1
3	Wilbarger	FM 91	702-1	P10/P11.8	8/26/74	9	3.84	.328	8.54	3.3	4.3	1.0
4	Carson	IH 40	275-4	P105/P104	8/25/74	5	4.52	.192	4.26	4.1	4.5	0.4
4	Carson	US 60	169-5	WDCL/P26	8/25/74	8	4.48	.249	5.57	3.9	4.7	0.8
4	Carson	FM 1342	1884-1	P12/P10	8/25/74	10	3.69	.318	8.61	3.1	4.0	0.9
4	Hartley	US 87	41-1	P6/P4	8/24/74	9	3.59	.488	13.61	2.7	4.3	1.6
4	Hartley	FM 998	1662-2	P2/P4	8/24/74	9	2.88	.406	14.09	2.3	3.5	1.2
4	Hutchinson	SH 152	557-2	P8/P6	4/24/74	8	3.86	.283	7.31	3.3	4.1	0.8
4	Hutchinson	FM 1598	1515-3	P2/P0	8/24/74	10	2.43	.533	21.95	1.5	3.0	1.5
4	Lipscomb	SH 305	582-1	P2/P4	8/24/74	9	2.66	.553	20.81	1.9	3.4	1.5
4	Lipscomb	FM 1265	1337-2	P28/P30	8/25/74	9	3.68	.315	8.57	3.2	4.2	1.0
4	Oldham	IH 40	90-3	P20/P22	8/24/74	10	4.23	.142	3.35	4.0	4.4	0.4
4	Oldham	US 385	226-2	P6/P4	8/24/74	10	4.33	.495	11.42	3.1	4.8	1.7
4	Oldham	FM 290	461-13	O-DS CL/P4	8/24/74	8	3.40	.233	6.85	3.1	3.7	0.6
4	Hartley	US 54	238-2	P34/P36	8/24/74	9	4.57	.173	3.79	4.2	4.7	0.5
5	Hale	US 87	67-6	P24/P26	10/08/74	10	3.80	.392	10.3	3.1	4.2	1.1
5	Hale	SH 194	439-4	P6/P8	8/24/74	10	3.31	.431	13.01	2.6	3.9	1.3
5	Hale	FM 400	1041-1	P26/P28	8/24/74	10	2.77	.380	13.73	2.1	3.4	1.3
5	Hale	FM 1612	2332-2	P2/P0	8/24/74	10	3.14	.263	8.39	2.7	3.5	0.8
5	Hockley	US 385	227-5	P8/P10	8/27/74	10	3.64	.414	11.38	2.8	4.2	1.4
5	Hockley	FM 1585	2182-2	P30/P28	8/23/74	10	3.78	.181	4.80	3.5	4.0	0.5
5	Lubbock	US 84	52-7	P2/P4	8/23/74	10	3.07	.440	14.32	2.5	3.9	1.4
5	Lubbock	FM 1729	1632-2	P18/P20	8/23/74	9	3.34	.219	6.54	3.0	3.6	0.6
5	Parmer	SH 86	302-1	P20/P18	8/24/74	9	3.40	.180	5.30	3.2	3.8	0.6
5	Parmer	FM 2013	2185-1	P4/P2	8/24/74	10	4.16	.201	4.83	3.8	4.4	0.6
5	Swisher	US 87	67-3	P24/P26	8/24/74	10	2.48	.343	13.81	2.1	3.1	1.0
5	Swisher	FM 1424	1635-1	P12/P10	8/24/74	10	2.35	.521	22.81	1.6	3.0	1.4
5	Yoakum	SH 214	461-5	P4/P2	8/23/74	10	2.59	.321	12.40	1.9	3.0	1.1
5	Yoakum	FM 1780	967-4	P4/P2	8/23/74	10	2.20	.365	16.60	1.5	2.8	1.3
6	Ector	IH 20	4-7	P110/P108	8/22/74	10	4.38	.266	6.07	3.9	4.7	0.8
6	Ector	US 385	229-1	P26/P24	8/22/74	10	4.77	.095	1.99	4.6	4.9	0.3
6	Ector	FM 866	1127-4	P4/P2	8/22/74	10	3.81	.381	10.00	3.1	4.4	1.3
6	Loving	SH 302	479-2	P2/P0	8/22/74	9	3.73	.206	5.52	3.4	4.0	0.6
6	Pecos	IH 10	441-7	P251/P250	8/20/74	5	4.26	.114	2.68	4.1	4.4	0.3
6	Pecos	SH 18	292-6	P24/P22	8/20/74	9	4.58	.228	4.98	4.2	4.8	0.6

TABLE 22 (Continued)

