TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-87/83+400-1F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SERVICEABILITY RATINGS OF TEXAS HIGHWAY SYSTEM FOR PAVEMENT MANAGEMENT		5. Report Date August 1986
		6. Performing Organization Code
7. Author(s) Hernan E. Desolminihac, W. R. Hudson, and Eduardo Ricci		8. Performing Organization Report No. Research Report 400-1F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075		10. Work Unit No.
		11. Contract or Grant No. Research Study 3-8-84-400
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Serviceability Rating of Texas Highways for Pavement Management or Related Research Studies"

16. Abstract

Serviceability Index (SI) values define the riding quality of a section of pavement and they are required input parameters for several design methods. Accurate pavement design requires good estimates of the true serviceability index value at periods in the pavement's life: (1) SI immediately after the construction of a new pavement, (2) SI of worn out pavement just before rehabilitation, and (3) SI restored to the pavement just after rehabilitation.

This study describes the analysis used to find the mean values and the variability of the serviceability index for the three pavement stages described above for use in Texas pavement management activities.

17. Key Words Serviceability index (SI), root-mean-square vertical acceleration (RMSVA), analysis of variance (ANOVA), Pavement Management System (PMS), profilometer	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	142	

Form DOT F 1700.7 (8-69)

SERVICEABILITY RATINGS OF TEXAS HIGHWAY SYSTEM FOR PAVEMENT MANAGEMENT

by

Hernan E. Desolminihac
W. R. Hudson
Eduardo Ricci

Research Report Number 400-1F

Serviceability Rating of Texas
Highways for Pavement Management
or Related Research Studies
Research Project 3-8-84-400

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

August 1986

PREFACE

This report presents details, procedures and findings from Research Study 3-8-84-400, "Serviceability Ratings of Texas Highways for Pavement Management and Related Research Studies." The main objective of the study was to measure the actual serviceability index of (a) initial serviceability index immediately after construction, (b) before scheduled rehabilitation projects, (c) after rehabilitation, and (d) after reconstruction.

This report describes the work carried out by the Center for Transportation Research at The University of Texas at Austin to obtain the mean value and variability of the serviceability index at different periods of the pavement's life to be used in the Texas Pavement Management System.

We would like to express our appreciation for the cooperative efforts of the State Department of Highways and Public Transportation contact representative, Bob Mikulin. Special thanks are extended to Gary Graham, Richard Rogers, and Robert Harris for helping in the selection and identification of the sections used in the study. We also wish to acknowledge the important contribution made by James Wyatt, Joe Wise and Robert Light for helping furnish the profilometer data for the study.

Finally, we are deeply grateful to Dr. Virgil Anderson, from Purdue University, for his valuable advice in the statistical analysis.

LIST OF REPORTS

Report No. 400-1F, "Serviceability Ratings of Texas Highway System for Pavement Management," by Hernan E. Desolminihac, W. R. Hudson, and Eduardo Ricci, discusses the analysis carried out to obtain the mean value and the variability of the serviceability index at different periods of the pavement's life to be used in the Texas Pavement Management System.

ABSTRACT

Serviceability Index (SI) values define the riding quality of a section of pavement and they are required input parameters for several design methods. Accurate pavement design requires good estimates of the true serviceability index value at periods in the pavement's life: (1) SI immediately after the construction of a new pavement, (2) SI of worn out pavement just before rehabilitation, and (3) SI restored to the pavement just after rehabilitation.

This study describes the analysis used to find the mean values and the variability of the serviceability index for the three pavement stages described above for use in Texas pavement management activities.

KEYWORDS: Serviceability index, root-mean-square vertical acceleration (RMSVA), surface dynamic profilometer, analysis of variance (ANOVA), Pavement Management System (PMS).

SUMMARY

The main objective of this study was to estimate the serviceability index (SI) of the highways of the state of Texas at different points during their life. Three specific periods were studied: (1) immediately after construction of a new pavement (NEW), (2) immediately before rehabilitation (TERMINAL), and (3) immediately after rehabilitation (RESURFACE).

The SI equations developed on Research Study 3-8-83-354 were used to calculate the serviceability indices from the root-mean-square vertical acceleration (RMSVA) values generated by VERTAC.

Five factors were considered in the analysis of the serviceability index: climatic region, pavement type, category of use, highway classification, and surface type.

The analysis of variance (ANOVA) technique was used to study the data. The results showed that the climatic region has no significant effect, but the other factors have significant effect in the variation of the serviceability index.

The serviceability index (SI) for new pavements was found equal to 4.0 for flexible pavements and 3.8 for rigid pavements, when the pavement is located on a principal highway. For new secondary roads, the SI was found to be as low as 2.5. The SI for new surface treatments was found equal to 3.0.

The serviceability index for pavements with asphalt concrete surface was found to be 4.0 for overlaid flexible pavement and 3.9 for overlaid rigid pavements; when the pavement is located on a principal highway. For new secondary roads, the SI averaged about 3.5. When surface treatment is used as a resurface layer, the SI may be as low as 2.9. It is important to note that no data in this study related serviceability to overlay thicknesses. It is possible that thicker overlays or two layer overlays could produce smooth pavements with higher SI values.

The average terminal serviceability was found to be 3.2 for flexible pavements and 3.5 for rigid pavements, when the pavement is located on a primary highway. For secondary roads, the SI averaged 2.8. The SI for terminal surface treatments was found to average 2.9. It should be noted that these pavements may have been overlaid for other than structural reasons.

The variability of SI observations within a rigid section or project, at all three levels of use, is low. On the otherhand, flexible pavement show considerable SI variability for pavements in terminal condition. This suggests that some pavements are overlaid for functional, rather than structural reasons.

IMPLEMENTATION STATEMENT

It is suggested that the serviceability values found in this study can be used in activities related to Pavement Management Systems of Texas. These SI values reflect more accurate and realistic predictions of the pavement's condition and thus will reflect properly in PMS predictions.

The findings of this study are already reflected in better attention being given to ride quality in Texas.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

GENERAL BACKGROUND

The measurement of pavement serviceability has increased in importance since the development of the concept at the AASHO Road Test, because it defined performance and it relates directly to the road user and vehicle operating costs. The AASHO Road test was conceived and sponsored by the American Association of State Highway Officials (Ref 1) (AASHO, today the American Association of State Highway and Transportation Officials, AASHTO). This test was conducted near Ottawa, Illinois, over a two-year period (1959-1960) to provide research data on pavement cost allocation and design.

Serviceability index (SI) values define the riding quality of a section of pavement and they are required input parameters for several design methods. The AASHTO design method for both flexible and rigid pavements uses a formula to predict SI loss as a function of traffic, structural and environmental variables (Ref 2).

In Texas, serviceability index is an important input for the Flexible Pavement Design System (FPS) (Ref 3) and the Rigid Pavement Design System (RPS) (Ref 4). In these two methods, the initial serviceability index (p_i), the terminal or minimum serviceability level (p_t), and the serviceability index after overlaying (p_o) are used to predict pavement life and performance.

The initial serviceability index is related to the quality of construction procedures, specifications and equipment. If the assumed initial serviceability is not achieved during the construction, the design life will be less than predicted. Better estimates of pavement performance can be achieved by more accurate initial serviceability estimates. Prior to this study, the most recent study of the initial serviceability index of flexible pavements in Texas was performed in 1971 by the Texas Highway Department, Texas A&M University, and The University of Texas at Austin. It is entitled "A System Analysis of Pavement Design and Research Implementation" (Ref 5).

The study was aimed at estimating the expected average values and the variations of initial serviceability. An equation for predicting the initial serviceability index of asphalt concrete pavements was stated in the report entitled "Stochastic Study of Design Parameters and Lack-of-Fit of Performance Model in the Texas Flexible Pavement Design System" (Ref

6). The prediction model is based on variables such as number of asphaltic concrete layers, type of materials and layer thickness.

The terminal serviceability index is a value set by the design engineer. The serviceability index which is achieved after overlay construction is related to the serviceability before the overlay, the thickness of the overlay, and the quality of the rehabilitation techniques. If the assumed serviceability index after the overlay is not achieved, the actual performance life of the pavement could be lower than predicted.

Accurate pavement design requires good estimates of the true SI for at least three periods: (1) SI immediately after the construction of new pavement, (2) SI of worn out pavement just before rehabilitation, and (3) SI restored to the pavement just after rehabilitation.

STUDY OBJECTIVES

The main objective of the project was to measure the present serviceability index on both rigid and flexible pavements to determine: (1) mean values and variability of initial serviceability index immediately after construction, (2) mean values and variability of serviceability index before scheduled rehabilitation projects, (3) mean values and variability of the serviceability index of the pavements resulting after rehabilitation, and (4) mean values and variability of serviceability index of pavements just after reconstruction.

METHODOLOGY USED IN THE STUDY

This study followed a combination of the systems method recommended by Haas and Hudson (Ref 7) and the scientific approach to experiment recommended by Anderson and McLean (Ref 8). The main steps of this approach are:

Step 1: Recognition that the problem exists.- This step resulted in the proposal for this research.

Step 2: Formulation of the problem.- In the research proposal, the problem was formulated and the objectives were presented.

Step 3: Design of the experiment.- An experiment was designed to collect and to analyze efficiently all the information required for this study. The main aspects considered are: (1) factors and levels to be used in the experiment, (2) variables to be measured, (3) definition of the inference space for the problem, (4) amount of replication to be used, and (5) random selection of the experimental units.

Step 4: Collection of the data.- The success of scientific research depends upon the validity of all data obtained, therefore special care was given to this particular aspect of the study.

Step 5: Analysis of the data.- The analysis of the data depends on the experiment design. Basically, there were three stages during the analysis: (1) a check to see that all the assumptions require for the statistical analysis were met, (2) analysis of the main factors, and (3) analysis of the secondary factors.

Step 6: Conclusions and recommendations - Once the analysis of the data has been completed, the conclusions are formalized and the recommendations for implementation are reported.

SCOPE OF THE REPORT

This report presents the entire finding of the study. Relevant background required in the study is presented in Chapter 2, including: the serviceability performance concept and its direct relationship to roughness, and the serviceability indices recommended in the past.

Chapter 3 presents a detailed description of the roughness measuring system used in this study. The design of experiment is presented in Chapter 4.

Chapter 5 describes the processing and statistical analysis of the data. Results are discussed in Chapter 6. Chapter 7 highlights the findings and conclusions of the study and presents the recommendations for future applications.

Finally, two appendices are included in the report to provide supporting information about the study. Appendix A presents a general description and the location of all sections used in the study. Appendix B, contains the roughness data on all sections collected in the study.

CHAPTER 2. SUMMARY OF THE PRIOR KNOWLEDGE

THE SERVICEABILITY - PERFORMANCE CONCEPT

Carey and Irick developed the pavement serviceability performance concept in 1960 (Ref 1). Five assumptions were considered in developing this concept: (1) The primary purpose of a highway or road is to serve the traveling public, taking into consideration its smoothness, comfort, and safety. (2) The users' opinions as to how they are being served by highways are subjective. (3) There are characteristics of the highway that can be measured objectively and they can be related to the subjective users' opinions. (4) The serviceability of a highway may be expressed by the average evaluations given by all of the highway users. The mean evaluation of all users should be a good measure of serviceability. (5) Performance is expressed by the serviceability history of a pavement.

The users' opinions represent pavement evaluations in terms of the riding quality provided by the pavement. Basically, the serviceability-performance concept involves the correlation of subjective user evaluations with objective measurements using statistics.

A group of people were selected as a rating panel in a manner that would reflect the average population of highway users. This panel then rated a set of predetermined sections of pavement according to established rules. Such ratings are termed the Individual Present Serviceability Ratings (IPSR) and the mean of these individual ratings for each section is termed the Present Serviceability Rating (PSR).

At the same time the panel rates the pavement sections, physical measurements are made on the same sections. These objective measurements include roughness and/or condition variables. Such data are collected by using a roughness measuring device and by conducting a condition survey. Once the Present Serviceability Ratings and the physical measurements are available, the two sets of data can be related to each other using a mathematical model.

$$PSI = PSR \pm e$$

where "e" is the error of estimate.

The PSI (Present Serviceability Index) is an objective estimate of the subjective PSR. In Texas, the PSI has been termed SI.

The mathematical model, which expresses a relationship between PSI and the summary statistics or variables defined from the physical measurements, may then be used to measure serviceability indices by simply going to the field, and measuring roughness and/or quantifying cracks and patches for use in the equation. The history of the serviceability indices of a section of pavement over a period of time is termed as its performance. These concepts are presented in Fig 2.1.

SERVICEABILITY AND ROUGHNESS

The serviceability of a pavement is largely a function of its roughness. Results from the AASHO Road Test (Ref 9) for both rigid and flexible pavements have shown that, among all the factors that affect the serviceability of a pavement, the surface profile is what most influences it. In other words, even if other variables are included in the analysis, only about 5 percent additional variation is explained (Ref 7).

Pavement roughness is a function of (1) the profile of the road surface; (2) the characteristics of the vehicle, including tires, suspension, body mounts, seats, etc.; and (3) the acceleration and speed sensibilities of the passengers. Roughness has been defined as the distortion of the pavement surface which contributes to an undesirable or uncomfortable ride (Refs 7 and 10).

Many previous studies have shown that measuring the longitudinal road profile is the best way to describe road roughness (Refs. 1, 11, and 12). Williamson found that longitudinal road surface waves with wavelengths ranging from 5 to 100 feet are important for predicting serviceability (Ref 11). From these findings it is clear that longitudinal profiles can provide the best characterization of roughness. Thus, today most serviceability equations consider only roughness as a predictor variable to estimate serviceability index.

PAVEMENT MANAGEMENT CONCEPT

Pavement management involves the coordination, scheduling, and accomplishment of all activities performed by a highway agency in the process of providing adequate pavements to serve the public (Ref 13). The systems approach to pavement management provides a rational

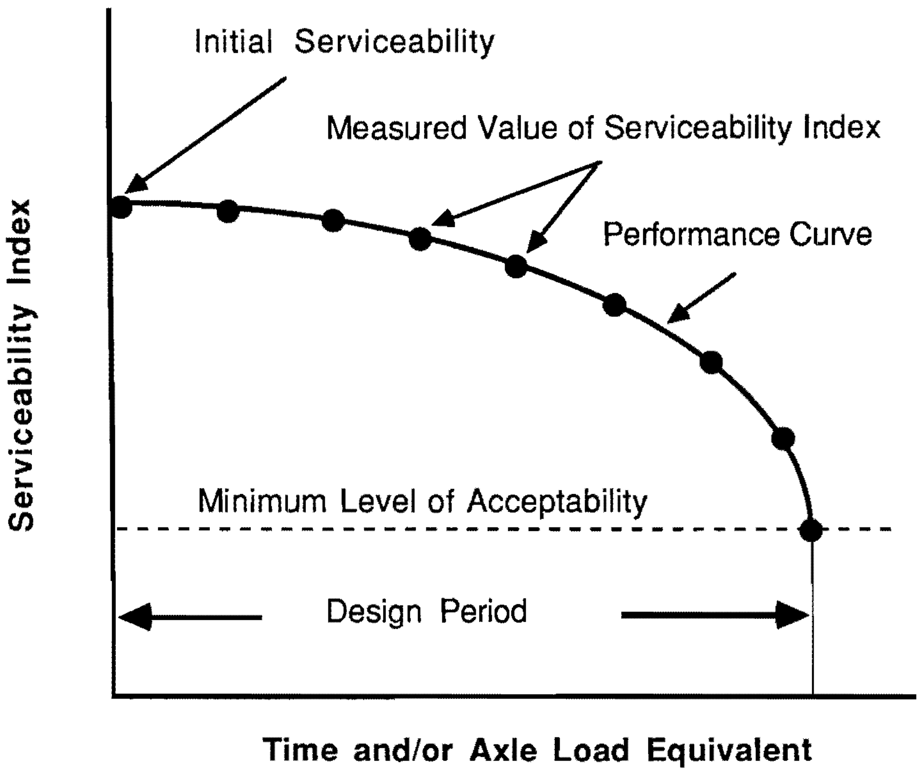


Fig 2.1. The serviceability performance concept (after Ref 7).

decision process with the objective of providing the highest possible value for the funds expended on pavements. This is accomplished by comparing investment alternatives; coordinating design, construction, maintenance and evaluation activities; and making efficient use of existing methods and knowledge (Ref 7).

A Pavement Management Systems (PMS) is an organized procedure which provides decision-makers at all management levels with optimal strategies derived through clearly established rational procedure. A PMS provides an evaluation of the alternative strategies over a specified analysis period, subject to predetermined criteria and constraints. It involves an integrated, coordinated treatment of all areas of pavement management and is a dynamic process which incorporates feedback on the various attributes, criteria, and constraints included in the optimization procedure.

The project management level is characterized by predominantly technical management concerns of individual projects. The network management level primarily involves programming and budgeting decisions for groups of projects or an entire network (Ref 14). Other activities that provide feedback for updating components are vital to the proper functioning of the entire system.

According to Haas and Hudson (Ref 7), there are six major classes of activities or subsystems in a PMS: (1) planning subsystem, (2) design subsystem, (3) construction activities, (4) maintenance activities, (5) pavement evaluation subsystem, and (6) research activities.

The essential characteristics of a PMS, and their secondary requirements are more fully discussed in Refs 7, 13, 15, and 16.

PAVEMENT MANAGEMENT SYSTEM AND ROUGHNESS

Roughness measurements are important in all phases of a pavement management system. The following paragraphs present a discussion of the role of roughness in each of the PMS activities.

(a) Planning Activities. In these activities roughness is used to detect network deficiencies, as a thermometer is used by a medical doctor to examine a patient. When a problem is detected in a pavement section, the agency can do a more detailed evaluation of that specific section.

(b) Design Activities. Serviceability index values are important inputs of several design methods. The AASHTO design method for both flexible and rigid pavements considers a factor (G_t) on the design formula (Ref 2) which is a function of the ratio of loss in serviceability at time "t" to the potential loss taken to a point where SI reaches a value of 1.5. In Texas the serviceability index is an important input for the Flexible Pavement Design System (FPS) (Ref 3) as well as for the Rigid Pavement Design System (RPS) (Ref 4). In these two methods the initial serviceability index (p_i), the terminal or minimum serviceability level (p_t), and the serviceability index after overlay (p_o) are important for determine the best pavement design strategy for a specific section. These three parameters are illustrated on a performance curve in Fig 2.2. Any variation of any of these parameters will change the pavement performance. A picture of this phenomenon is presented in Fig 2.3. There are three parts in this figure. Each of them shows only the effect of one factor, keeping all the other factors constant. Part (a) displays the effect of a lower initial SI value, where the performance of the design strategy 2 is less than that of design strategy 1. Part (b) presents the effect of a lower terminal SI value, showing that the performance of a pavement increases as its terminal SI decreases, but the rehabilitation cost increases. Part (c) presents the effect of a higher overlay SI value, showing that the performance of a pavement increases when the overlay SI value increases.

(c) Construction Activities: The serviceability index (SI) should be used for quality control. A minimum SI value, the one used on the design models, should be used to accept a new pavement section. This concept is important because it represents the user's opinion, and it represents the value used on the design. Therefore any difference between the actual SI and the one used on the design will change the performance of the pavement.

(d) Evaluation and Maintenance Activities. The use of roughness measurement in these activities can be considered separately for the network level and the project level. Its role on the network level has already been discussed. At the project level the SI value should be used as a part of a detailed design evaluation of the section under consideration.

(e) Research Activities. Roughness is used as a measure of pavement performance in research.

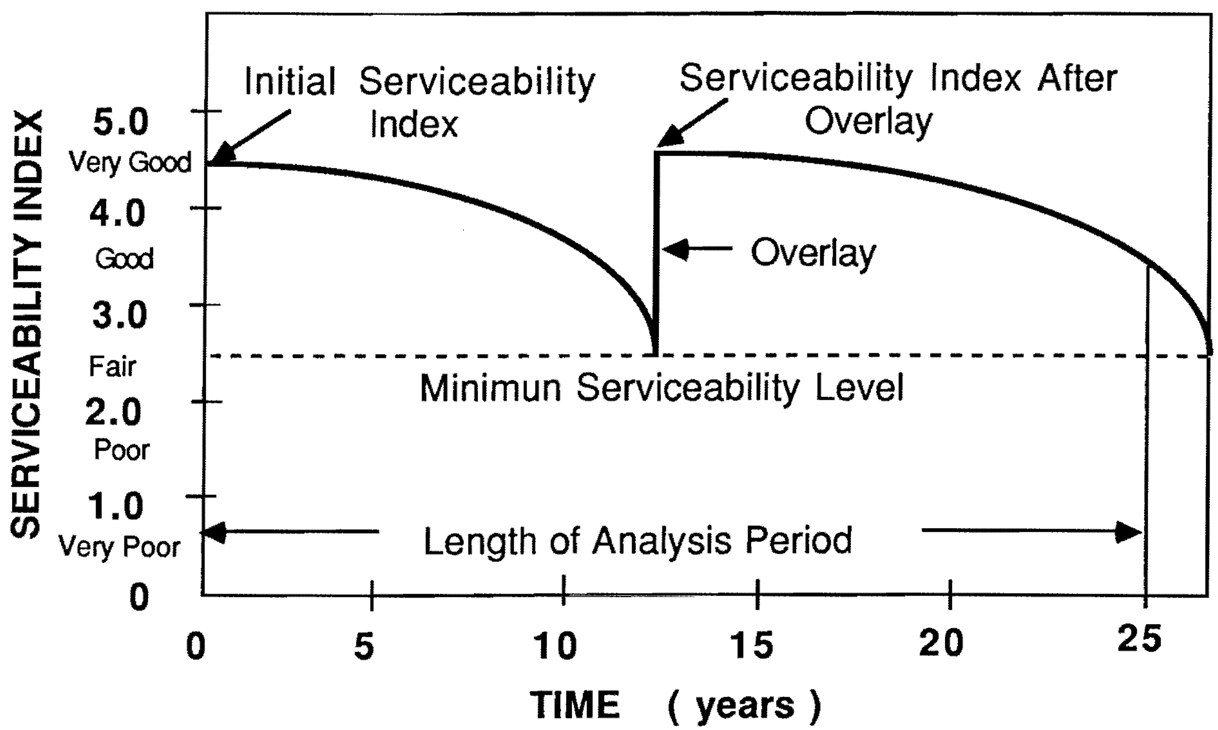
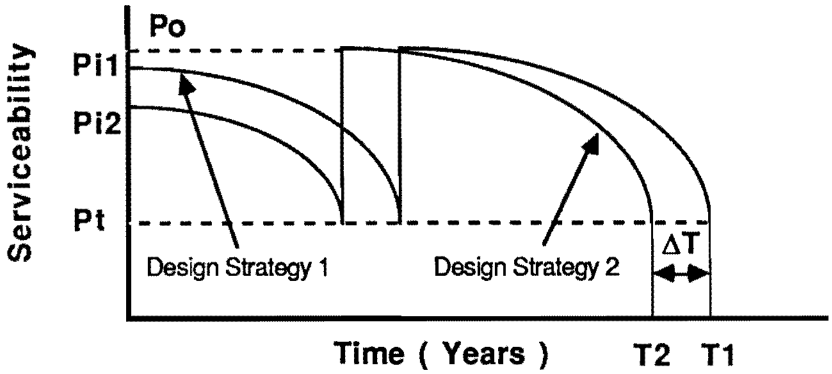
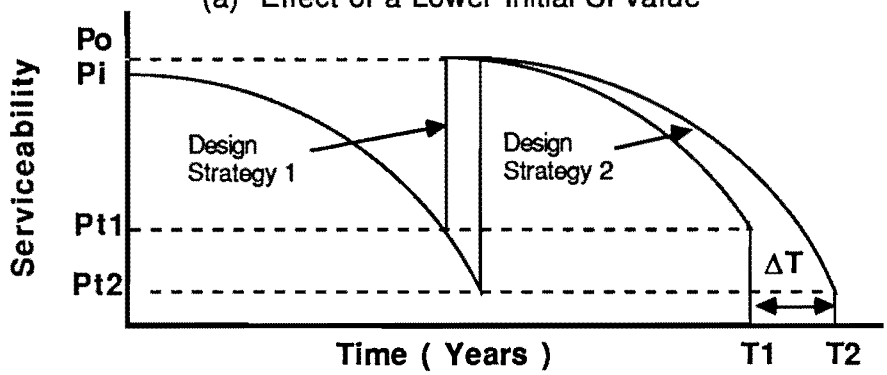


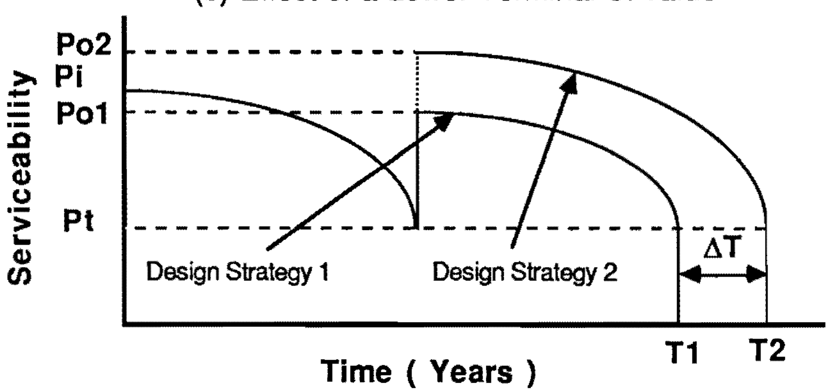
Fig 2.2. Example of a performance curve for one pavement design strategy (after Ref 3).



(a) Effect of a Lower Initial SI value



(b) Effect of a Lower Terminal SI value



(c) Effect of a Higher Overlay SI value

Fig 2.3. Effect of the design SI values on pavement performance.

PROFILOMETRY SYSTEM

There are many ways to evaluate the riding quality of a road. In general, they can be grouped into two categories; response type road roughness measurement systems and profilometry systems. A detailed description of the former is given in references 17 and 18, a general description of the latter is given herein.

A profilometry system measures the actual road profile and then a mathematical analysis is used to develop a statistical summary which characterizes roughness (profile data processing). The measurements are generally stable, and they can provide a reference for calibrating the response type devices. The methods or types of equipment used in these systems can be classified as follows : rod and level surveying and profilometry equipment, such as the Surface Dynamics Profilometer.

The Surface Dynamics Profilometer

The profilometer is a vehicle that measures and records road profiles at normal vehicle speeds. The operating principle of the GMR profilometer involves differences between the vertical movement of the frame of the vehicle and the vertical movement of the contact wheel that follows the pavement profile, combined with the actual vertical movement of the frame itself. Thus, the "true profile" of the pavement is obtained. A detailed description of the 690-D profilometer is presented on Chapter 3.

Profile Data Processing

Many methods have been developed for processing road data profile, but there is no standard or most-commonly-used method. The available methods can be classified into three groups: wave analysis techniques, the theoretical roadmeter simulation method, and the indirect roadmeter simulation method.

(1) Wave Analysis Techniques. Road profiles can be considered to be random signals of finite duration, and, as such, profile data can be analyzed in three domains, namely; time (space), amplitude, and frequency. In the time domain, the profile data is the unprocessed-signal versus time. In the amplitude domain, the data are described by picking up a set of amplitude values and characterizing the signal by computing an amplitude probability

distribution. In the frequency domain, profile data are analyzed by three fundamental methods: harmonic analysis, power spectral analysis, and amplitude-frequency distribution. More information in this subject can be found in Ref 12.

(2) Theoretical Roadmeter Simulation Method. In this method, computer programs are used to simulate the dynamic response of a vehicle to measure profiles using a set of differential equations to model the vehicle behavior. The characteristic parameters, such as masses and spring constants, are selected so they are representative of a real vehicle. This method, which is time stable, provides the roughness response of a vehicle or roadmeter to a measured profile. More information in this subject can be found in Ref 19.

(3) Indirect Road Meter Simulation Method. The indirect simulation method does not attempt to model the response of a vehicle to the road profile, as the theoretical simulation methods do; rather, it attempts to develop a regression model which predicts a single-value roughness index. This method uses a simple and physically meaningful function of a measured profile as the summary statistic. Some of the processing techniques which can be classified with this method are slope variance (SV) and root-mean-square vertical acceleration (RMSVA). The latter method is presented in detail in Chapter 3.

PAST STUDIES OF SERVICEABILITY INDICES

Average serviceability index values, based on the AASHO Road test experience are 4.2 for new flexible pavements and 4.5 for new rigid pavements. On the other hand, AASHTO recommends a terminal SI of 2.5 for maJor highways and 2.0 for highways with lesser traffic volumes (Ref 2).

A survey in fall and winter of 1961 by the Bureau of Public Roads (BPR) (Ref 20) found the average SI values shown in Table 2.1.

A recent study done by the Center for Transportation Research (CTR) at The University of Texas at Austin shows that the average Texas resident rates 3.06 as acceptable for interstate highways. The corresponding value on secondary highways is 2.20 (Ref 21).

For the design of flexible pavements, the SDHPT recommends the following serviceability for different categories of use in FPS (Ref 3):

(a) Initial Serviceability Index (p_i): The input for FPS depends on the materials used and construction practices. The FPS, in general, considers initial serviceability indices of

TABLE 2.1. AVERAGE TERMINAL SI VALUES BASED ON BPR SURVEY

Highway Surveyed	Terminal SI Values Based on BPR Survey	
	Rigid	Flexible
Major	2.2	2.1
Lesser	--	1.8

4.2. For surface treatments, it considers 3.8 for a very smooth asphalt concrete pavements (ACP), or 4.8 for continuously reinforced concrete pavements (CRCP).

(b) Minimum Serviceability Index (p_t): FPS recommends that a minimum serviceability index of 3.0 be used on highways with "Legal Posted Speeds" in excess of 45 mph and 2.5 on those posted 45 mph or less. If signal spacing, stop signs, dips, etc. prevent drivers from operating faster then 20 mph the minimum serviceability index can be decreased to 2.0.

(c) Serviceability Index After Overlay (p_o): In general, the serviceability index after an overlay should be about the same as that of initial construction. In FPS, the p_o must be specified by the engineer.

CHAPTER 3. ROUGHNESS MEASURING SYSTEMS USED IN THIS STUDY

INTRODUCTION

The SD Model 690D profilometer was selected for use in this study because (a) it is used by the Texas State Department of Highways and Public Transportation for Maysmeter calibration, (b) it is time stable, (c) it can be used with several profile data processing methods, and (d) it allows for comparisons of different serviceability models.

The root mean square vertical acceleration (RMSVA) was selected for analysis of road profile data because it is the Texas standard.

This chapter describes the main characteristics of the 690D profilometer and the RMSVA procedure, which represents the roughness characteristic of a section of pavement. Finally, it presents the serviceability models used in the study.

THE MODEL 690D PROFILOMETER

The Model 690D Surface Dynamics profilometer used here consists of two road-following wheels, two potentiometers, two accelerometers, and analog-to-digital and digital processing subsystems, all housed in a custom van.

The road-following wheels are mounted on trailing arms under the van. They are located so that they follow the right and left wheel paths on the pavement. The material of these wheels consists of solid polyurethane. These two wheels have a diameter of 6 inches to reduce geometric filtering when in contact with the road profile. Each of these wheels is held in contact with the road surface with a normal force of approximately 300 pounds. A fast acting hydraulic pump is provided to lift the following wheels off the road when they are not being used.

The profilometer system contains suitable transducers to measure road surface profiles and to obtain supporting data such as distance traveled and vehicle speed. The transducers for measuring road surface profile consist of a potentiometer and an accelerometer for each wheel path. The potentiometer measures the relative displacement of the road following wheel with respect to the measuring vehicle body (output signal= w-z). The accelerometer, mounted inside the vehicle directly above the top of the potentiometer, measures the vertical acceleration of the measuring vehicle body to determine its motion (output signal = z).

The profile signal is processed by a computer mounted in the vehicle. The profile computations of both wheel paths are performed as the vehicle is moving along the road. Two independent circuits in the computer produce different road profiles for each wheel path by integrating each accelerometer signal twice and adding it to the respective potentiometer output. Therefore, the measured pavement profile , w_f, is given by

$$w_f = \text{potentiometer signal} + \iint (\text{accelerometer signal})\, dt\, dt$$

$$W_f = (w\text{-}u) + \iint z\, dt\, dt$$

where

z	=	displacement of the vehicle body.
z	=	acceleration of the vehicle body.
w	=	relative displacement between the following road-wheel and the vehicle body.

How this profilometer process produces a road profile is summarized in Fig 3.1. More details about the profilometer are presented in Refs 10, 19, 21, 22, and 23.

All the sections used in this study were profiled using the Model 690D Surface Dynamic Profilometer, which was set for normal operating conditions:

(1) Accelerometer Filter Wavelength : 200 feet.
(2) Sampling Frequency : 6.00 inches.
(3) Profiling Distance : 0.2 mile (1056 ft) per subsection.
(4) Average Profiling Speed : 20 miles per hour.