District	County	Highway	Control-Section	Location	Date	N	$\overline{X}$	S	CV (%)	LV	HV	R
6	Pecos	US 385	76-1	P54/P56	8/20/74	10	3.76	.143	3.80	3.6	4.1	0.5
6	Pecos	FM 1776	2262-4	P34/P32	8/20/74	9	4.70	.132	2.81	4.5	4.8	0.3
6	Pecos	FM 1450	1639-2	P10/P8	8/20/74	10	2.99	.179	5.99	2.7	3.2	0.5
6	Pecos	FM 2886	2905-1	P2/P4	8/20/74	10	4.06	.324	7.98	3.6	4.4	0.8
6	Upton	FM 1492	2906-2	P12/P14	8/22/74	7	2.84	.305	10.70	2.4	3.3	0.9
8	Borden	US 180	295-3	P30/P28	8/23/74	10	2.72	.286	10.51	2.3	3.1	0.8
8	Borden	FM 612	682-2	P2/P4	8/23/74	10	2.00	.471	23.60	1.2	2.9	1.7
8	Callahan	IH 20	7-1	P311/P313	8/29/74	3	4.50	.173	3.85	4.3	4.6	0.3
8	Callahan	US 283	437-3	P16/P14	8/29/74	9	2.48	.264	10.64	2.1	3.0	0.9
8	Callahan	FM 604	974-1	P12/P14	8/29/74	10	2.59	.640	24.72	1.7	3.3	1.6
8	Fisher	US 180	296-3	P28/P30	8/23/74	9	3.40	.680	20.00	2.5	4.4	1.9
8	Fisher	FM 1606	1526-4	P2/P4	8/22/74	9	3.52	.409	11.60	3.0	4.1	1.1
8	Mitchell	IH 20	5-8	P208/P210	8/22/74	10	4.60	.189	4.1	4.3	4.9	0.6
8	Mitchell	SH 208	454-3	P22/P24	8/22/74	9	2.83	.308	10.90	2.3	3.2	0.9
8	Mitchell	FM 1899	2472-1	P4/P2	8/22/74	8	3.69	.125	3.38	3.6	3.9	0.3
9	Bell	IH 35	15-6	P291/P289	11/24/74	9	4.39	.117	2.66	4.2	4.6	0.4
9	Bell	US 190	185-1	P38/P36	11/24/74	10	4.42	.270	6.11	4.0	4.7	0.7
9	Bell	FM 440	836-2	P6/P8	11/24/74	9	4.06	.219	5.39	3.7	4.5	0.8
9	Bosque	SH 6	258-7	P38/P40	10/27/74	9	4.53	.158	3.49	4.2	4.7	0.5
9	Falls	FM 434	1077-1	P0/P2	10/27/74	8	1.85	.484	26.16	1.5	3.0	1.5
9	Hill	SH 31	162-2	P10/P8	11/22/74	9	3.84	.283	7.37	3.3	4.1	0.8
9	Hill	FM 309	888-2	P8/P6	10/27/74	7	2.30	.311	13.52	2.0	2.8	0.8
9	Falls	SH 7	382-2	P16/P17.6	10/27/74	8	2.35	.233	9.91	2.0	2.7	0.7
10	Van Zandt	SH 110	505-1	P2/P4	10/25/74	9	2.42	.444	18.32	1.6	2.9	1.3
10	Van Zandt	FM 1256	1172-1	P0/P2	10/25/74	9	1.12	.393	35.02	0.6	1.7	1.1
10	Van Zandt	FM 1395	2477-1	P4/P2	10/25/74	10	2.51	.300	11.94	2.1	2.9	0.8
11	Sabine	US 96	64-5	P8/P6	9/21/74	10	2.63	.287	10.90	2.2	3.0	0.8
11	Sabine	FM 330	896-1	P4/P2	9/21/74	10	1.55	.467	30.10	0.9	2.5	1.6
12	Brazoria	SH 35	178-3	P28/P26	11/25/74	10	4.32	.155	3.59	4.1	4.5	0.4
12	Brazoria	FM 523	1003-1	P8/P10	11/25/74	9	3.39	.491	3.39	2.5	3.9	1.4
12	Harris	IH 45	500-3	P26/P24	11/26/74	8	4.21	.196	4.65	3.8	4.4	0.6
12	Galveston	SH 6	192-4	P2/P4	11/26/74	9	4.43	.050	1.13	4.4	4.5	0.1
12	Galveston	FM 517	978-2	P14/P12	11/26/74	10	3.66	.222	6.07	3.3	4.0	0.7
12	Montgomery	IH 45	110-4	P81/P79	10/22/74	8	4.14	.367	7.40	3.7	4.6	0.9
12	Montgomery	SH 105	338-3	P11.3/P12	10/22/74	3	4.27	.058	1.350	4.2	4.3	0.1
12	Montgomery	FM 1485	1062-3	P12/P14	10/22/74	4	4.28	.126	2.940	4.1	4.4	0.3
12	Waller	US 290	50-5	P12/P14	11/27/74	11	3.62	.289	7.99	3.3	4.3	1.0
12	Waller	FM 359	543-1	P12/P14	11/27/74	9	3.76	.235	6.260	3.4	4.0	0.6
13	DeWitt	SH 72	270-1	P22/P20	11/24/74	9	3.02	.570	18.85	1.9	3.6	1.7
13	DeWitt	FM 1447	1113-2	P10/P8	11/24/74	10	2.14	.406	18.98	1.5	2.7	1.2
13	Fayette	US 77	211-6	P6/P8	10/15/74	10	4.17	.223	5.34	3.7	4.4	0.7
13	Fayette	FM 2237	2096-1	P4/P2	10/15/74	10	2.04	.476	23.40	1.5	2.6	1.1
13	Fayette	FM 155	211-9	P10/P8	10/15/74	10	2.81	.577	20.50	1.8	3.8	2.0
13	Gonzales	US 90A	25-5	P6/P4	10/15/74	10	3.76	.348	9.25	3.1	4.1	1.0
13	Gonzales	FM 532	1007-2	P6/P4	10/15/74	10	1.45	.289	20.00	1.1	1.9	0.8
13	Wharton	US 59	89-5	P32/P30	11/25/74	9	4.40	.122	2.78	4.2	4.6	0.4
13	Wharton	FM 1300	420-10	P0/P2	11/25/74	10	3.22	.291	9.02	2.8	3.7	0.9
13	Wharton	FM 1301	1412-3	W-MCL/N 1MI	11/25/74	9	3.62	.222	6.14	3.2	3.9	0.7
14	Bastrop	SH 21	471-5	P6/P8	11/06/74	9	3.70	.255	6.89	3.3	4.1	0.8
14	Bastrop	FM 1704	1533-1	P4/P6	11/06/74	10	2.87	.236	8.22	2.5	3.3	0.8
14	Blanco	US 281	253-1	P22/P24	11/07/74	9	4.61	.127	2.75	4.4	4.7	0.3
14	Blanco	FM 1323	1056-5	P8/P6	11/07/74	9	2.33	.308	13.20	1.9	2.8	0.9
14	Hays	US 290	113-7	P4/P2	11/07/74	9	4.11	.414	10.06	3.4	4.7	1.3
14	Hays	FM 12	683-3	P10/P12	11/07/74	9	3.57	.387	10.90	2.7	4.0	1.3
14	Llano	SH 71	700-4	P30/P32	11/07/74	10	3.77	.200	5.31	3.5	4.2	0.7
15	Atascosa	SH 16	517-1	P28/P30	10/15/74	10	3.64	.581	15.98	2.8	4.1	1.3
15	Bexar	IH 10	25-2	P588/P590	10/17/74	9	3.30	.325	9185	2.9	3.9	1.0
15	Bexar	US 90	24-7	FM 1604/W 2MI	10/16/74	10	3.61	.475	13.17	2.8	4.3	1.5
15	Comal	FM 306	1728-2	P14/P12	11/07/74	9	3.56	.377	10.60	2.8	4.0	1.2
15	Guadalupe	IH 10	535-2	P616/P618	10/17/74	9	3.92	.298	7.60	3.4	4.3	0.9

TABLE 22 (Continued)

District	County	Highway	Control-Section	Location	Date	N	$\bar{X}$	S	CV (%)	LV	HV	R
15	Guadalupe	SH 123	366-3	P24/P26	10/17/74	9	2.54	.316	12.40	2.1	2.9	0.8
15	Guadalupe	FM 1044	2021-2	P4/P2	10/17/74	9	2.69	.411	15.30	2.1	3.5	1.4
15	LaSalle	SH 97	483-1	P10/P12	10/15/74	9	2.53	.382	15.50	2.0	3.1	1.1
15	LaSalle	FM 468	652-5	P32/P34	10/15/74	9	3.01	.436	14.47	2.2	3.5	1.3
16	Aransas	SH 35	180-5	P26/P24	11/25/74	10	3.65	.172	4.70	3.4	4.0	0.6
16	Aransas	FM 881	507-4	P2/P4	11/25/74	10	3.22	.391	12.14	2.5	3.6	1.1
16	Live Oak	SH 72	483-4	P8/P6	11/24/74	9	2.59	.355	13.72	2.2	3.3	1.1
16	Live Oak	FM 1358	1206-1	P14/P12	11/24/74	10	2.44	.552	22.63	1.6	3.3	1.7
16	Live Oak	US 281	254-1	P28/P30	11/24/74	10	3.56	.532	14.93	2.6	4.3	1.7
16	Nueces	US 77	102-2	P14/P12	11/24/74	10	3.79	.173	4.56	3.5	4.0	0.5
16	Nueces	FM 665	86-20	P4/P6	11/24/74	9	3.50	.212	6.06	3.2	3.8	0.6
16	Refugio	SH 202	447-04	P6/P4	11/25/74	10	3.50	.552	15.76	2.5	4.1	1.6
16	Refugio	FM 774	447-5	P2/P4	11/25/74	9	3.32	.640	19.26	2.2	4.3	2.1
17	Burleson	SH 21	116-3	P20/P22	8/31/74	9	2.43	.339	13.94	2.0	2.8	0.8
17	Burleson	FM 60	648-3	P24/P22	12/10/74	9	3.31	.252	7.62	3.0	3.7	0.7
17	Madison	SH 21	117-4	P8/P10	12/10/74	9	3.34	.340	10.17	2.8	3.9	1.1
17	Robertson	US 79	205-2	P6/P8	12/10/74	10	3.67	.302	8.23	3.0	4.1	1.1
17	Robertson	FM 979	2400-1	P24/P22	12/10/74	10	2.36	.504	21.35	1.6	3.1	1.5
17	Walker	FM 1374	578-3	P16/P14	12/10/74	9	2.73	.466	17.06	1.8	3.3	1.5
18	Collin	FM 547	1041-1	P2/P0	10/26/74	9	2.36	.246	10.42	1.9	2.7	0.8
18	Collin	FM 2478	2351-1	P4/P6	9/23/74	8	3.98	.260	6.55	3.4	4.2	0.8
18	Denton	US 377	81-6	FM 428/SW 2MI	11/23/74	9	4.24	.194	4.58	3.8	4.4	0.6
18	Denton	FM 156	718-1	1MI N 114/3MI N 114	11/23/74	10	3.68	.169	4.58	3.4	3.9	0.5
18	Ellis	US 287	172-8	P26/P28	10/26/74	10	3.86	.222	5.75	3.6	4.0	0.4
18	Ellis	FM 660	1048-2	P4/P6	10/26/74	10	3.26	.554	17.00	2.0	3.9	1.9
18	Ellis	FM 55	1451-2	P12/P14	10/26/74	10	2.12	.371	17.48	1.5	2.7	1.2
18	Rockwall	IH 30	9-12	P18/P20	10/26/74	10	3.35	.165	4.93	3.1	3.6	0.5
18	Rockwall	SH 66	9-4	RHBRG/E 1.5MI	10/26/74	7	3.17	.395	12.45	2.4	3.6	1.2
18	Rockwall	FM 548	1016-4	1.2MI SW/P10	10/26/74	10	1.70	.311	18.29	1.3	2.1	0.8
20	Chambers	SH 146	389-2	MBCL/LCL	11/26/74	4	3.52	.096	2.72	3.4	3.6	0.2
21	Kennedy	US 77	327-2	P6/P8	3/25/74	9	3.58	.252	7.05	3.1	3.9	0.8
21	Duval	US 59	542-3	P26/P28	6/25/74	10	3.39	.307	9.06	2.8	3.8	1.0
21	Duval	FM 716	1083-2	P4/P6	6/26/74	10	1.94	.250	12.90	1.6	2.3	0.7
21	Hidalgo	US 281	255-7	P24/P26	3/25/74	10	3.80	.258	6.79	3.4	4.2	0.8
22	Dimmit	US 83	37-6	P18/P20	10/15/74	10	2.35	.587	25.00	1.6	3.3	1.7
22	Dimmit	FM 186	301-4	P2/P4	10/15/74	10	3.19	.328	10.29	2.6	3.6	1.0
22	Edwards	SH 55	235-2	P48/P46	8/19/74	10	3.55	.438	12.30	2.5	4.0	1.5
22	Edwards	FM 674	375-5	P4/P6	8/19/74	9	2.92	.331	11.30	2.2	3.3	1.1
22	Maverick	US 277	300-1	P36/P38	10/15/74	10	3.42	.662	18.20	2.6	4.1	1.5
22	Maverick	FM 1021	1229-1	P10/P12	10/15/74	9	3.44	.482	14.00	2.6	3.9	1.3
22	Zavala	US 57	276-3	P6/P4	10/16/74	10	3.83	.433	11.30	3.2	4.4	1.2
23	Comanche	SH 16	289-1	P32/P30	8/29/74	10	4.55	.135	2.98	4.3	4.7	0.3
23	Comanche	FM 679	2107-2	P4/P6	8/29/74	10	2.55	.403	15.82	1.8	3.0	1.2
23	Eastland	IH 20	314-5	P362/P360	8/29/74	10	4.28	.494	11.54	3.6	4.8	1.2
23	Eastland	SH 206	2638-1	P2/P4	8/29/74	10	3.26	.433	13.27	2.5	4.1	1.6
23	Eastland	FM 2214	1697-2	P6/P8	8/29/74	9	2.63	.320	12.16	2.2	3.0	0.8
23	McCulloch	SH 71	1102-1	P6/P8	8/30/74	10	4.73	.116	2.45	4.5	4.9	0.4
23	McCulloch	FM 1028	1306-1	P0/P2	8/30/74	9	2.90	.274	9.44	2.4	3.4	1.0
23	San Saba	SH 16	289-4	P4/P2	8/29/74	10	3.30	.356	10.78	2.8	3.8	1.0
23	San Saba	FM 2732	2729-1	P6/P8	8/29/74	10	2.20	.657	29.85	1.6	3.5	1.9
25	Culberson	SH 54	233-5	P50/P48	8/21/74	9	3.88	.277	7.15	3.4	4.2	0.8
24	Culberson	FM 2185	1158-1	P8/P10	8/21/74	9	2.00	.166	8.29	1.8	2.2	0.4
24	El Paso	US 180	374-2	P18/P16	8/22/74	9	3.46	.246	7.10	3.1	3.8	0.7
24	El Paso	LP 375	255-2	P2/P4	8/22/74	10	4.35	.151	3.47	4.0	4.5	0.5
24	Jeff Davis	SH 17	104-4	P34/P36	8/20/74	10	2.34	.227	9.70	2.1	2.7	0.6
24	Jeff Davis	FM 505	871-1	4MI W 166/6MI W 166	8/21/74	10	1.81	.292	16.20	1.4	2.2	0.8
24	Presidio	US 90	20-8	P34/P36	8/21/74	10	4.67	.125	2.68	4.4	4.8	0.4
24	Presidio	FM 2810	1283-2	P4/P6	8/21/74	10	3.16	.477	15.10	2.7	4.0	1.3
25	Briscoe	SH 256	541-1	P14/P12	8/25/74	10	2.68	.290	10.81	2.3	3.3	1.0
25	Briscoe	FM 1065	740-3	P2/P0	8/26/74	10	3.65	.299	8.19	3.1	4.0	0.9
25	Childress	SH 256	381-3	P4/P2	8/25/74	9	2.87	.406	14.17	2.3	3.4	1.1