ROOT-MEAN-SQUARE-VERTICAL ACCELERATION (RMSVA)

Road profiles provide a complete characterization of the road surface. Therefore, they contain information from which the nature of the roughness can be inferred. It is necessary to

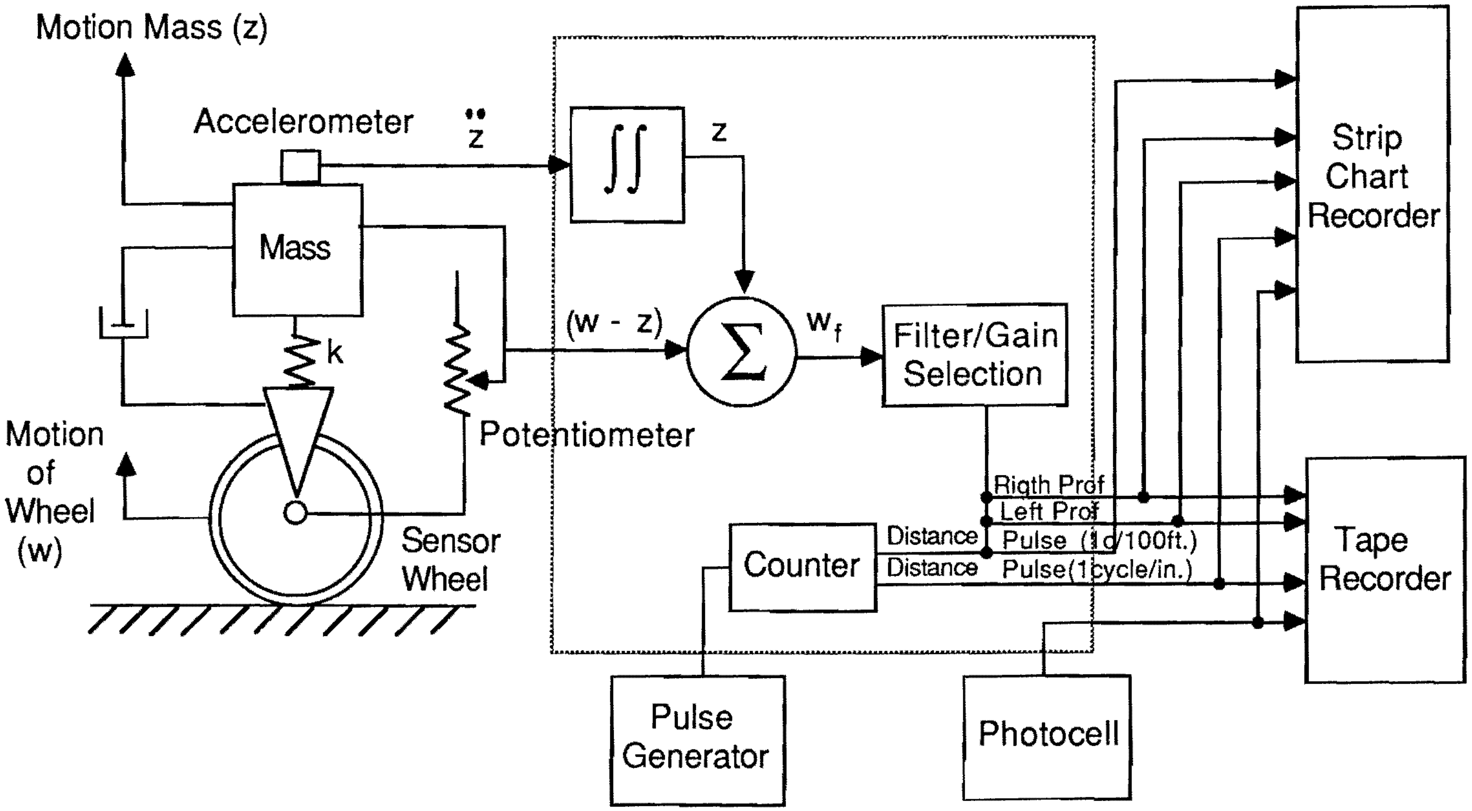


Fig 3.1. Schematic diagram of the SDP measurement system (after Ref 21).

have a method for reducing the road profiles to a set of quantities which (a) properly characterize the road profile, (b) are stable, (c) are simple to use, and (d) are meaningful for ride quality.

The RMSVA can be described as the root-mean-square difference between adjacent profile slopes, where each slope is the ratio of elevation change to distance over a fixed distance increment. A detailed description of the computation of this statistic is given in Reference 24.

Having the left and right wheel path profiles obtained from the profilometer, the RMSVA values are computed using the computer program VERTAC (Refs 24 and 25). The left and right wheelpath RMSVA values for each base length are averaged. Finally, for each section, the RMSVA are computed for the following base lengths : 0.5, 1, 2, 4, 8, 16, 32, 64, and 128 feet.

The profilometer data are originally stored on a 9-track, 800 BPI, RT-11 format tape written for the 690D profilometer. This tape has to be converted to an IBM compatible format before it can be used as input to VERTAC. The version of VERTAC used (Version 5.0) was last updated February, 1986.

SERVICEABILITY MODELS USED IN THIS STUDY

This research uses the serviceability models developed in Project 354 (Ref 21). This project was conducted at the Center for Transportation Research (CTR) at The University of Texas at Austin, sponsored by the Texas State Department of Highways and Public Transportation (SDHPT).

The models developed on Project 354 explain the panel's opinions only through the RMSVA values. These models were developed according to a stepwise multiple regression technique. This method selected only those independent variables (RMSVA at different base lengths) that best explained the dependent variable (serviceability index). Project 354 proposed different models for rigid and flexible pavements. These models are

$$SI = 5.00 - 0.069\ VA_2 - 0.136\ VA_4 - 23.07\ VA_{128}$$

for flexible pavements, and

$$SI = 5.00 - 0.064\ VA_4 - 0.839\ VA_8 - 3.084\ VA_{64}$$

for rigid pavements.

Finally, to obtain the serviceability index which represents the riding quality of a section of the road, it is necessary to calculate the SI value using these equations and the corresponding RMSVA values calculated by VERTAC.

CHAPTER 4. DESIGN OF EXPERIMENT

INTRODUCTION

The main objective of the design of an experiment is to determine the effect of various factors (independent variables) on some characteristic of a variable of interest (dependent variable). The factorial approach is efficient and results in a considerable saving of time and resources, when compared to the alternative procedure of conducting separate experiments where each of these deals with a single factor. Moreover, in a factorial experiment, the effects of each factor are examined for every combination of all other factors (interaction) included in the experiment.

The main objective of this analysis is to estimate the serviceability index (dependent variable) of the highways of the State of Texas at different points during their life. This chapter describes the design of the experiment used in the analysis.

DEFINING THE INFERENCE SPACE AND THE EXPERIMENTAL UNITS

The inference space, defined as the space where the results of the study may be applied, is the highway system in the State of Texas. This concept is important and it is necessary to keep it in mind when applying the results or the conclusions of the study. According to Anderson and McLean, the experimental or elemental unit is the type of experimental material that is being used to receive the application of various treatments and allows the investigation of the desired inference space (Ref 8). In this study, any road is an experimental unit.

EXPERIMENTAL DESIGN FACTORS

There are many independent variables that could be studied, for example, environmental condition, construction procedure, structural design, surface materials, traffic, and many others. After statistical, timing, and economical considerations, a three-factor experiment was developed. Three main factors were selected : (1) environmental-geographical regions, (2) type of pavement, and (3) category of use. These three factors are fixed because all levels of interest of all factors are included in the experiment.

The first factor, "environmental/geographical regions", has four levels. This factor was developed from the six climatic regions in the United States, which are differentiated on the basis of moisture availability and freeze-thaw activity (Fig 4.1) (Ref 26). This figure shows that the State of Texas is divided into four areas according to this national classification. To keep a uniform system, it was decided to use this division for this study. Therefore, the levels on this factor are the four climatic zones present in Texas: Climatic zone I, which is wet and does not freeze; Climatic zone II, which is wet and has freeze-thaw cycling; Climatic zone IV, which is dry and does not freeze; and climatic zone V which is dry and has freeze-thaw cycling. These are illustrated in Fig 4.2.

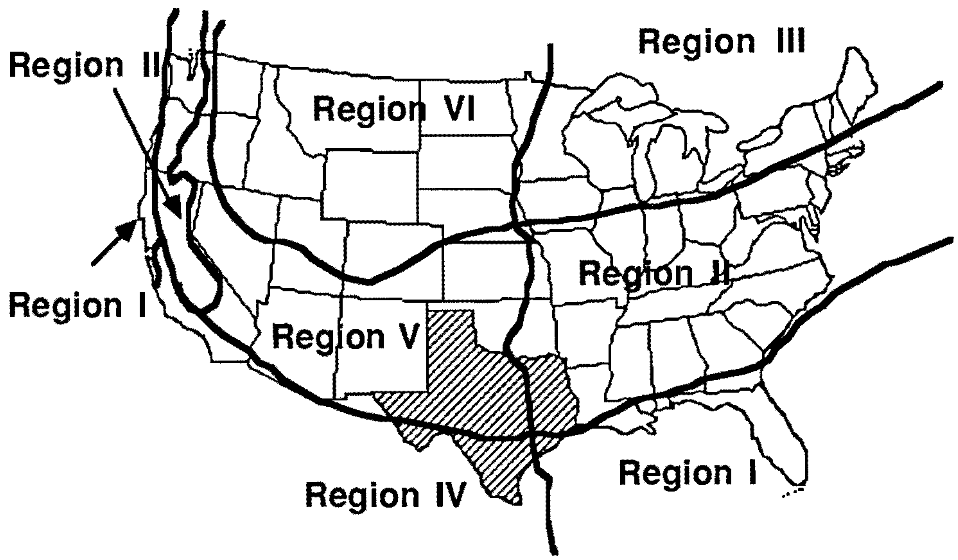
The second factor, "type of pavement ", has two levels, the two most representative pavement types: rigid pavements and flexible pavements.

The third factor, "category of use," has four levels. These four levels are (a) serviceability immediately after construction (new pavements), (b) serviceability before scheduled overlay projects (terminal pavements), (c) serviceability immediately after rehabilitation (resurfaced pavements), and (d) serviceability after reconstruction (reconstructed pavements).

Finally, with these three main factors, it is possible to build a factorial design matrix that we will use for the analysis. This matrix is presented in Fig 4.3. A summary of the main factors and their respective levels used in this study is shown in Table 4.1.

It is important to note for this study that a "rigid-overlaid pavement" was considered to be a rigid pavement overlaid with asphalt concrete. The Portland Cement Concrete (PCC) type of overlay exists primarily in specified research sections today.

Two other variables were selected as secondary fixed factors: (1) highway classification (H) and (2) surface type (S). Highway classification has two levels: primary highways and secondary highways. Surface type has different levels for each pavement type. Rigid pavements have continuous and jointed surfaces. On the other hand, flexible pavements have asphalt concrete and surface treatment. Table 4.2 presents a summary of the secondary factors and their respective levels selected for this research.



REGION	CHARACTERISTICS
I	Wet and no freeze
II	Wet and freeze-thaw cycling
III	Wet, hard freeze and spring thaw
IV	Dry and no freeze
V	Dry and freeze-thaw cycling
VI	Dry, hard freeze and spring thaw

Fig 4.1. The six climatic regions in the United States (after Ref 26).

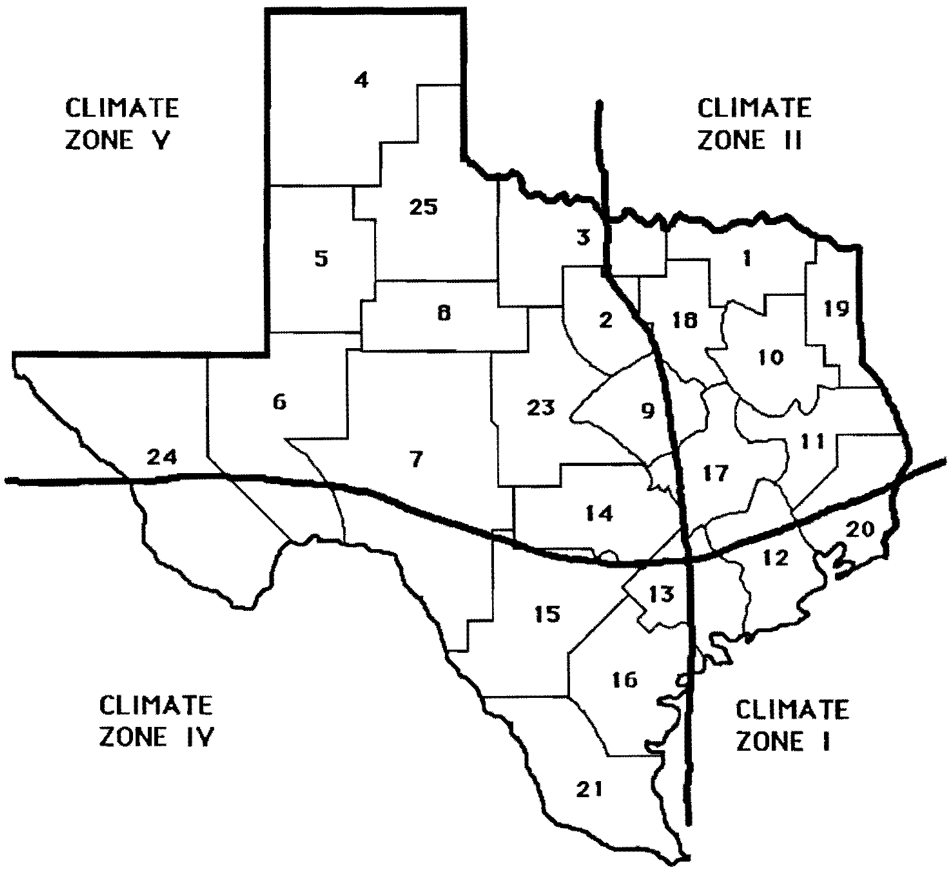


Fig 4.2. Location of the four climatic regions in Texas.

Climatic Zones		Region I		Region II		Region IV		Region V	
Pavement Types		Rigid	Flexible	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
Category of Use	New								
	Reconst.								
	Resurfaced								
	Terminal								

Fig 4.3. Factorial design matrix.

TABLE 4.1. MAIN FACTORS USED ON THE STUDY

Factor	Number of Levels	Name of Levels
Region (R)	4	Region I, Region II, Region IV, and Region V
Pavement Type (P)	2	Rigid Pavements and Flexible Pavements
Category of Use (C)	4	New, Reconstructed, Resurfaced, and Terminal

TABLE 4.2. SECONDARY FACTORS USED IN THE STUDY

Factor	Number of Levels	Name of Levels
Highway Classification	2	Primary Roads and Secondary Roads
Surface Type for Rigid Pavement	2	Continuous and Jointed
Surface Type for Flexible Pavement	2	Asphalt Concrete and Surface Treatment

SELECTION OF THE EXPERIMENTAL UNITS

Selection of the Sections

The selection method adopted in this study was a screening process that used the monthly list of bids and construction reports from the Texas State Department of Highways and Public Transportation .

To determine the pavement type of each section, two basic sources of information are needed: first, the tabulation of bids , which normally shows the type of work that will be done; second, the Pavement Evaluation System in Texas (PES), which indicates the type and pavement condition existing before the work was done .

If the profile was obtained before the rehabilitation work, the pavement is in "terminal" condition. On the other hand, if the profile was obtained after the work, the pavement is in the "resurfaced" category.

Sampling Technique Within a Section

Ideally, we would like to have the complete profile of the section, but the following wheels of the profilometer (described previously in Chapter 3) cannot be used for a long continuous period of time. Therefore, a sampling technique, which represents the entire section, is required. The sampling method most appropriate in this case is systematic random sampling.

A systematic random sample is a subset of the population, chosen by randomly selecting one of the first "k" elements and then including every "k^{th}" element thereafter, where "k" is determined by dividing the population size by the desired sample size (Ref 27).

In this study, a section or project was divided into several subsections of one mile each. In the first subsection, a sample of 1056 feet was taken, starting at a random distance (a) from the beginning of this subsection. For the following subsections, a sample was taken starting at the same distance (a) used on the first subsection. This concept is presented in Fig 4.4.

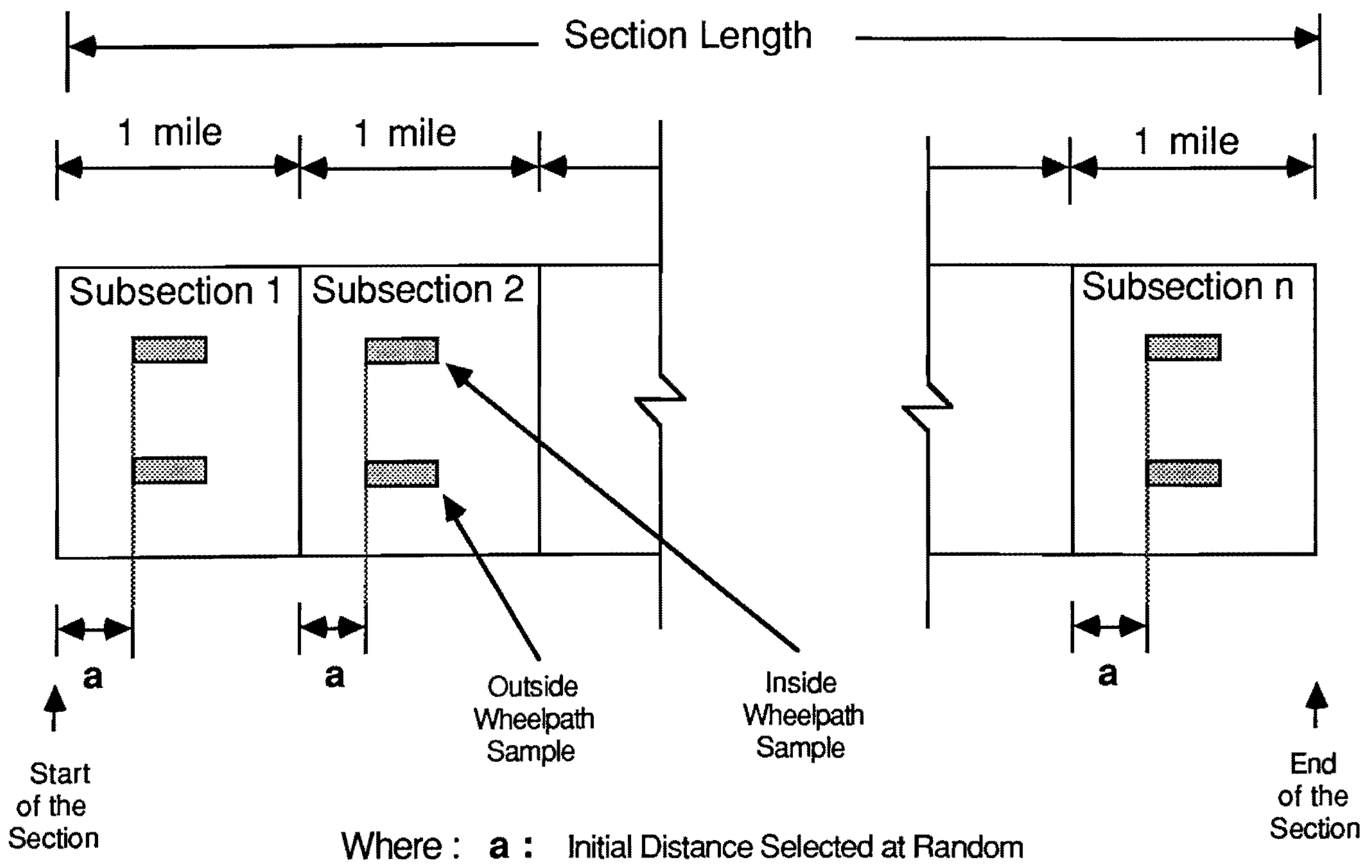


Fig 4.4. Sampling technique used within a section.