TABLE 22 (Continued)

District	County	Highway	Control-Section	Location	Date	N	$\overline{X}$	S	CV (%)	LV	HV	R
25	Childress	FM 1438	1346-2	P4/P2	8/25/74	10	3.28	.266	8.10	2.8	3.6	0.8
4	Gray	IH 40	275-7	P122/P124	8/25/74	10	4.73	.134	2.83	4.4	4.8	0.4
25	Donley	US 287	42-8	HCL/P34	8/26/74	11	4.75	.113	2.38	4.6	4.9	0.3
25	Donley	FM 2362	2252-1	P0/P2	8/25/74	9	3.58	.164	4.58	3.3	3.8	0.5
25	Knox	SH 283	98-4	P2/P4	8/25/74	9	1.70	.477	28.06	1.2	2.7	1.5
25	Knox	FM 1756	538-5	P2/P0	8/26/74	10	2.19	.242	11.07	1.7	2.4	0.7

N = Number of readings
$\overline{X}$ = Mean
S = Standard Deviation
CV = Coefficient of Variation
LV = Low Value
HV = High Value
R = Range

From a highway network inventory standpoint, a variation of ± 0.3 Serviceability Index number can probably be tolerated as the roughness along a highway section under consideration for rehabilitation or maintenance will likely be of this order of magnitude or greater. Accuracy required for research purposes depends upon the nature of the research. Many projects such as roughness associated with bridge and bridge ends and with the study of swelling clays require the use of an instrument such as the Surface Dynamics Profilometer (27). The Mays Ride Meter and other types of road meters are not sufficiently sensitive for these uses.

As discussed above, errors associated with calibration and operation of the test vehicle occur. An appreciation of the magnitude of these errors can be obtained by referencing Table 23. This table indicates that the errors associated with the calibration of Serviceability Index and Present Serviceability Rating for a particular vehicle dominate. Standardization of operational features such as tire pressure, vehicle weight, operating speed and driver training will greatly reduce the possible errors indicated on Table 23 associated with these variables. Control over temperatures and wind velocity is possible by specifying under that environmental conditions data can be collected.

If vehicles are properly maintained and calibrated and if operational procedures are standardized, the Mays Ride Meter can probably be used to predict the Present Serviceability Rating with a range of between 0.1 and 0.3 units. (Clark (22) suggests about 0.1 units.) This degree of accuracy is reasonably acceptable from a network and project inventory standpoint.

TABLE 23. Measurement Errors Associated with the Determination of Serviceability Index by Use of the Mays Ride Meter* on a Given Section of Roadway.

Source of Error	Error of magnitude given below represents about 60-70 percent of all deviations from true mean measured by Texas Transportation Institute	Maximum error observed by Texas Transportation Institute
Calibration of Surface Dynamics Profilometer Present Serviceability Index with Panel Present Serviceability Rating (28)	0.3	1.1
Calibration of Mays Ride Meter Serviceability Index with Surface Dynamics Profilometer Present Serviceability Index	0.3	1.88
Changes in Vehicles during Life of Vehicles	0.3	1.5
Tire Pressure	0.2	0.30
Air Temperature	0.1	0.18
Vehicle Weight	0.2	0.35
Wet vs. Dry Pavement	0.1	0.15
Wind Velocity	0.05	0.1
Vehicle Speed (30-70 mph)	0.4	1.6
Driver Variation	0.2	1.3

*Errors are expressed in terms of Serviceability Index values.

CONCLUSIONS AND RECOMMENDATIONS

Based on the included literature review and data obtained during the course of the study presented herein the following conclusions appear warranted.

Type of Vehicle

Data developed in this study and that presented by Hughes (15) and Argue (16) indicate that each vehicle equipped with a road meter must be calibrated even if the vehicles are the same make and model. Vehicles with coil springs and standard suspension systems are preferred over those with leaf springs (15, 18).

Changes in Vehicles

Vehicle response to road roughness will change with time. Shock absorbers must be changed, tires replaced and balanced and front ends aligned. The changes created by shock absorber wear out should be considered significant and recalibration should be scheduled and performed.

Tire Pressure

Brokaw (17), Clark (22), and Curtayne (23) have performed tests to determine the effect of varying tire pressure on the PCA Road Meter output. Brokaw (17) found that variation of tire pressure between 24 and 26 psi was insignificant, and Clark's (22) tests over a range from 22 to 32 psi showed that while linear relationships exist and tire pressure variation does cause variation in results, the magnitude of the variation is small from a practical standpoint. Results reported in this report indicate that varying the pressure between 25 and 35 psi has no significant effect on vehicle response in a practical sense.

Air Temperature

Studies reported by Clark (22) and Dunn and Schultz (24) indicate a stiffening of the vehicle suspension system at low temperatures. The study conducted in Louisiana (25) resulted in an equation which predicts a change in 10 inches of roughness per mile for each 20°F change in temperature. The majority of research performed to date (15, 16, 17, 18, 22, 25) indicates that changes due to temperature variations are insignificant for temperatures above about 10 to 15°F.

Passengers and Luggage

As discussed above, several studies have been conducted in which the number and location of passengers have been studied as well as weight in the vehicles due to luggage and gasoline (15, 16, 17, 18, 22, 25). Results in general have shown that passengers riding in the back seat affect the results significantly. Mays Ride Meter testing shows essentially the same thing with the added observation that luggage in the trunk (if greater than or equal to 200 pounds) also has a significant effect on the measured Serviceability Index. One anomalous fact has been observed, however. Testing by Hughes, while showing an insignificant decrease in Serviceability Index for 100 pounds of weight in the trunk, shows a significant increase for the case of one passenger in the back seat. In the tests with the Mays Ride Meter it was found that the significant change for both loading cases was a decrease from the normal. There is no obvious reason for the disagreement between the two instruments.

Wet or Dry Pavements

No reports of testing to determine how the PCA Road Meter performs on wet versus dry pavements were found in the literature. As has been noted above, "wet" pavement seems to have little or no effect on the results obtained with the Mays Ride Meter.

Wind Velocity

Few definitive studies have been performed indicating the effect of wind on ride meter performance. Brokaw's (17, 18) studies suggest that testing should be curtailed when cross wind velocities exceed 15 mph. Insufficient data were collected in this study to support this statement. However, wind velocities do not exceed 10 to 15 miles per hour in most of Texas for a significant part of the year.

Vehicle Speed

Sufficient data are available in the literature to point out the necessity to maintain speed control during testing. If the testing must be performed outside of the calibration speed by more than about ± 3 mph, a calibration should be obtained at the desired test speed.

Driver Variability

Driver variability does not appear to be a significant factor provided proper training is given and concentration is maintained during testing.

Operational Guidelines

1. Vehicles to be utilized as Mays Ride Meter test vehicles should have coil springs and standard suspension systems unless data are developed to demonstrate the adequacy of other types of vehicles.

2. Each test vehicle should be calibrated.

3. Control sections should be established as described in Appendix A and periodic check runs made to insure that the equipment remains in calibration.

4. Recalibrations should be performed when the control sections indicate an out of calibration condition or after about 20,000 miles of operation. After 20,000 miles new standard shock absorbers and new tires should be installed and the front end aligned.

5. The tire pressure should be checked daily when the vehicle is in use and should be adjusted to the pressure used when the vehicle was last calibrated. For the TTI 1975 LTD, this pressure is currently 30 psi for the front and back tires. The tires should be be checked after a minimum travel distance of five miles and no more than ten miles. This will allow the tires to heat to a somewhat standardized temperature.

6. Testing should be curtailed at temperatures below 25°F unless data are available for the test vehicle which will allow an appropriate temperature correction to be made.

7. Two operators and 100 pounds of luggage is all that should be allowed in the vehicle. The gasoline tank should be maintained above 1/4 full.

8. Testing can be allowed during light rainfall provided the pavement does not pond water excessively.

9. Testing should be curtailed when cross winds exceed 15 mph.

10. The test speed should be maintained at 50 mph ± 3 mph.

11. Drivers should be familiar with the vehicle and understand the variation in Serviceability Index that can result from poor operational control.

REFERENCES

1. Haas, Ralph, "Surface Evaluation of Pavements: State of the Art," Proceedings of Pavement Rehabilitation Workshop held September 19-22, 1973, Report Number DOT-05-40022, Task Order 1, July, 1974.

2. Balmer, G. G., "Road Roughness Technology, State of the Art," Report No. FHWA-RD-73-54, Federal Highway Administration, December, 1973.

3. McCullough, B. F. and J. A. Epps, "Evaluation of the Pavement Rehabilitation Workshop," Proceedings of Pavement Rehabilitation Workshop held September 19-22, 1973, Report Number DOT-05-40022, Task Order 1, July, 1974.

4. Carey, W. N., Jr., "Uses of Surface Profile Measurements," HRB Special Report 133, 1973, pp. 5-7.

5. Williamson, H. J. and W. R. 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, University of Texas, August, 1975.

6. Carey, W. N., Jr., and Irick, P. E., "The Pavement Serviceability-Performance Concept," HRB Bulletin 250, January, 1960, pp. 40-58.