CHAPTER 5. DATA PROCESSING AND ANALYSIS

INTRODUCTION

This chapter presents the analysis of the data collected for the study. The interpretation of the results obtained herein is discussed on Chapter 6.

Before the data were put into a computer system for analysis, different software packages were considered. The most important features required in the software were (1) data processing and (2) statistical techniques. The Statistical Analysis System (SAS) package was selected because it best suited the overall computing needs. The various tools provided by SAS include (1) information storage and retrieval, (2) data modification and programming, (3) file handling, and (4) sophisticated statistical analysis procedures (Refs 28 and 29). These features proved to be valuable in processing and analyzing these experimental data.

Ideally, the analysis should include all the factors of interest to the researcher in one single model; but when this condition is not possible, the data may be divided using more than one model.

The procedure followed during the analysis is summarized in Fig 5.1. The first step was to verify whether or not the data met the assumptions required for the analysis. The second step in this analysis was to run an analysis of variance (ANOVA) with a complete model, including the dependent variable (serviceability index), and all independent factors of interest: region (R), pavement type (P), category of use (C), highway classification (H), and surface type (S). The results of this analysis were most unsatisfactory. Some of the sum square (SS) were undefined, mainly because there were not enough data to run this complete model.

The third step of the analysis considered only the main factors of interest; that is, region, pavement type, and category of use. After obtaining the results with that model, some of the factors that were non-significant at a pre-determined level could be discarded. The fourth step was to run a separate ANOVA for rigid and flexible pavements. In both cases, the model included the following three factors: category of use (C), highway classification (H), and surface type (S).

The fifth step, a multiple comparison test among the significant factors found in the previous steps, allowed the final conclusions for the factors of interest. The next step of this analysis involved interpreting the results, which is discussed in the next chapter.

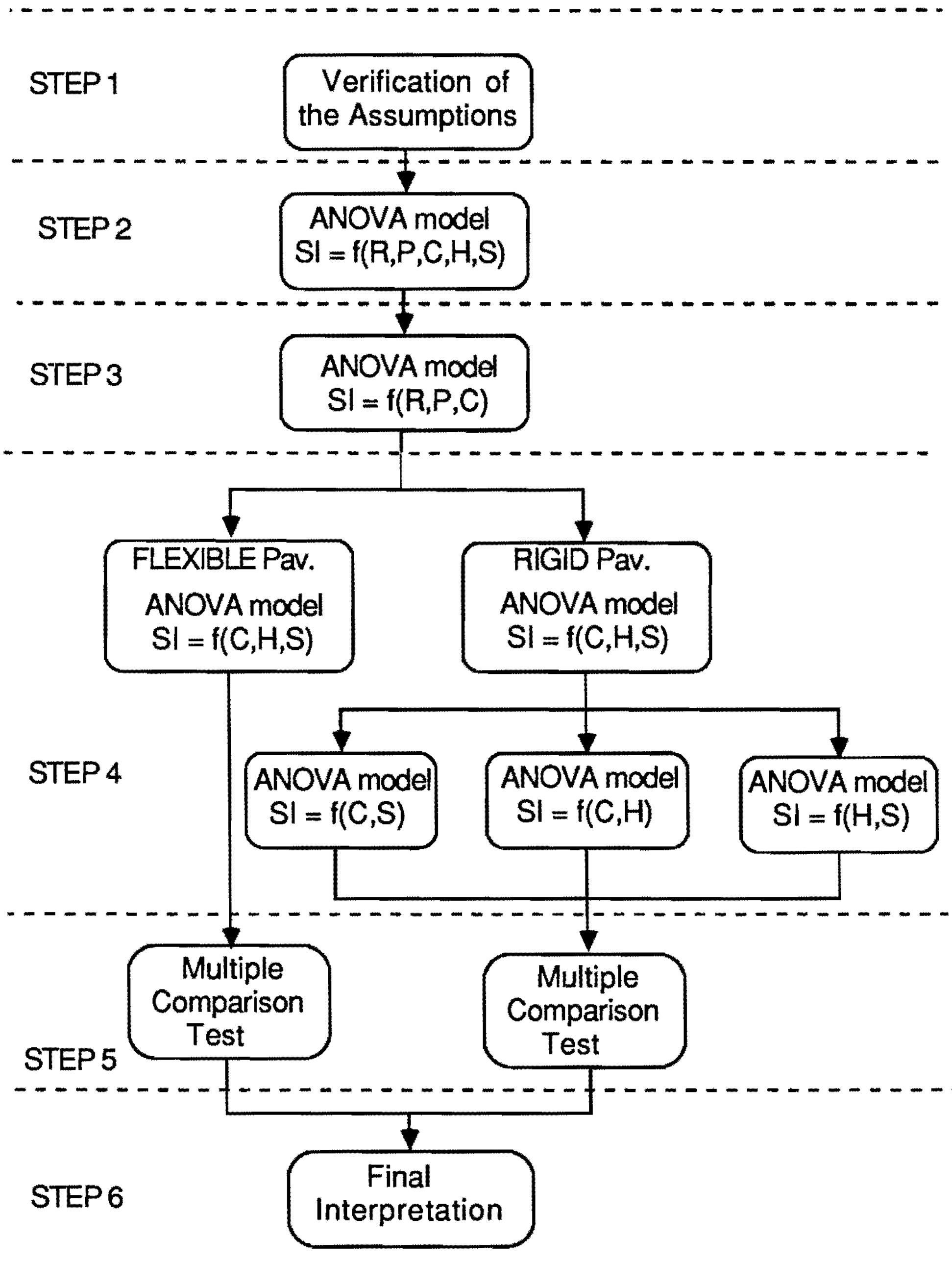


Fig 5.1. Summary of the steps used in the statistical analysis.

Finally, the variability of the serviceability index was studied. To achieve this new task: an ANOVA was run using the coefficient of variation as the dependent variable, and the climatic region as the independent variables, the pavement type, and the category of use.

The layout of this chapter includes: a description of the data bases developed for the study, a description of the characteristics of the data collected, a verification of the assumptions required for the analysis, an analysis of the serviceability indices (SI) including the main factors, an ANOVA including the secondary factors, and an analysis of the variability of the serviceability index.

DATA BASE SYSTEM DEVELOPED FOR THE STUDY

Two data bases were created to manage the information generated during the study. The first, called Data Base A, was designed to store the "raw data" generated by the VERTAC program. The second, called Data Base B, was designed to prepare and retrieve the information for the analysis. The following paragraphs describe these two data bases.

Data Base A

This data base has twelve fields. The first field contains an identification number. The code developed in this case was a unique number of ten digits, as follows:

<table>
<tr><td>(1)</td><td>(2)</td><td>(3)</td><td>(4)</td><td>(5)</td><td>(6)</td><td>(7)</td><td>(8)</td><td>(9)</td><td>(10)</td></tr>
<tr><td>R</td><td colspan="2">D</td><td>P</td><td>C</td><td colspan="3">Sec</td><td colspan="2">SSec</td></tr>
</table>

where

R = Climatic Region . It can be any number, from 1 to 5, excepting number 3 (this region is not present in Texas)

- 1 = Region I
- 2 = Region II
- 4 = Region IV
- 5 = Region V

D	=	District Number. It can be a number between 1 and 25, except number 22 (this District is not present in Texas.)
P	=	Pavement Type. It can be 1 or 2. 1 = Rigid 2 = Flexible
C	=	Category of Use. It can be any number between 1 and 4. 1 = Immediately after construction (new) 2 = Before Scheduled Reconstruction (reconstructed) 3 = After Scheduled Overlay (resurfaced) 4 = Before Scheduled Overlay (terminal)
Sec	=	Section Number. It is a consecutive number, starting with 1 and finishing with 145, used in the project to control the sections.
SSec	=	Sub-Section Number. It is a helper number used to group the sub-sections in a section.

The second field was created for comments, it contain district number, highway identification, identification of the bond profiled, starting point, and run number. The third field contains the date when the profile was taken. Finally the last nine fields (from the 4th to the 12th field) were created for the RMSVA values at the nine different base lengths generated by VERTAC (0.5, 1, 2, 4, 8, 16, 32, 64, and 128 feet).

Data Base B

This data base, which has fifteen fields, was created to allow the use of the data in the analysis. The characteristics of these fields are summarized in Table 5.1.

TABLE 5.1. INFORMATION CONTAINED IN DATA BASE B

Field	Name	Abbreviation	Contents
1	Region	R	The climatic regions where the sections are located.
2	District	D	The district number where the sections are located.
3	Pavement Type	P	The pavement type associated with the section under consideration
4	Category of Use	C	The category of use of the section at the time the profile was taken.
5	Highway Class	H	The highway classification of the road where the section is located.
6	Surface Type	S	The surface type of the road where the section is located.
7	Section Number	Sec	A consecutive number used in the study to identify the sections.
8	Road Name	Road	The name of the road where the section is located.
9	Begining	From	Identification of the beginning of the section.
10	End	To	Identification of the end of the section.
11	Date	Date	The date when the profile was taken.
12	Tape Number	Log	The profilometer tape number from where of all this information was generated.
13	Observations	Obs.	The number of observations taken on a section (number of subsections).
14	Serviceability	SI	Serviceability Index.
15	Variance	CV	Coefficient of variations within a section.

DATA COLLECTED

One hundred and forty-five sections (145) around the State of Texas were selected and profiled for this study. The location of these sections is shown in Fig 5.2. Of these 145 sections, 36 are on rigid pavements and 109 are on flexible pavements. The information collected for all sections will be presented in two parts. The first part contains a general description and the locations of the sections. The second part includes, mainly, the roughness information.

General Description and Location of the Studied Sections

The general characteristics of all sections used in the study are presented in Appendix A. The variables shown in that Appendix are pavement type (P), section number (Sec), climatic region (R), district number (D), category of use (C), highway classification (H), surface type (S), road name (Road), section starting (From), section end (To), tape number (Log) , and date (Date).

Roughness Information of the Studied Sections

The roughness information of all sections is shown in Appendix B. The variables described in that Appendix are pavement type (P),section number (Sec), climatic region (R), category of use (C), highway classification (H), surface type (S), number of observations (Obs), SI value (SI), and coefficient of variation of the SI value within a section (CV).

Summary of the Data Collected

A summary of the data collected is presented in Fig 5.3. Each cell of that figure contains the sample size, the average SI value, and the standard deviation for all the studied sections located in that specific condition.

From that figure it is possible to conclude that the second category of use, "reconstruction," does not contain sufficient sections to allow a good statistical analysis. Therefore, this category is not considered for further analysis.

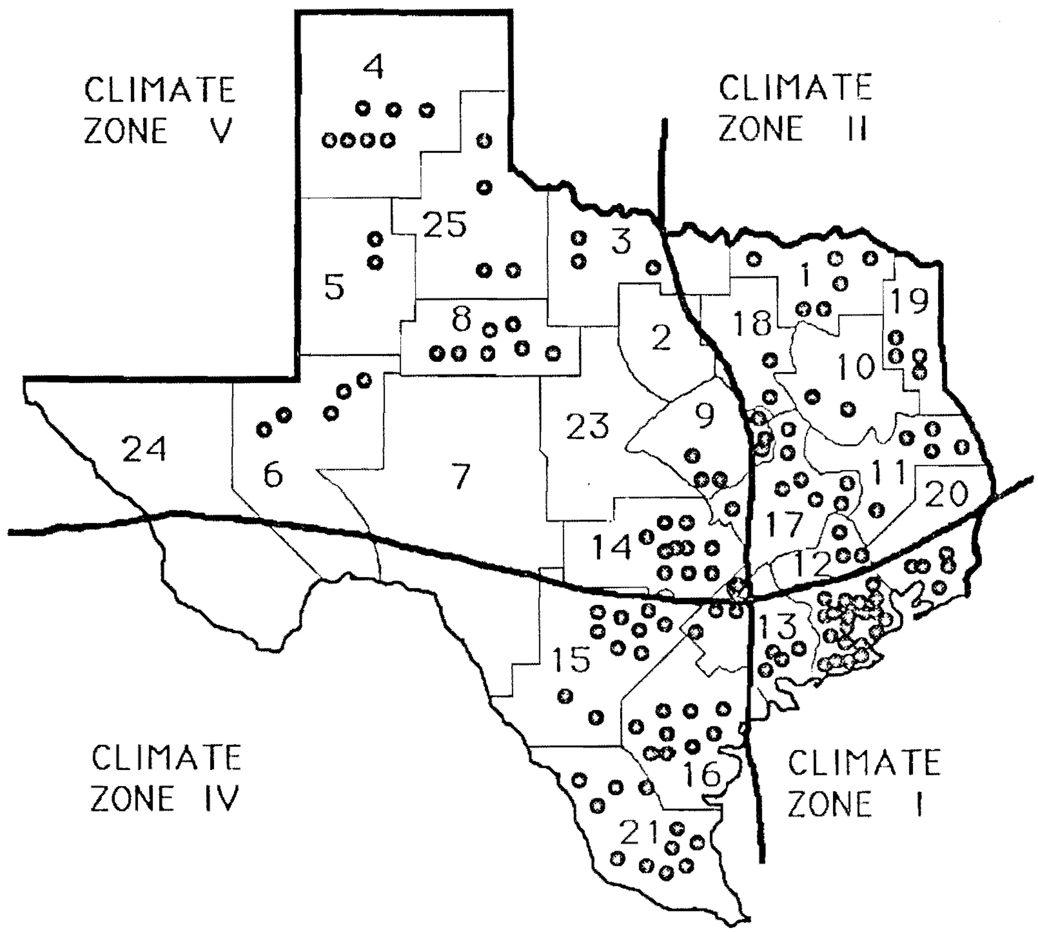


Fig 5.2. Distribution of the sections used in the study.

Climatic Zones	Region I		Region II		Region IV		Region V	
Pavement Types	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
Category of Use								
New	5 3.71 0.62	---	4 3.67 0.28	3 3.47 1.14	1 4.04 ---	1 3.84 ---	3 3.94 0.08	4 3.64 0.58
Reconst.	---	---	---	---	---	1 3.73 ---	---	1 4.13 ---
Resurfaced	2 4.02 0.45	7 4.06 0.15	6 3.71 0.41	4 3.52 0.21	1 4.16 ---	14 3.95 0.20	2 4.15 0.10	18 3.81 0.59
Terminal	4 3.25 0.34	12 2.85 0.72	4 3.67 0.12	13 3.01 0.65	2 3.26 0.89	17 3.24 0.55	2 4.12 0.04	14 3.07 0.77

Fig 5.3. Summary of results (each cell contains: number of observations, average SI-values, and standard deviation).

VERIFICATION OF THE ASSUMPTIONS FOR THE ANALYSIS

Before performing an analysis of variance (ANOVA), we must check the fundamental assumptions that are required in the analysis. The four traditional assumptions are (1) the variable of interest (y) is a random variable, (2) variances are homogeneous, (3) the model used for the analysis is additive, and (4) the response variable (y) is normally and independently distributed.

Figure 5.4 shows an identification of the cells on the factorial which were useful for this part of the study.

Homogeneity of Variances Test

The Burr-Foster test (Q-test) was selected to perform this verification. A good description of this test is given in Ref 8.

The value of the test statistic is denoted by q and for unequal sample sizes it is

$$q = \bar{v} \frac{\sum_{i=1}^{p} v_i s_i^4}{\left[\sum_{i=1}^{p} v_i s_i^2 \right]^2}$$

$$\bar{v} = \frac{p}{\sum_{i=1}^{p} \frac{1}{v_i}}$$

where

v	=	degree of freedom
$\bar{v}$	=	harmonic mean of the degree of freedom
s	=	standard deviation

p = total number of cells to be compared

The critical values for q (q_c) are given in Appendix 8 of Ref 8. From the 24 cells to be analyzed (Fig 5.4), only those cells with two or more observations could be considered for this test. Table 5.2 presents the initial calculations required for this test.

Finally, as a conclusion, the hypothesis of equality of variances among these twenty cells is accepted, because the q-value calculated from the data is lower than the critical q–value at 0.01 level of significance. Therefore, the variances are declared homogeneous.