7. The AASHO Road Test: Report No. 5--Pavement Research, HRB Special Report 61E, 1962, p. 292.

8. Nakamura, V. F. and Michael, H. L., "Serviceability Ratings of Highway Pavements," Highway Research Record 40, 1963, pp. 21-36.

9. Hughes, P. C., "Development of a Rating System to Determine the Need for Resurfacing Pavements," Investigation No. 189, Office of Research Coordination, Minnesota Department of Highways, 1971.

10. Phillips, M. B. and Swift, G., "A Comparison of Four Roughness Measuring Systems," Research Report 32-10, Texas Transportation Institute, Texas A&M University, August, 1968.

11. "Pavement Evaluation Using Road Meters," Highway Research Board, Special Report 133, 1973.

12. Mays Ride Meter Booklet. Rainhart Company, Austin, Texas, 1972.

13. "Mays Ride Meter Digital Counter System," Transportation Planning Division, Research Section, the State Department of Highways and Public Transportation.

14. Walker, R. S. and Hudson, W. R., "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, September, 1972.

15. Hughes, P. C., "Evaluation of the PCA Road Meter," HRB Special Report 133, 1973, pp. 23-40.

16. Argue, G. H., "A Canadian Evaluation Study of Road Meters," HRB Special Report 133, 1973, pp. 41-48.

17. Brokaw, M. P., "Development of the PCA Road Meter: A Rapid Method for Measuring Slope Variance," Highway Research Record 189, 1967, pp. 137-149.

18. Brokaw, M. P., "A 5-Year Report on Evaluation of Pavement Serviceability with Several Road Meters," HRB Special Report 116, 1971, pp. 80-91.

19. LeClerc, R. V., T. R. Marshall and K. W. Anderson, "Use of the PCA Road Meter in the Washington Pavement Condition Survey System," Highway Research Board Special Report 133, 1973.

20. Chong, G. J. And W. A. Phang, "PCA Road Meter Measuring Road Roughness at 50 MPH," HRB Special Report 133, 1973, pp. 51-65.

21. Ringer, L. J., "Statistical Analysis of Tire Pressure Data," Memorandum to G. G. Harvey, February 22, 1974.

22. Clark, M. F., "Road Meter Output and Its Correlation with Panel Ratings in Saskatchewan," HRB Special Report 133, 1973, pp. 77-90.

23. Curtayne, P. C., and Walker R. N., "A Fresh Look at the Interpretation of Pavement Serviceability and an Experiment to Measure the Riding Quality of Roads in South Africa," Proceedings of the 3rd International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 776-785.

24. Dunn, K. H. and R. O. Schultz, "Temperature and Vehicle Suspension Effects," HRB Special Report 133, 1973, pp. 91-96.

25. Law, S. M. and W. T. Burt, III, "Road Roughness Correlation Study," Research Report No. 48, Louisiana Department of Highways, June, 1970.

26. Shaw, C. W., "Influence of Testing Variables of the Mays Ride Meter," Thesis submitted to Graduate College of Texas A&M University, December, 1972.

27. Law, D. B., H. J. Williamson and W. R. Hudson, "The Characterization of Road Roughness on Bridge Decks and the Adjoining Pavement," Research Report 156-4, Center for Highway Research, University of Texas, April, 1975.

28. Roberts, F. L. and W. R. Hudson, "Pavement Serviceability Equations Using the Surface Dynamics Profilometer," Report 73-3, Center for Highway Research, University of Texas, 1970.

APPENDIX A

Mays Ride Meter Calibration Control (9)[*]

Measurement Control

Accurate Serviceability Index measurements will depend on proper usage and operation of the Mays Ride Meter. Proper usage has been described in the preceding section. Proper operation of the equipment can be insured by development of a set of control procedures in which Mays Ride Meter results are continually monitored.

These control procedures provide a means of detecting Mays Ride Meter out-of-calibration conditions and involve the use of replication runs or measurements over a known test or control section. Twenty such sections are established immediately following the initial Mays Ride Meter calibration procedures, providing a pool from which a control section can be selected for testing for an out-of-calibration condition. The mean and range Serviceability Index values from the replication control runs are compared against known control values determined at the time the control sections were initially established.

The paragraphs to follow provide descriptions of the control procedures which should be followed by Mays Ride Meter operators in order to insure proper operation of their instruments. This section is divided into two segments; namely, selection of Mays Ride Meter control sections and establishing the operation control charts Mays Ride Meter

---

[*] Adopted after Walker and Hudson (14).

control operations. A further description of these segments follows.

Selection of Mays Ride Meter control sections - A set of twenty 0.2-mile control sections should be selected, convenient to the Mays Ride Meter base of operations. These sections should be selected so as to provide a representative sample of smooth-to-rough sections of the area or District in which the Mays Ride Meter is to operate. Roughness variations within each section should be homogenous; that is, the roughness within any 0.05-mile segment should be approximately the same as in any other 0.05-mile segment. Obviously a smooth section with an abrupt bump at the end of the section is not a good test section. As a general rule, if an experienced highway technician cannot say that any particular 0.05-mile segment of an 0.2-mile section rides any better than any other segment within the section, the section can be considered homogenous. Transverse uniformity across the surface is also a good quality for a control section. This will minimize driver induced variability into the recorded data. Since these sections are to be used for roughness control, sections where expected changes in the pavement conditions are minimal should be selected, so that the sections can be used as long as possible. If the pavement section is scheduled for sealing or overlaying, it should not be utilized.

Twenty sections are selected so as to provide a large pool from which control measurements can be made for both convenience and in the event several sections are lost due to pavement aging, construction, etc., and to provide needed samples for developing the mean and range control charts. As pavements are lost, no attempt should be made to replace these sections unless only four sections remain. At this time, the instrument should be recalibrated and at such time, 20 new sections should be selected. The selection of the control sections is an important part of the control procedures, since they will be used to determine whether or not the Mays Ride

Meter remains in calibration.

Establishing control charts - Two control charts will be used for monitoring Mays Ride Meter measurement validity, one for checking the measurement mean (or average) from repeated Serviceability Index measurements and the second for checking the range of replication measurements. The two control charts are established with measurements obtained from 20 control sections. The range, R, of several Mays Ride Meter repeat measurements on a single section is the greatest difference between Serviceability Index measurements. This number is always a positive number, as $R = SI_{max} - SI_{min}$. To develop the two control charts, a work sheet similar to Figure A1 is used. To compute the control limits for these charts, each of the control sections is run five times and its Serviceability Index (in terms of 0.2-mile measurements) obtained and entered on the work sheet (Figure A1). The following values are then computed for each section:

(1) The mean $\overline{X}$ of the five test runs is computed and entered on the work sheet and the mean control chart (Figure A2).

(2) The range R of the five test runs for each section is computed and entered on the work sheet.

(3) The average range $\overline{R}$ is computed and entered on the work sheet.

(4) The upper and lower control limits for the mean control chart are computed by multiplying the mean range $\overline{R}$ by ± 0.577. These values, $(\overline{R})(0.577)$ and $(\overline{R})(-0.577)$, are entered on the work sheet and plotted as two straight lines on the mean control chart (Figure A2).

(5) The upper range control limit is computed by multiplying the mean range $\overline{R}$ by 2.114 and entering this value on the work sheet. This value is plotted on the range control chart (Figure A3).

MRM CONTROL CHART

Work Sheet

District 17 MRM No. 2 - 72 Ford Date August 1972

	S1 Replication							
Section	1	2	3	4	5	$\bar{X}$	s	R
FM 2347	3.2	3.3	3.4	3.3	3.2	3.25	0.08	0.2
Unmarked	2.9	2.8	2.7	2.8	2.8	2.82	0.07	0.2
FM 50 S	3.5	3.6	3.4	3.4	3.5	3.48	0.10	0.2
FM 50 N	3.0	2.8	3.0	2.8	2.9	2.87	0.10	0.2
SH 6	4.1	4.0	3.9	4.0	3.9	3.98	0.10	0.2
East By-Pass	3.7	3.9	3.8	3.8	3.8	3.79	0.08	0.2
OSR	2.2	2.3	2.2	2.2	2.3	2.25	0.06	0.1
SH 21	3.3	3.4	3.3	3.4	3.4	3.38	0.05	0.1
FM 2038	2.7	2.7	2.6	2.7	2.6	2.65	0.05	0.1
FM 1179	2.4	2.2	2.3	---	---	2.30	0.07	0.2
Prct. 4 Cty Rd	2.5	2.4	2.4	2.3	2.4	2.40	0.07	0.2
SH 30 EBL	2.6	2.7	2.7	2.6	2.6	2.65	0.06	0.1
SH 30 WBL	3.2	3.4	3.2	3.4	3.5	3.37	0.13	0.3

Upper Control Limit for R = $2.114 \times \bar{R} = 0.38$

Control Limits for Mean = $\pm 0.577\bar{R} = 0.10$

$R_{total} = 2.30$

$\bar{R} = \frac{R_{total}}{n} = 0.18$

n = number of sections

FIGURE A1. Typical Mays Ride Meter Work Sheet.

Control checks will involve making a set of five repeat runs over any one of the 20 test sections and finding the mean Serviceability Index, $\bar{X}$ and range R (see Figure A4). The difference between the current $\bar{X}$ and the one initially established for the control section, as listed in the left-hand portion of Figure A2, is then plotted with the upper and lower mean control limits. If this difference is greater than the control range, an out-of-calibration condition can be suspected. The range provides an additional control check and is compared to the upper range control limit of Figure A3. A range value falling outside this limit will also indicate an out-of-calibration condition. By plotting the mean differences and range values, a past history or record can be maintained to help identify true out-of-calibration situations (Figures A2 and A3).

<u>Mays Ride Meter operations</u> - As indicated above, Mays Ride Meter control is provided by comparing the mean and range values from periodic test runs against control limits. When these values fall outside these limits, then out-of-calibration conditions can be suspected. Periodic control runs should be made once per month when the Mays Ride Meter is not in use and at least once during each week the Mays Ride Meter is being used. The best testing procedure would be to randomly select the particular test section for any given control check. Attempts should be made to at least try never to repeat the same section twice in succession and to include as many, preferably four or greater, other sections between tests which include the same section. For example, if during the first week, Section 1 (FM 2347) of Figure A2 is run, then at least four weeks should pass before this section is again used for control purposes.