Normality Test

The test developed by Shapiro and Wilk (W-test) was selected for this verification. This test is recommended for sample sizes ranging from 5 to 50 (Ref 8), such as is the case for this study. From the 24 cells in the factorial (Fig 5.3), only those cells with five or more observations were selected to run this test. An alpha level equal to 0.01 was selected for this test.

The value of the test statistics is denoted as "w". A table with the critical values for "w" (w_c) is in Appendix 10 of Reference 8. Table 5.3 presents the normality test. Part (a) shows the steps recommended in Reference 8 to run a W-test. Part (b) presents a summary of the analysis of the W-test for the nine selected cells.

These results show that 89 percent of the cells tested are normally distributed. This conclusion is good enough, from a practical point of view, for acceptance of the assumption of normality for the ANOVA.

Summary of the Results of the Assumption Tests

According to the results of the Q-test and W-test, the data met the assumptions of the ANOVA; therefore, they do not need any transformation before the analysis is run.

TABLE 5.2. INITIAL CALCULATIONS FOR THE Q-TEST

Sequence	Cell	v	s	s^2	s^4	$v \times s^2$	$v \times s^4$
1	1	4	0.6149	0.378	0.143	1.512	0.572
2	3	3	0.2808	0.079	0.006	0.237	0.018
3	4	2	1.1390	1.297	1.682	2.594	3.364
4	7	2	0.0751	0.006	0.000	0.012	0.000
5	8	3	0.5763	0.332	0.110	0.996	0.330
6	9	1	0.4525	0.205	0.042	0.205	0.042
7	10	6	0.1477	0.022	0.000	0.132	0.000
8	11	5	0.4052	0.164	0.027	0.820	0.135
9	12	3	0.7258	0.527	0.278	1.581	0.834
10	14	13	0.1962	0.038	0.001	0.494	0.013
11	15	1	0.0990	0.010	0.000	0.010	0.000
12	16	17	0.5936	0.352	0.124	5.984	2.108
13	17	3	0.3359	0.113	0.013	0.339	0.039
14	18	11	0.7216	0.521	0.271	5.731	2.981
15	19	3	0.1152	0.013	0.000	0.039	0.000
16	20	12	0.6539	0.428	0.183	5.136	2.196
17	21	1	0.8980	0.806	0.650	0.806	0.650
18	22	16	0.5543	0.307	0.094	4.912	1.504
19	23	1	0.0354	0.001	0.000	0.001	0.000
20	24	13	0.7659	0.587	0.345	7.631	4.485
					Total	39.172	19.271

where $\bar{v}$ = 20 / 7.733 = 2.586

q = 2.586 x 19.271 / $(39.172)^2$ = 0.032

q_c (v = 2.586 , p = 20, and a = 0.01) = 0.136

TABLE 5.3. NORMALITY TEST

(A) STEPS USED IN THE W-TEST

STEP	DESCRIPTION
1	Order the n observations as $y_1 \leq y_2 \leq \ldots\ldots\ldots\ldots \leq y_n$
2	Compute SSy = $\sum [y_i^2 - n\bar{y}^2]$
3	Calculate b = $\sum a_{n-i+1} (y_{n-i+1} - y_i)$ where "a" values are in Appendix 9 of Reference 8
4	Compute w = $b / \sum (y_i - \bar{y})^2$
5	Compare w of step 4 to the critical value. The critical values for w are given in Appendix 10 of Reference 8.

(continued)

TABLE 5.3. (CONTINUED)

(B) SUMMARY OF THE RESULTS FOR THE NORMALITY TEST

Cell Number	n	SSy	b	w	w_c	Acceptance of Normality at 0.01 Level
1	5	1.513	1.069	0.755	0.686	Yes
10	7	0.107	0.358	1.196	0.730	Yes
11	6	0.821	0.857	0.894	0.731	Yes
14	14	0.485	0.695	0.997	0.825	Yes
16	18	6.050	2.168	0.777	0.858	No
18	12	5.728	2.314	0.935	0.805	Yes
20	13	5.151	2.166	0.909	0.814	Yes
22	17	4.865	2.112	0.917	0.851	Yes
24	14	7.663	2.522	0.830	0.825	Yes

Climatic Zones		Region I		Region II		Region IV		Region V	
Pavement Types		Rigid	Flexible	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
Category of Use	New	1	2	3	4	5	6	7	8
	Resurfaced	9	10	11	12	13	14	15	16
	Terminal	17	18	19	20	21	22	23	24

Fig 5.4. Identification of the cells in the factorial.

ANALYSIS OF VARIANCE OF THE MAIN FACTORS

The analysis of the main factors (Region, or R; Pavement Type, or P; and Category of Use, or C) was performed using the Generalized Linear Model (GLM) procedure available in SAS (Ref 29). The GLM procedure is used in data from an unbalanced design, such as the one in this study. The analysis of variance model can be written as a linear model, in the form of an equation that predicts the response variable (SI) as a linear function of the design variables (R, P, and C) and their interactions (R*P, P*C, and R*P*C). In other words;

$$SI_{ijkl} = \mu + R_i + P_j + R*P_{ij} + C_k + R*C_{ik} + P*C_{jk} + R*P*C_{ijk} + \varepsilon_{(ijk)l}$$

where

SI_{ijkl}	=	serviceability index of a section located on region i, for the pavement type j, and the category of use k
μ	=	overall mean
R_i	=	effect of the region i
P_j	=	effect of the pavement type i
$R*P_{ij}$	=	effect of the interaction of the region i with the pavement type j
C_k	=	effect of the category of use k
$R*C_{ik}$	=	effect of the interaction of the pavement type j with the category of use k
$P*C_{jk}$	=	effect of the interaction of the pavement type j with the category of use k
$R*P*C_{ijk}$	=	effect of the interaction of region i, the pavement type j, and the category of use k
$e_{(ijk)l}$	=	random error of the l^{th} section in the region i, with the pavement type j, and in the category of use k.

where

"e" is normally and independently distributed with zero mean and variance s^2, NID $(0, s^2)$, assuming all sections used in this study wereselected at random from the population of sections in each i, j, k^{th} cell.

We need to derive the expected mean squares (EMS) for each source of variation. An algorithm to derive the EMS is fully explained in Reference 8. Table 5.4 shows the derivation of the EMS for the model used in this analysis. Where f is a non-negative function dependent

TABLE 5.4. DERIVATION OF THE EXPECTED MEAN SQUARE (EMS)

Source	levels factor	4 f i	2 f j	3 f k	m r l	EMS
R_i		0	2	3	m_1	$\sigma^2 + 6\ m_1\ \phi(R)$
P_j		4	0	3	m_2	$\sigma^2 + 12\ m_2\ \phi(P)$
$R*P_{ij}$		0	0	3	m_3	$\sigma^2 + 3\ m_3\ \phi\ (R*P)$
C_k		4	2	0	m_4	$\sigma^2 + 8\ m_4\ \phi(C)$
$R*C_{ik}$		0	2	0	m_5	$\sigma^2 + 2\ m_5\phi\ (R*C)$
$P*C_{jk}$		4	0	0	m_6	$\sigma^2 + 4\ m_6\phi\ (P*C)$
$R*P*C_{ijk}$		0	0	0	m_7	$\sigma^2 + m_7\phi\ (R*P*C)$
Error		1	1	1	1	σ^2

upon the effect contained within the parentheses, m_i is a different number for each source of variation because there are unequal numbers in the various level combinations, f means that the factor is fixed, and r means that the factor is random. From Table 5.4, it is possible to conclude that all F-tests will use the within-error-mean-square as their denominator. This is always true for all completely randomized designs with all fixed factors (Ref 8). In others words, the test statistics for all sources will be

F-test = MS (source to be analyzed) / MS (error)

Finally, the actual tests for the main factors and their interaction are presented in Tables 5.5 and 5.6. The only effects that are significance are obtained for pavement type and category of use. Region and all the interactions are not significant at a = 0.25. This a-level was chosen mainly because, at that level, on the average, b (type II error) is small enough to accept the null hypothesis without assuming too much risk in that decision (Ref 8). Since region and none of the interactions with region was significant at a = 0.25 , we may pool over region. In other words, the factor region will not be considered for further analysis.

ANALYSIS OF VARIANCE INCLUDING THE SECONDARY FACTORS

The factors included in this analysis, besides the main factors (pavement type and category of use), are the highway classification (H) and the surface type (S).

This part of the analysis will consider the flexible pavements separately from the rigid pavements. The main reason for that decision is that the two levels of surface types selected in this study for flexible pavements are completely different from the ones for rigid pavements.

Flexible Pavements Analysis

The variables to be included in this part of the analysis are category of use (C), highway classification (H), and surface type (S). The model used to analyze these effects is

$$SI_{ijkl} = \mu + C_i + H_j + C^*H_{ij} + S_k + C^*S_{ik} + H^*S_{jk} + C^*H^*S_{ijk} + \varepsilon_{(ijk)l}$$

TABLE 5.5. ANOVA TABLE FOR THE MAIN FACTORS

Source of Variance	d.f.	SS	MS
R	3	1.1881	0.3960
P	1	1.3805	1.3805
R*P	3	0.4705	0.1568
C	2	5.9865	2.9933
R*C	6	1.5304	0.2551
P*C	2	0.5944	0.2972
R*P*C	5	0.4488	0.0898
Error	122	39.2920	0.3221

TABLE 5.6. TESTING THE MAIN FACTORS AND THEIR INTERACTIONS

Source of Variance	F-test	Fcrit(0.25)	Significance at a = 0.25
R	1.23	1.39	NO
P	4.29	1.34	YES
R*P	0.49	1.39	NO
C	9.29	1.40	YES
R*C	0.79	1.33	NO
P*C	0.92	1.40	NO
R*P*C	0.28	1.35	NO

where

SI_{ijkl}	=	serviceability index of a section in the category of use i, for the highway classification j, and for the surface type k
μ	=	overall mean
C_i	=	effect of the category of use i
H_j	=	effect of the highway classification j
$C*H_{ij}$	=	effect of the interaction of the category i with the highway classified as j
S_k	=	effect of the surface type k
$C*S_{ik}$	=	effect of the interaction of the category i with the surface type k
$H*S_{jk}$	=	effect of the interaction of the highway classified as j with the surface type k
$C*H*S_{ijk}$	=	effect of the interaction of category of use i, the highway classified as j, and the surface type k
$e_{(ijk)l}$	=	random error of the l^{th} section in the category of use i, for the highway classified as j, and for the surface type k. Where e is NID(0, s^2).

After running the GLM procedure in SAS using the model above for the flexible pavement data (sample size equal to 109 observations), the ANOVA table presented in Table 5.7 was obtained. The results of the F-tests are presented in Table 5.8.

That table shows category of use (C) and its interaction with highway classification and surface type are significant. Since there is a significant interaction between category of use and highway classification and between category of use and surface type, care must be taken to interpret the results. Usually, when some interactions are presented, we must be careful in interpreting the main effects even though they are significant. The conclusions may be obtained from the interactions. The recommendation given in Reference 8 for this type of analysis will be followed in this case.

Table 5.9 displays the sample sizes and the mean serviceability index values identified by the combinations of the levels of category of use (C) and highway classification (H). To obtain Fig 5.5, which better explains the behavior of this interaction, Table 5.9 was used.

A Bonferroni multiple comparison test (Ref 30) was selected to compare the pairs of means presented in Fig 5.5. This test consists of running a t-test at a* level, where a* is the

TABLE 5.7. ANOVA TABLE FOR THE FLEXIBLE PAVEMENTS

Source of Variance	d.f.	SS	MS
C	2	2.7636	1.3818
H	1	0.4379	0.4379
C*H	1	4.2645	4.2645
S	1	0.4098	0.4098
C*S	1	2.6140	2.6140
H*S	1	0.3120	0.3120
C*H*S	1	0.1462	0.1462
Error	99	25.8436	0.2610

TABLE 5.8. TESTING THE EFFECTS FOR FLEXIBLE PAVEMENTS

Source of Variance	F-test	Fcrit(0.10)	Significance at $\alpha = 0.10$
C	5.59	2.76	YES
H	1.68	2.76	NO
C*H	16.34	2.76	YES
S	1.57	2.76	NO
C*S	10.02	2.76	YES
H*S	1.20	2.76	NO
C*H*S	0.56	2.76	NO

TABLE 5.9. MEANS FOR THE INTERACTION BETWEEN C AND H

Category of Use	Highway Classification					
	Primary			Secondary		
	n	mean	Ident.	n	mean	Ident.
New	5	3.98	B	3	2.96	A
Resurfaced	38	3.94	D	7	3.49	C
Terminal	39	3.18	F	17	2.75	E

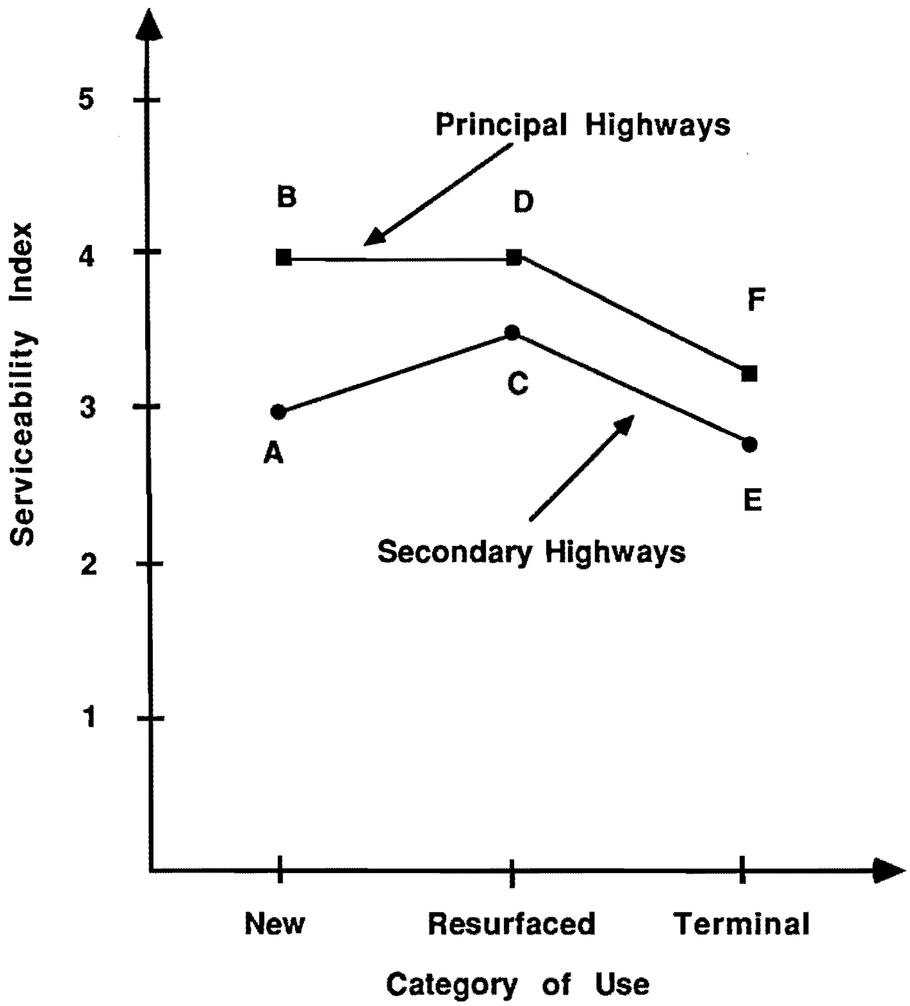


Fig 5.5. Highway classification and category of use SI–interaction flexible pavements.

actual level selected (a) divided by the total number of tests to run in the multiple comparison. The results must be interpreted at α level.

The hypothesis to be tested is "the difference between the two selected means is zero". The α level selected is 0.05, the number of tests is nine, and, therefore, the a* is equal to 0.0056. The results of this multiple comparison test (one tail test) are shown in Table 5.10. The "MS_{error}" is equal to 0.2610, obtained from Table 5.7, the degree of freedom is equal to "$n_i + n_j - 2$", and n_i and n_j are the number of observations used to obtain the respective means (obtained from Table 5.9).

Table 5.11 presents the sample sizes and the mean serviceability index for the combinations of levels of category of use (C) and surface type (S).

A graphical representation of these values is presented in Fig 5.6, where a new surface treatment is a flexible pavement which was built using a surface treatment; surface layer over an overlaid surface treatment is a flexible pavement originally (asphalt concrete or surface treatment) which has been resurfaced with a surface treatment; and a terminal surface treatment is a flexible pavement at terminal condition whose last resurfacing was a surface treatment.

A Bonferroni multiple comparison test (Ref 30) was selected to compare the pairs of means shown in Fig 5.6. The results of this multiple comparison test (one tail test) are shown in Table 5.12.

<u>Rigid Pavement Analysis</u>

The variables to be included in this part of the analysis are category of use (C), highway classification (H), and surface type (S). The sample size for rigid pavements is 36 observations.