MRM MEAN CONTROL CHART

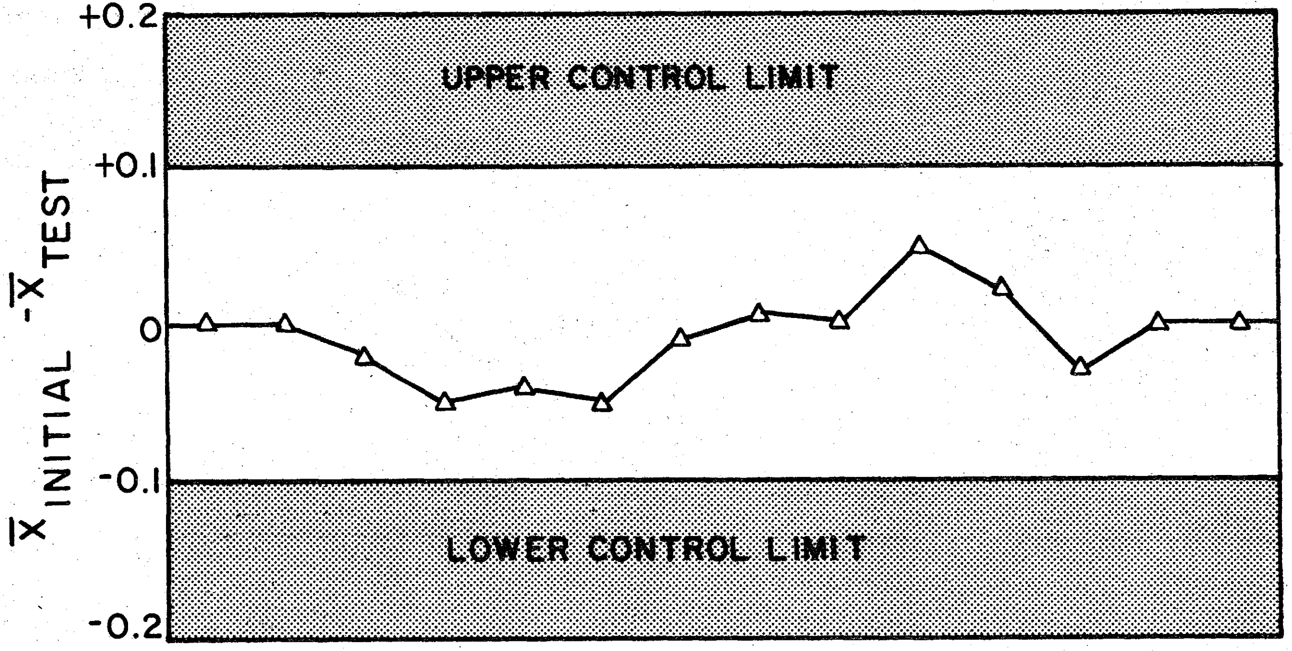
District 17 - Brazos County

MRM No. 2 - 72 Ford

Date Aug - Oct. 1972

Initial Mean

Section	$\bar{x}$
FM2347	3.25
Unmarked	2.28
FM50S	3.48
FM50N	2.87
SH6NBTL	3.98
E.By/Pas	3.79
OSR	2.25
SH21	3.38
FM2038	2.65
FM1179	2.30
Prct. 4	2.40
SH30EBL	2.65
SH30WBL	3.37



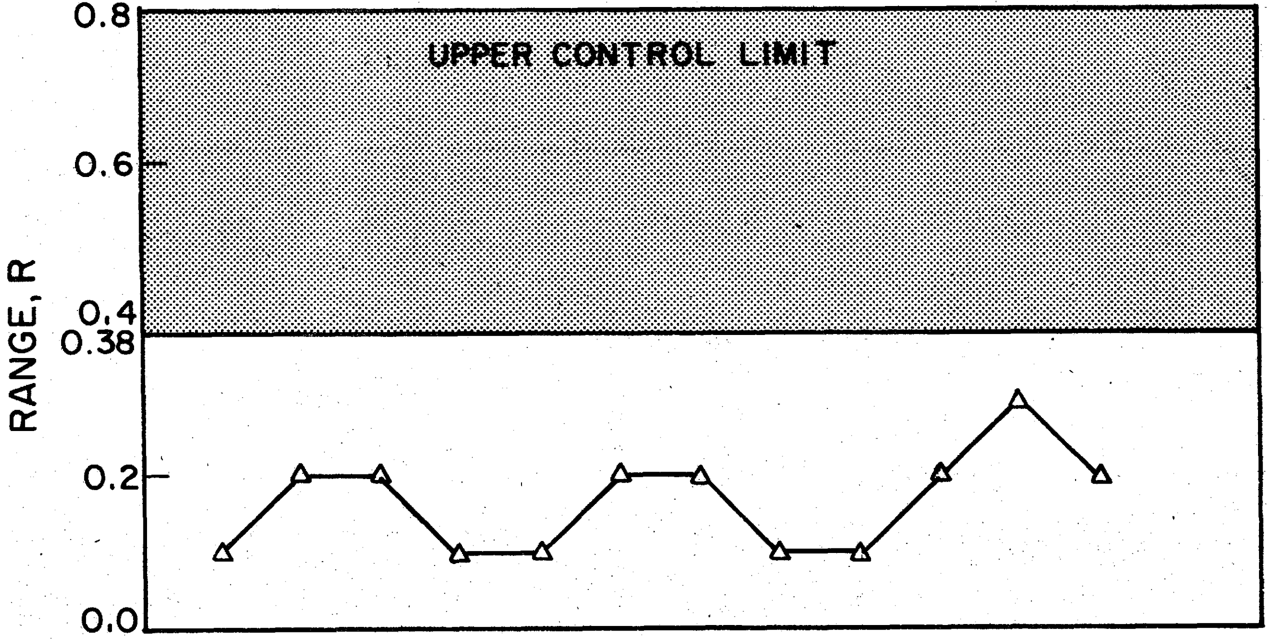
Test Date________________

FIGURE A2. Typical Mean Control Chart.

MRM Control Chart

Control of Range

District No. 17 MRM No. 2-72 Ford Date Aug - Oct. 1972



Test Date: Aug. - Oct. 1972

FIGURE A3. Typical Range Control Chart.

MRM No. 2 Date 5 Oct 1972 Section FM2347

$\bar{X}_{initial}$ (Initial SI Average) = 3.25

Run	SI
1	3.2
2	3.2
3	3.3
4	3.3
5	3.2

SUM SI = 16.2

$$\bar{X}_{current} = \frac{\text{SUM SI}}{5} = 3.24$$

RANGE = $SI_{MAX} - SI_{MIN}$ = 0.1 Enter on Range Control

$X_{initial} - X_{current}$ = 0.01 Enter on Mean Control

FIGURE A4. Typical Worksheet for Mays Ride Meter Control Run.

The basic idea in the control procedure is to determine if the Mays Ride Meter is measuring the same, i.e., within its measurement errors. Since measurement errors can and will occur, the control limits are used to identify extreme occurrences of these measurement errors. These errors are related to the individual Mays Ride Meter and the control sections used; thus, the importance of insuring proper selection of these sections and a proper testing procedure cannot be overemphasized.

As indicated, an out-of-calibration condition can be suspected when either the range or mean control limits are exceeded. If a control limit is exceeded on either the mean or range (or both), the first action which should be immediately taken is to carefully examine the Mays Ride Meter device and the vehicle in which it is installed for the possible problem source. If the problem source can be found and corrected, then the Mays Ride Meter control procedures should be performed again. If no cause can be found, five new sections should be selected and each tested. If all control runs from the five sections are in control, then the section which indicated the out-of-calibration condition should be removed from the pool of control sections and not used again. If, however, another out-of-calibration condition occurs on any of these five control sections, an out-of-calibration should be reported, and the Mays Ride Meter returned for calibration.