The same model used for flexible pavements was run first to analyze these effects. It was impossible to run an ANOVA with these data, mainly due to the lack of rigid pavements on secondary roads. Therefore, the effect of these three factors was evaluated using three different models with two factors each, in order to include all of the two factor interactions. The three models used are the following:

TABLE 5.10. MULTIPLE COMPARISON TEST FOR THE MEANS IN FIG 5.5

Nº	Pair	$y_i - y_j$	$s_{\bar{y}}$	t	t_{crit}	Significant $\alpha = 0.05$
1	A-B	-1.01	0.3731	-2.707	-3.638	NO
2	C-D	-0.45	0.2101	-2.142	-2.670	NO
3	E-F	-0.43	0.1491	-2.884	-2.628	YES
4	D-B	-0.03	0.2430	-0.723	-2.670	NO
5	F-B	-0.79	0.2427	-3.255	-2.667	YES
6	F-D	-0.76	0.1165	-6.524	-2.624	YES
7	A-C	-0.53	0.3525	-1.504	-3.439	NO
8	E-A	-0.21	0.3129	-0.656	-2.530	NO
9	E-C	-0.74	0.2294	-3.226	-2.782	YES

where

$$s_{\bar{y}} = \sqrt{MS_{error}\left[\frac{1}{n_i} + \frac{1}{n_j}\right]} \quad \text{and} \quad t = \frac{y_i - y_j}{s_{\bar{y}}}$$

TABLE 5.11. MEANS FOR THE INTERACTION BETWEEN C AND S

Category of Use	Surface Type					
	Asphalt Concrete			Surface Treatment		
	n	mean	Ident.	n	mean	Ident.
New	5	3.98	B	3	2.96	A
Resurfaced	40	4.00	D	5	2.87	C
Terminal	32	3.15	F	24	2.91	E

TABLE 5.12. MULTIPLE COMPARISON TEST FOR THE MEANS IN FIG 5.6

Nº	Pair	$y_i - y_j$	$s_{\bar{y}}$	t	t_{crit}	Significant $\alpha = 0.05$
1	A-B	-1.02	0.3649	-2.795	-3.638	NO
2	C-D	-1.13	0.2370	-4.768	-2.670	YES
3	E-F	-0.24	0.1349	-1.779	-2.550	NO
4	D-B	-0.02	0.2370	-0.084	-2.670	NO
5	F-B	-0.83	0.2403	-3.454	-2.710	YES
6	F-D	-0.85	0.1185	-7.173	-2.628	YES
7	C-A	-0.09	0.3649	-0.247	-3.639	NO
8	E-A	-0.05	0.3060	-0.163	-2.751	NO
9	C-E	-0.04	0.2457	-0.163	-2.727	NO

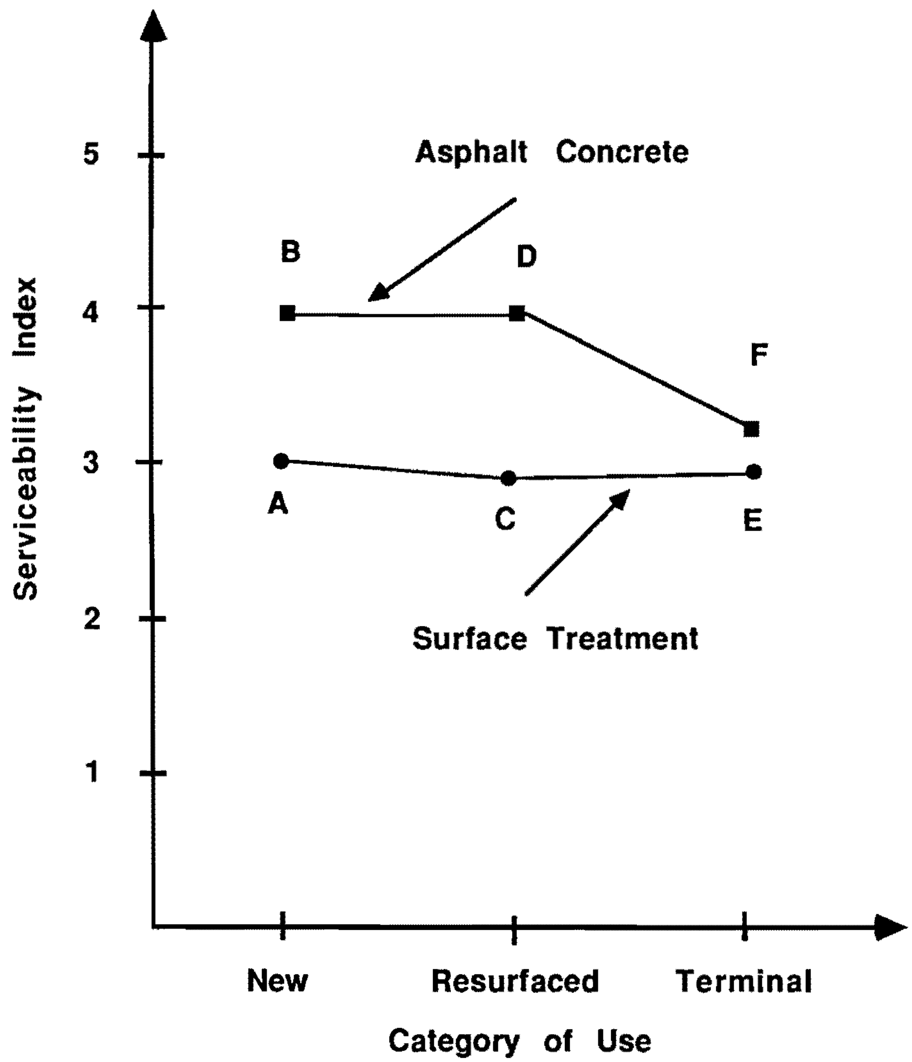


Fig 5.6. Surface type and category of use SI–interaction–flexible pavements.

$$\text{Model 1} \quad : SI_{ijl} = \mu + C_i + H_j + C^*H_{ij} + e_{(ij)l}$$

$$\text{Model 2} \quad : SI_{ikl} = \mu + C_i + S_k + C^*S_{ik} + e_{(ik)l}$$

$$\text{Model 3} \quad : SI_{jkl} = \mu + H_j + S_k + H^*S_{jk} + e_{(jk)l}$$

where

SI_{ijl} = serviceability index of a section in the category of use i and in the highway classification j

SI_{ik} = serviceability index of a section in the category of use i and in the surface type k

SI_{jkl} = serviceability index of a section in the highway classification j and the surface type k

$e_{(ij)l}$ = random error of the l^{th} section in the category of use i and for the highway classified as j. e is NID(0, s^2).

$e_{(ik)l}$ = random error of the l^{th} section in the category of usei and for the surface type k. e is NID(0, s^2).

$e_{(jk)l}$ = random error of the l^{th} section in the the highway classified as j and for the surface type k. e is NID(0, s^2).

All the other factors are already defined.

The results of the analysis of variance for model 1 are given in Table 5.13, for model 2 in Table 5.14, and for model 3 in Table 5.15. The results indicate no significant interaction in all three cases; however, category of use and highway classification appear significant as main effects when analyzed together but not when analyzed with surface type. To explain this phenomenon better, the Table 5.16 was developed. Table 5.16(a) shows the number of observations per cell used in the analysis of model 1. Table 5.16(b) shows the number of observations per cell used in the analysis of model 2. Table 5.16(c) shows the number of observations per cell used in the analysis of the third model.

Since the data in Table 5.16(a), (b), and (c) are so sparse in some cells, no conclusion can be drawn. However, the tendency seems to be the one presented in Table 5.17.

TABLE 5.13. ANOVA TABLE FOR MODEL 1 - RIGID PAVEMENTS

Source of Variance	d.f.	MS	F-value	Fcritical α = 0.10
C	2	0.5885	3.73	2.49 #
H	1	0.5325	3.38	2.88 #
C*H	1	0.1743	1.11	2.88
Error	31	0.1576		

where # : Significant at α = 0.10

TABLE 5.14. ANOVA TABLE FOR MODEL 2 - RIGID PAVEMENTS

Source of Variance	d.f.	MS	F-value	Fcritical $\alpha = 0.10$
C	2	0.3434	1.77	2.49
S	1	0.0000	0.00	2.88
C*S	2	0.0141	0.07	2.49
Error	31	0.1945		

TABLE 5.15. ANOVA TABLE FOR MODEL 3 - RIGID PAVEMENTS

Source of Variance	d.f.	MS	F-value	Fcritical α = 0.10
H	1	0.2847	1.55	2.87
S	1	0.1638	0.89	2.87
H*S	1	0.2174	1.19	2.87
Error	32	0.1836		

TABLE 5.16. OBSERVATIONS PER CELL USED IN THE ANALYSIS OF RIGID PAVEMENTS

(A) FOR MODEL 1

Category of Use	Highway Classification	
	Primary	Secondary
New	11	2
Resurfaced	10	1
Terminal	12	0

(B) FOR MODEL 2

Category of Use	Surface Type	
	Asphalt Concrete	Surface Treatment
New	9	4
Resurfaced	5	6
Terminal	7	5

(continued)

TABLE 5.16. (CONTINUED)

(C) FOR MODEL 3

Highway Classification	Surface Type	
	Asphalt Concrete	Surface Treatment
Primary	19	14
Secondary	2	1

A Bonferroni multiple comparison test (Ref 30) was selected to compare the pairs of interest in Table 5.17(a). To compare the different levels of the category of use, Table 5.18 was generated. The MS_{error} of model 2 was selected because its data are better distributed (see Table 5.16(b), and $\alpha^* = 0.05 / 3 = 0.017$ was used to determine the t-critical (t_{crit}).

These analyses show that the three effects (C, H, and S) considered in the study for rigid pavements are not significant. More specifically, in rigid pavements the three categories of use (New, Resurfaced, and Terminal) are statistically equivalent, the two types of highways (Principal and Secondary) are also statistically equivalent, and there are no statistical differences between the two surface types (Jointed and Continuous).

ANALYSIS OF THE VARIABILITY OF THE SERVICEABILITY INDEX

The coefficient of variation (CV) was selected for the variability analysis of the serviceability index, mainly because when CV ≤ 0.30, it has approximately a chi-square distribution with "n-1" degree of freedom (Ref 31). Figure 5.7 presents the coefficient of variation of the sections. From the total of 142 of those sections, only six sections had a CV > 0.30. Hence it is concluded that the CV is approximately normally distributed, and the ANOVA can be run on these data. The model used to run the analysis of variance is

$$CV_{ijkl} = \mu + R_i + P_j + R^*P_{ij} + C_k + R^*C_{ik} + P^*C_{jk} + R^*P^*C_{ijk} + \varepsilon_{(ijk)l}$$

where

CV_{ijkl} = coefficient of variation of a section located in region i, for the pavement type j, and the category of use k

All the other factors are already described in this chapter.

This part of the study considers two analyses, the first using all the sections (n=142), including those six sections with a CV > 0.30, and the second using only those sections which have CV< 0.30 (n = 136).

TABLE 5.17. MEAN SI VALUES FOR RIGID PAVEMENTS

(A) CATEGORY OF USE

New (A)		Resurfaced (B)		Terminal (C)	
n	mean	n	mean	n	mean
12	3.78	11	3.88	12	3.54

(B) HIGHWAY CLASSIFICATION

Principal		Secondary	
n	mean	n	mean
33	3.77	3	3.33

(C) SURFACE TYPE

Principal		Secondary	
n	mean	n	mean
33	3.77	3	3.33

TABLE 5.18. BONFERRONI MULTIPLE COMPARISON TEST FOR CATEGORY OF USE

Nº	Pair	$y_i - y_j$	$s_{\bar{y}}$	t	t_{crit}	Significant $\alpha = 0.05$
1	A-B	-0.10	0.1846	-0.543	-2.612	NO
2	C-A	-0.24	0.1800	-1.333	-2.601	NO
3	C-B	-0.34	0.1841	-1.847	-2.612	NO

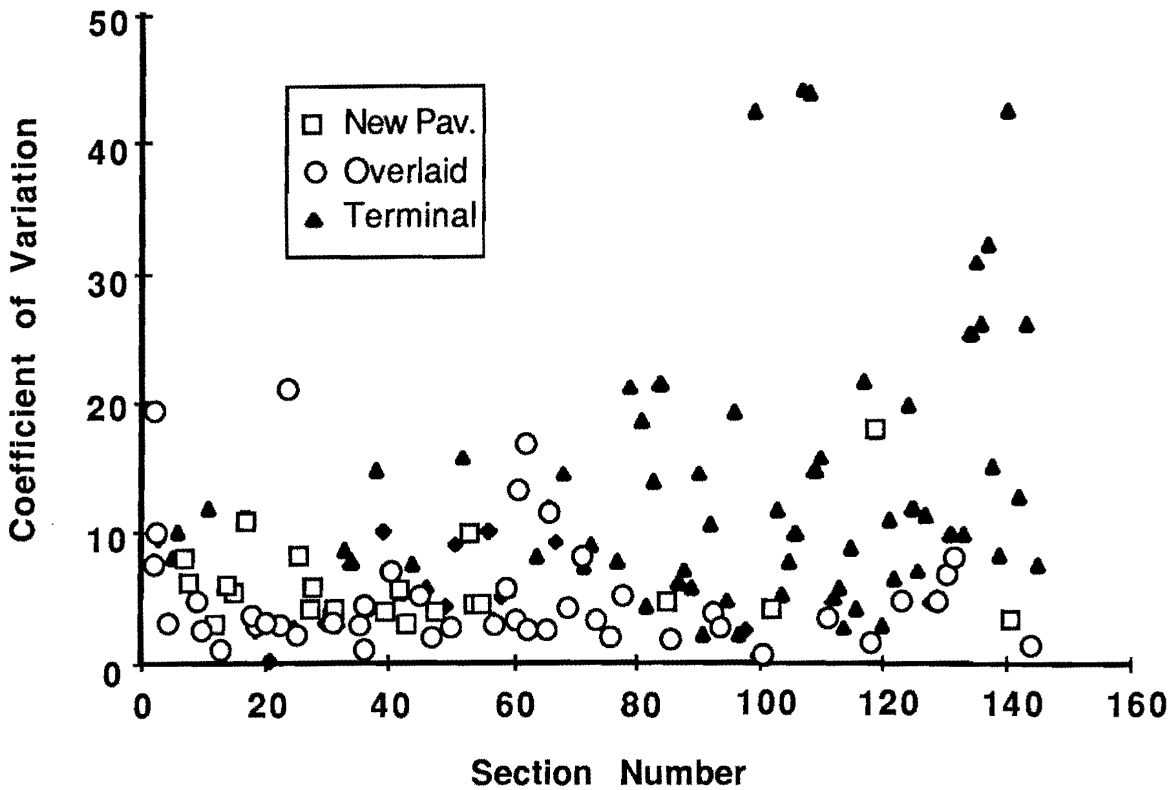


Fig 5.7. Coefficient of variation of the SI of the sections.

Variability Analysis Using All Sections

The ANOVA output generated using the model above is presented in Table 5.19. The F-statistic tests for these factors and their interactions are shown in Table 5.20.

To analyze these results, we will study the interaction between pavement type and category of use. Table 5.21 shows the mean of that combination. Figure 5.8 displays the CV-means presented in Table 5.21.

A Bonferroni multiple comparison test (Ref 30) was selected to compare the pairs of means in Fig 5.8. The results of this multiple comparison test (one tail test) are shown in Table 5.22 (MS_{error} = 50.357 from Table 5.19).

Variability Analysis Using Only Those Sections With CV < 0.30

The GLM procedure was run with the model used in the previous analysis but using only those sections which have CV < 0.30 (n=136), and the ANOVA output is presented in Table 5.23. Finally, the F-statistic tests for these factors and their interactions are presented in Table 5.24.

For the previous analysis, the significant interaction should be studied more carefully. Table 5.25 shows the CV-means of the pavement type and category of use combination. Figure 5.9 displays the CV-means presented in Table 5.25.

A Bonferroni multiple comparison test (Ref 30) was selected to compare the pairs of CV-means presented in Fig 5.9. The results of this multiple comparison test (one tail test) are shown in Table 5.26 (MS_{error} = 22.565 from Table 5.23).

Comparison of Both Analyses

The only difference between these two analyses is the mean CV for flexible pavements in terminal condition. Tables 5.22 and 5.26 show no difference in the results of the multiple comparison test. Therefore, we will use the results obtained in the first analysis for the final interpretation of the results, because it has more observations than the second analysis.

TABLE 5.19. ANOVA TABLE FOR THE COEFFICIENT OF VARIATION (n=142)

Source of Variance	d.f.	SS	MS
R	3	212.720	70.907
P	1	234.985	234.985
R*P	3	33.624	11.208
C	2	522.775	261.388
R*C	6	78.754	13.126
P*C	2	337.167	168.584
R*P*C	5	199.042	39.808
Error	119	5992.476	50.357

TABLE 5.20. F-TEST FOR THE COEFFICIENT OF VARIATION (n=142)

Source of Variance	F-test	Fcrit(0.10)	Significance at α = 0.10
R	1.41	2.68	NO
P	4.65	3.92	YES
R*P	0.22	2.68	NO
C	5.17	3.07	YES
R*C	0.26	2.17	NO
P*C	3.34	2.03	YES
R*P*C	0.79	2.29	NO

TABLE 5.21. MEANS FOR THE INTERACTION BETWEEN P AND C (CV-PERCENT, n=142)

Category of Use	Pavement Type					
	Rigid Pavements			Flexible Pavements		
	n	mean	Ident.	n	mean	Ident.
New	13	5.81	A	8	5.89	B
Resurfaced	11	6.16	C	45	4.81	D
Terminal	12	5.56	E	53	14.96	F

TABLE 5.22. MULTIPLE COMPARISON TEST FOR THE MEANS IN FIG 5.8

Nº	Pair	$y_i - y_j$	$s_{\bar{y}}$	t	t_{crit}	Significant $\alpha = 0.05$
1	A-B	-0.08	2.1346	-0.037	-2.822	NO
2	C-D	-1.35	1.5978	-0.845	-2.666	NO
3	E-F	-6.30	1.5364	-4.100	-2.632	YES
4	D-B	-1.08	1.8227	-0.593	-2.667	NO
5	B-F	-5.97	1.8168	-3.286	-2.632	YES
6	D-F	-7.05	0.9907	-7.116	-2.594	YES
7	A-C	-0.35	1.9461	-0.180	-2.782	NO
8	E-A	-0.25	1.9016	-0.131	-2.793	NO
9	E-C	-0.60	1.9829	-0.303	-2.770	NO

TABLE 5.23. ANOVA TABLE FOR THE COEFFICIENT OF VARIATION (n=136)

Source of Variance	d.f.	SS	MS
R	3	142.685	47.562
P	1	125.767	125.767
R*P	3	19.104	6.368
C	2	277.999	139.000
R*C	6	73.061	12.177
P*C	2	151.549	75.775
R*P*C	5	138.699	27.740
Error	113	2549.828	22.565

TABLE 5.24. F-TESTS FOR THE COEFFICIENT OF VARIATION (n=136)

Source of Variance	F-test	Fcrit(0.10)	Significance at α = 0.10
R	2.11	2.69	NO
P	5.57	3.93	YES
R*P	0.28	2.69	NO
C	6.16	3.08	YES
R*C	0.54	2.18	NO
P*C	3.36	3.08	YES
R*P*C	1.23	2.30	NO

TABLE 5.25. MEANS FOR THE P AND C COMBINATION (CV-PERCENT, n=136)

Category of Use	Pavement Type					
	Rigid Pavements			Flexible Pavements		
	n	mean	Ident.	n	mean	Ident.
New	13	5.81	A	8	5.89	B
Resurfaced	11	6.16	C	45	4.81	D
Terminal	12	5.56	E	47	11.86	F

TABLE 5.26. MULTIPLE COMPARISON TEST FOR THE MEANS IN FIG 5.9

Nº	Pair	$y_i - y_j$	$s_{\bar{y}}$	t	t_{crit}	Significant $\alpha = 0.05$
1	A-B	-0.08	2.1346	-0.037	-2.822	NO
2	C-D	-1.35	1.5978	-0.845	-2.666	NO
3	E-F	-6.30	1.5364	-4.100	-2.632	YES
4	D-B	-1.08	1.8227	-0.593	-2.667	NO
5	B-F	-5.97	1.8168	-3.286	-2.632	YES
6	D-F	-7.05	0.9907	-7.116	-2.594	YES
7	A-C	-0.35	1.9461	-0.180	-2.782	NO
8	E-A	-0.25	1.9016	-0.131	-2.793	NO
9	E-C	-0.60	1.9829	-0.303	-2.770	NO

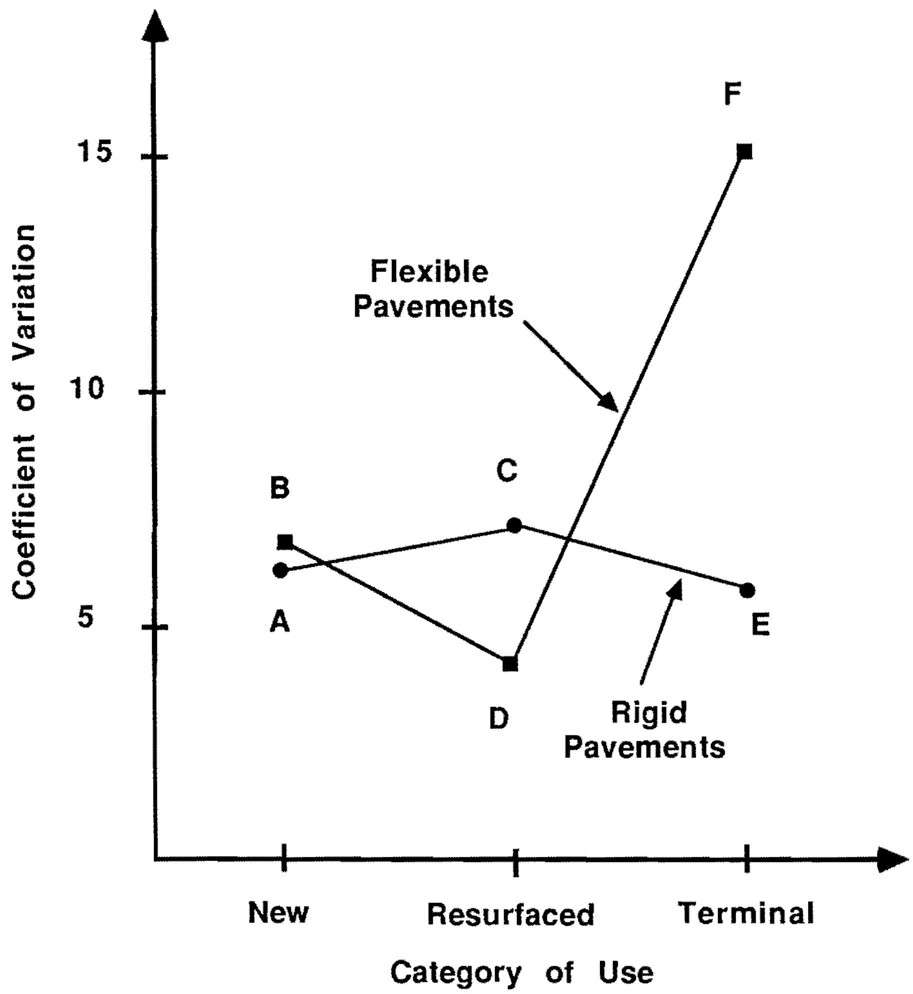


Fig 5.8. Pavement type and category of use CV–interaction (n = 142).

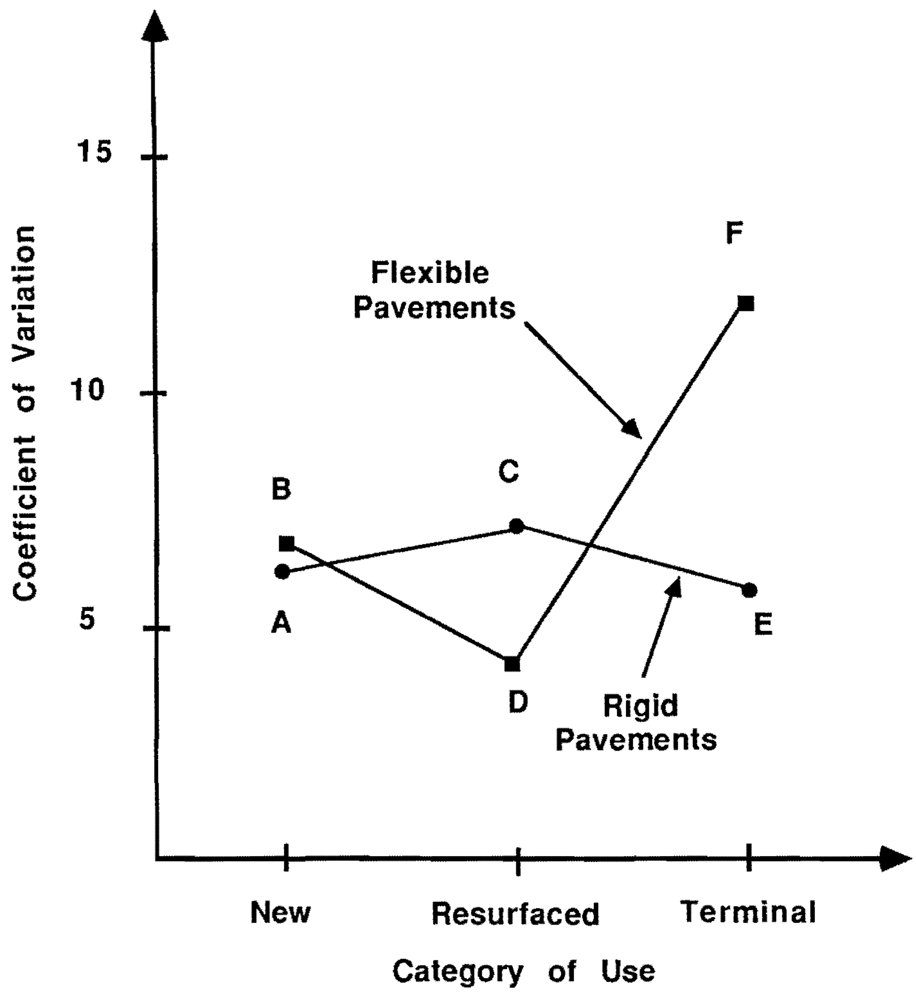


Fig 5.9. Pavement type and category of use CV–interaction (n = 136).

CHAPTER 6. DISCUSSION OF THE RESULTS

INTRODUCTION

The previous chapter reported the statistical analysis of the data collected during the study. This chapter focuses on the interpretation of the results obtained and presented in Chapter 5. It should be pointed out that there is no such thing as a random sample for a study such as this. Pavements were located and measured as available. It is possible that "problem pavements" were more prevelant in the data than desired.

Step 3 of the analysis concluded (Table 5.6) that climatic region has no significant influence on the variation of the serviceability index around the State of Texas. This conclusion agrees very well with the initial supposition, that the climatic zone seemed not to be connected with the quality of new or overlaid pavements or how the engineers decide when to overlay a pavement. However, the climatic regions were included in the analysis to provide a broader inference space for the results.

All cells in the factorial were filled except the one corresponding to new flexible pavements located in Region I and the category of use "reconstruction". Therefore, the conclusions obtained herein are generally good inferences for the State of Texas.

This chapter first presents a discussion of the results obtained for flexible pavements, followed by an interpretation of the results for rigid pavements then a discussion of the variability of the serviceability index within sections. Finally, a comparison among the SI values found in this research and the SI values reported in previous studies is presented.

FLEXIBLE PAVEMENTS

The analysis presented in Fig 5.5 and Table 5.10 shows that the following pairs of average SI are statistically different: (1) the average terminal SI of flexible pavements located on principal highways is higher than average terminal SI of flexible pavements located on secondary highways, (2) SI of new flexible pavements located on principal highways is higher than terminal SI of flexible pavements located on principal highways, (3) SI of resurfaced pavements located on principal highways is higher than the terminal SI of pavements located on principal highways, and (4) SI of resurfaced pavements located on secondary roads is higher than the terminal SI of pavements located on secondary roads.

Furthermore, from the same figure and table, we may infer that the following pairs of average SI are statistically equivalent: (1) SI of new flexible pavements located on principal highways and SI of new flexible pavements located on secondary highways (2) SI of resurfaced flexible pavements located on principal highways and SI of resurfaced flexible pavements located on secondary highways , (3) SI of new flexible pavements located on principal highways and SI of resurfaced flexible pavements located on principal highways, (4) SI of new flexible pavements located on secondary highways and SI of resurfaced flexible pavements located on secondary highways, and (5) SI of new flexible pavements located on secondary highways and terminal SI of flexible pavements located on secondary highways.

On the other hand, the analysis presented in Fig 5.6 and Table 5.12 shows that the following pairs of average SI are statistically different: (1) SI of resurfaced flexible pavements with asphalt concrete is higher than SI of resurfaced flexible pavements with surface treatment, (2) SI of new asphalt concrete pavements is higher than terminal SI of asphalt concrete pavements, (3) SI of resurfaced flexible pavements with asphalt concrete is higher than terminal SI of asphalt concrete pavements.

Furthermore, same figure and table shows that the following pairs of average SI are statistically equivalent: (1) SI for new asphalt concrete pavements and SI for new surface treatment pavements, (2) terminal SI for asphalt concrete pavements and terminal SI for surface treatment pavements, (3) SI of new asphalt concrete pavements and SI of resurfaced pavements, (4) SI of new surface treatment pavements and SI of pavements resurfaced with surface treatment, (5) SI of new surface treatment pavements and terminal SI of surface treatment pavements, and (6) terminal SI of surface treatment pavements and SI of pavements resurfaced with surface treatment.

Therefore, the conclusions for flexible pavements are (1) principal highways, in general, have a better average riding quality than secondary roads and (2) surface treatment does not improve the riding quality of a road.

The average SI values for flexible pavements found in the analysis are summarized in Table 6.1.

TABLE 6.1. AVERAGE SI VALUES OBSERVED FOR FLEXIBLE PAVEMENTS

(A) CATEGORY OF USE AND HIGHWAY CLASSIFICATION

Category of Use	Highway Classification	
	Primary Mean	Secondary Mean
New	4.0	3.0
Resurfaced	3.9	3.5
Terminal	3.2	2.8

(B) CATEGORY OF USE AND SURFACE TYPE

Category of Use	Surface Type	
	Asphalt Concrete Mean	Surface Treatment Mean
New	4.0	3.0
Resurfaced	4.0	2.9
Terminal	3.2	2.9

RIGID PAVEMENTS

The average SI values observed for rigid pavements are shown in Tables 6.2. The SI values of new, resurfaced, and terminal pavements are similar to each other, because the terminal condition has a high serviceability index. This situation is due, mainly, to the characteristic of the performance curve of rigid pavements and the criteria used by the engineers to decide when a rigid pavement needs rehabilitation. Figure 6.1 clarifies this concept. The main conclusion for rigid pavements is that the three levels of category of use on rigid pavements seem to be statistically equivalent. In other words many rigid pavements are rehabilitated for preventative reasons. It is generally conceded that early rehabilitation ie economical than waiting for total failure or very low SI.

VARIATION OF THE RIDING QUALITY WITHIN SECTION

The variation within a section was studied using the coefficient of variation (CV) of the SI values obtained in that particular section. According to Fig 5.8, the following pairs are statistically different: (1) CV for terminal rigid pavements is smaller than CV for terminal flexible pavements, (2) CV of new flexible pavements is smaller than CV for terminal flexible pavements, and (3) CV of resurfaced flexible pavements is smaller than CV of terminal flexible pavements. All the other combinations presented in Fig 5.8 show no significant differences.

The conclusions for the variability of the riding quality within sections are (1) rigid pavements have low variability at all three categories of use (new, resurfaced, and terminal); (2) terminal flexible pavements show an important variation in serviceability index; and (3) both rigid and flexible pavements have a low variability in the categories "new" and "resurfaced".

TABLE 6.2. AVERAGE SI VALUES FOR RIGID PAVEMENTS

(A) CATEGORY OF USE

Category of Use	Average SI - value
New	3.8
Resurfaced	3.9
Terminal	3.5

(B) HIGHWAY CLASSIFICATION

Highway Classification	Average SI - value
Principal	3.8
Secondary	3.3

(C) SURFACE TYPE

Surface Type	Average SI - value
Jointed	3.7
Continuous	3.7

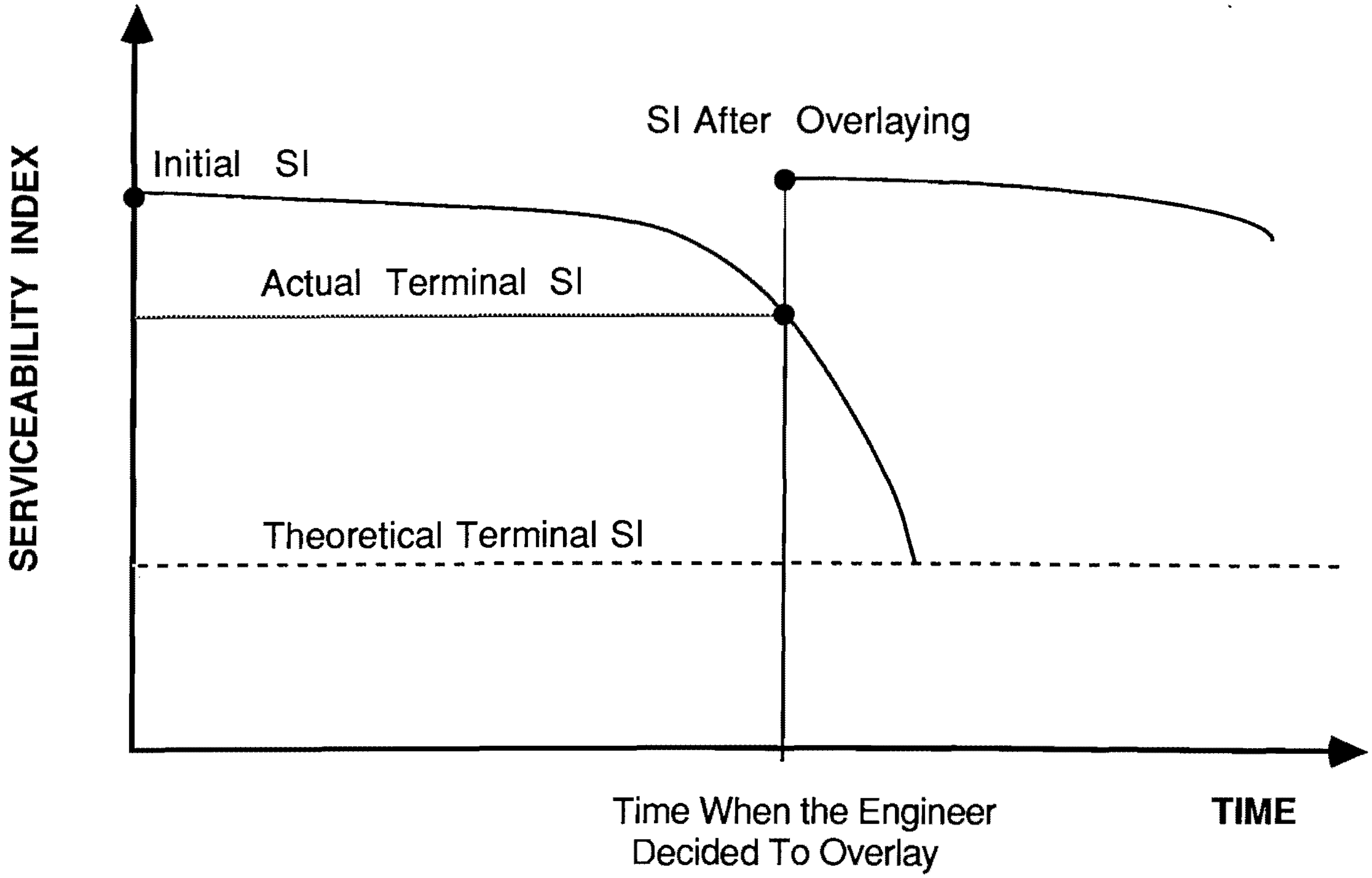


Fig 6.1. Location of the serviceability indices on the performance curve of a rigid pavement.

COMPARISON OF SI VALUES

This part of the chapter presents a comparison among the SI values obtained in this study and the SI values recommended in the literature. A summary of the previous SI values was discussed in Chapter 2.

SI of New Pavements

Table 6.3 summarizes the new SI values recommended by AASHTO (Ref 2), the State of Texas (Ref 3), and this study. The last row of this table shows the difference in percentage between the SI obtained in this research and the SI previously recommended by the State of Texas.

This table shows that the SI assumed for the design of new pavements is generally not achieved in the field. For flexible pavements, the difference between the average SI value found in this study and the SI recommended in the Texas design manual is only about 5 percent for asphalt concrete surface, but it increases to 21 percent for surface treatments. For rigid pavements the difference in riding quality between the average SI found in this study and the SI recommended in the manual is, in general, higher than for flexible pavements. For continuous pavements (CRCP), the average SI found in this study is 20 percent lower than the SI recommended in the Texas design manual.

SI of Resurfaced Pavements

Table 6.4 summarizes the SI values recommended by the State of Texas (Ref 3) and the SI values found in this research. The State of Texas does not make any special recommendation for resurfaced pavements. The Texas design manual suggests treating them as new pavements. Therefore, Table 6.4 contains the same values as Table 6.3 in the row corresponding to the State of Texas.

For resurfaced pavements, in general, the present rehabilitation techniques do not produce pavements with the riding quality assumed in the design models.

For flexible pavements, the difference between the SI value found in this research and the SI assumed for design is not so critical for asphalt concrete pavements, but it is important

TABLE 6.3. COMPARISON OF NEW SI BY PAVEMENT TYPE

AGENCY	FLEXIBLE		RIGID	
	Asphalt Concrete	Surface Treatment	Jointed	Continuous
(1) AASHTO	4.2	---	4.5	---
(2) Texas (T)	4.2	3.8	4.5	4.8
(3) This Study (S)	4.0	3.0	3.8	3.8
Δ [S - T] (%)	-5%	-21%	-16%	-20%

TABLE 6.4. COMPARISON OF RESURFACED SI BY PAVEMENT TYPE

AGENCY	FLEXIBLE		RIGID	
	Asphalt Concrete	Surface Treatment	Jointed	Continuous
(1) Texas (T) (2) This Study (S)	4.2 4.0	3.8 2.9	4.5 3.9	4.8 3.9
Δ [S - T] (%)	-5%	-24%	-13%	-19%

for surface treatment where this difference averages 24 percent lower. For rigid pavements with an asphalt concrete overlay, the difference is 19 percent .

SI of Terminal Pavements

Table 6.5 presents a summary of the terminal SI recommended in previous studies and compares them with the SI obtained in this study. The previous terminal SI values shown in this table are recommended by AASHTO (Ref 2), BPR (Ref 20), CTR (Project 354 - Ref 21), and the State of Texas (Ref 3).

This table shows that the Texas standards recommend higher terminal SI than the terminal SI recommended by AASHTO. The terminal SI values found in the field study are higher than the SI recommended by the State of Texas. This may be due to many factors but most likely reflects engineering attempts to rehabilitate or maintain pavements before they become extremely bad. Early rehabilitation results in stronger pavements at less expense.

TABLE 6.5. COMPARISON OF TERMINAL SI BY PAVEMENT TYPE

AGENCY	FLEXIBLE		RIGID
	Primary	Secondary	Primary
(1) AASHTO	2.5	2.0	2.5
(2) BPR	2.1	1.8	2.2
(3) Project 354	3.1	2.2	3.1
(4) Texas (T)	3.0	2.5	3.0
(5) This Study (S)	3.2	2.8	3.5
Δ [S - T] (%)	+7%	+12%	+17%

CHAPTER 7. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

INTRODUCTION

The main objective of this study was to determine realistic estimates of the riding quality of the Texas highway system to be used in the Texas pavement management activities. Three levels of riding quality were selected for study: new pavements, resurfaced pavements, and terminal pavements.

This chapter is divided in two sections. The first part summarizes the findings and the conclusions obtained during the study. The second part presents recommendations for use and further study.

FINDINGS AND CONCLUSIONS

The findings and conclusions reflect four categories: (a) general findings about the serviceability index, (b) conclusions about flexible pavement riding quality , (c) conclusions about rigid pavements riding quality, and (d) conclusions about the variability of the serviceability index.

General Findings

The findings of this research are summarized below. They reflect accurately the field observations made in this study. It is important to note however that other pavements may yield other results. It's difficult to obtain a balanced sample or a random sample for such measurements.

(1) Serviceability Index For New Pavements: When the pavement is located on a principal highway, the average initial serviceability index observed was 4.0 for flexible pavements and 3.8 for rigid pavements. For secondary roads, the observed SI was 3.0 and for new surface treatments it was 3.0.

(2) Serviceability Index After Resurfacing: When the pavement was located on a principal highway, the serviceability index of resurfaced pavements was observed to be 4.0 for flexible pavements and 3.9 for rigid pavement resurfaced with asphalt concrete. For secondary roads, the observed SI was 3.5. When a surface treatment is used to resurface a pavement, the SI was 2.9.

(3) Minimum Serviceability Index: When the pavement is located on a principal highway, the minimum observed serviceability index was 3.2 for flexible pavements and 3.5 for rigid pavements. For secondary roads, the observed SI was 2.8. The terminal SI for surface treatment pavements was 2.9.

(4) Climatic regions had no observable effect on the variability of the observed serviceability index in the State of Texas.

(5) The riding quality is an excellent index to use as a criterion for rehabilitation programs on flexible pavements. However, the SI must be combined with other parameters (e.g., condition data and/or structural evaluation) to have a better criterion for rehabilitation programs on rigid pavements.

(6) The initial serviceability index (p_i) used at the present time by the Texas State Department of Highways and Public Tranportation in its pavement design system is higher than the average SI observed in the field. This true values are 5 percent lower for asphalt concrete pavements and 20 percent for rigid pavements.

(7) The serviceability index after resurfacing (p_o) used at the present time by the Texas State Department of Highways and Public Transportation in its pavement design system is higher than the average SI observed in the field by 5 percent for asphalt concrete pavements and by 19 percent for rigid pavements.

(8) The minimum serviceability index (p_t) used at the present time by the Texas State Department of Highways and Public Transportation in its pavement design system is lower than the average SI observed in the field by 7 percent for asphalt concrete pavements and by 17 percent for rigid pavements.

Conclusions About Flexible Pavements

The conclusions obtained in this research about the serviceability index on flexible pavements can be summarized as follows:

(1) Application of a surface treatment does not improve the riding quality of pavements, but application of an asphalt concrete overlay does generally improve riding quality.

(2) Primary highways, in general, have a better average riding quality than secondary roads.

Conclusions About Rigid Pavements

The conclusions obtained in this research about the serviceability index of rigid pavements can be summarized as follows:

(1) The observed differences in riding quality among the three levels of the category of use in rigid pavements (new, resurfaced, and terminal) were not significantly different.

(2) The study shows no differences in riding quality between jointed pavements and continuous pavements.

Conclusions About the Variability of the Serviceability Index Within a Pavement Section

The conclusions obtained in this research about the variability of the serviceability index within a pavement section or project can be summarized as follows:

(1) Rigid pavements do not show a significant within-section variability in the three categories of use analyzed.

(2) Flexible pavements show an important within-section variability for terminal level pavements.

(3) The within-section variability of resurfaced flexible pavements is, in general, smaller than the within-section variability of resurfaced rigid pavements.

(4) Both rigid and flexible new pavements have low within-section variability.

RECOMMENDATIONS

The following recommendations result from the findings of this study:

(1) It is suggested that the SI values found in this study be implemented in all Texas pavement management activities.

(2) It is not necessary to divide the State of Texas by climatic regions when analyzing riding quality.

(3) Surface treatments are not recommended for rehabilitation where the need is to improve the riding quality of a pavement.

(4) The coefficient of variation (CV) of the SI of a pavement section could be used in the decision making process when alternatives for rehabilitating flexible pavements are compared.

(5) The CV of the SI of a pavement section could be used in quality control effects for new rigid and flexible pavements.

Special Note

It is useful to note that the results reported in this study reflect accurately the pavements observed, however it is not possible to say whether or not these observed conditions are truly reflective of the average statewide conditions in Texas. The results are considered to be useful but should not be taken as absolute.

REFERENCES

1. Carey, W. N., and P. E. Irick, "The Pavement Serviceability Perfomance Concept," Highway Research Bulletin Nº 250, Highway Research Board, Washington, D.C., 1960.

2. AASHTO Interim Guide for Design of Pavement Structures 1972, Chapter III Revised, 1981, American Association of State Highway and Transportation Officials, Washington, D.C., 1981.

3. "Pavement Design System - Part I : Flexible Pavement Designer's Manual," Highway Design Division, Texas Highway Department, 1972.

4. Kher R. K., W. R. Hudson, and B. F. McCullough, " A System Analysis of Pavement Design and Research Implementation," Research Report 123-5, Highway Design Division, Texas Department of Highways and Public Transportation, Texas Transportation Institute, Texas A&M University, and Center for Highway Research, The University of Texas at Austin, January 1971.

5. Hudson R. W., B. F. McCullough, F. H. Scrivner, and J. L. Brown, "A Systems Approach to Pavment Design and Research." Research Report 123-1, Highway Design Division, Texas State Department of Highways and Public Transportation, Texas Transportation Institute, Texas A&M University, and Center for Highway Research, The University of Texas at Austin, March 1971.

6. Holsen M., and W. R. Hudson, "Stochastic Study of Design Parameters and Lack-of-Fit of Perfomance Model in the Texas Flexible Pavement Design System," Research Report 123-23, Highway Design Division, Texas State Department of Highways and Public Transportation, Texas Transportation Institute, Texas A&M University, and Center for Highway Research, The University of Texas at Austin, April 1974.

7. Haas, R., and W. R. Hudson, Pavement Management System, R. E. Kreiger Publishing Company, Malabar, Florida, 1982.

8. Anderson V. L., R. A. McLean, Design of Experiments. A Realistic Approach, Marcel Dekker, Inc., New York, 1974.

9. "The AASHO Road Test: Report 5 - Pavement Research," Highway Research Board Special Report 61-E, Highway Research Board, National Academy of Sciences, Washington, D.C., 1962.

10. Hudson, W. R., "High-speed Road Profile Equipment Evaluation." Research Report 73-1, Center for Highway Research, The University of Texas at Austin, January 1966.

11. Williamson, H. J., W. R. Hudson, C. D. Zinn, "A Study of Relationships between Various Classes of Road Surface Roughness and Human Ratings of Riding Quality," Research Report 156-5F, Center for Highway Research, The University of Texas at Austin, August 1975.

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

13. Hudson, W. R. , R. Haas, and R. D. Pedigo, "Pavement Management System Development", NCHRP Report Nº 215, Transportation Research Board, November 1979.

14. Pavement Management Principles and Practices. Course Reference Notes, U.S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Implementation Division, Washington, D.C., and Austin Research Engineers, Inc., Austin, Texas, July 1980.

15. Hudson, W. R., E. Ricci, and H. E. de Solminihac, "Un Concepto de Administración de Pavimentos Para Paises en Desarrollo," Segundo Congreso Chileno de Ingeniería de Transporte, Santiago, Chile, November 1985.

16. Lee, H., and W. R. Hudson. "Reorganizing the PMS Concept" Proceedings of the North American Pavement Management Conference. March 1985. Ottawa, Canada.

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

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

19. Claros G. J., W. R. Hudson, C. E. Lee, "Correlation Between the Analog and the Digital Profilometer and the Use of Non-Contact Probes in Road Profiling," Research Report 251-3F, Center for Transportation Research, The University of Texas at Austin, March 1985.

20. Bartelsmeyer R. R., and E. A. Finney, "Use of AASHO Test Findings by The AASHO Committe on Highway Transport," Special Report 73, Highway Research Board, 1962, p 415-438.

21. Nair S. K. , W. R. Hudson, and Clyde E. Lee, "Development of Realistic and Up-to-Date Pavement Serviceability Equations Using the New 690 D Surface Profilometer," Research Report 354-1F, Preliminary Review Copy, Center for Transportation Research, The University of Texas at Austin, August 1985.

22. Elson B. S., and W. J. Kelly, "GMR Road Profilometer - A Method for Measuring Road Profile", Highway Research Record Nº121, pages 27-54, Highway Research Board, Washington, D.C., 1966.

23. "Specification for the Purchase of a Digital Road Profilometer," Texas State Department of Highways and Public Transportation, September 1979.

24. McKenzie D. W., W. R. Hudson, C. E. Lee, "The Use of Road Profile Statistics for Maysmeter Calibration," Research Report 251-1, Center for Transportation Research, The University of Texas at Austin, August 1982.

25. "VERTAC User's Manual - Version 3.1", Center for Transportation Research, The University of Texas at Austin, 1985.

26. Lytton R. L., and A. Garcia-Diaz, " Evaluation of AASHO Road Test Satellite and Environmental Studies," Final Report, Research Foundation Project R. F. 4083, Texas Transportation Institute, Texas, September 1980.

27. Kohler H., Statistics for Business and Economics, Scott, Foreman and Company, Illinois, 1985.

28. SAS User's Guide : Basics, SAS Institute, Inc., Cary, North Carolina, 1985.

29. SAS User's Guide : Statistics, SAS Institute, Inc., Cary, North Carolina, 1985.

30. Neter J., and W. Wasserman, Applied Linear Statistical Models, Richard D. Irwin, Inc., Illinois, 1974.

31. Arversen J. N., "Approximate Confidence Intervals for Coefficients of Variation", Mineograph Series Nº 305, Department of Statistics, Purdue University, September 1972.

APPENDIX A

GENERAL DESCRIPTION AND LOCATION OF THE SECTIONS

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
1	4	2	17	3	1	3	IH45	MP199	MP212	73	APR84
	5	2	17	4	1	3	IH45	MP197	MP182	73	APR84
	6	2	17	4	1	3	IH45	MP167	MP155	74	APR84
	7	2	18	1	1	4	IH30	MP70	MP75	85	MAY84
	8	2	1	1	1	3	SH19	MP2	FM1335	85	MAY84
	14	2	1	1	1	4	US75	TAYLOR ST.	FM691	95	JUL84
	15	2	1	1	1	4	SH503	PARK AVENUE	US75	95	JUL84
	18	2	1	3	1	3	IH30	GREENVILLE	GREENVILLE+	96	JUL84
	24	2	11	3	1	4	US59	TIMPSON	BRADLEY	99	AUG84
	25	2	11	3	1	3	US59	STA 730	STA 680	99	AUG84
	27	1	12	1	2	3	BWY8	CLAYPOOL	VANTAGE	99	AUG84
	28	1	12	1	1	3	US290	LADINO	FM1960	99	AUG84
	33	2	17	4	1	3	IH45	MP151	MP148	74	APR84
	34	1	12	4	1	4	IH10	MP733	HARRIS CO.	106	OCT84
	39	1	12	3	2	4	FM1093	FM723	CRYSTAL GR.	106	NOV84
	42	5	5	1	1	3	IH27	MP9	MP59	108	NOV84
	43	5	5	1	1	3	IH27	FM145	STA186	108	NOV84
	44	5	4	4	1	4	IH40	MP51	MP20	109	NOV84
	45	5	4	3	1	4	IH40	MP16	MP1	109	NOV84

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
1	46	5	4	4	1	4	IH40	MP20	MP50	109	NOV84
	47	5	4	3	1	4	IH40	MP79	MP84	109	NOV84
	48	5	4	1	1	4	IH40	MP146	MP145	109	NOV84
	62	2	17	3	1	3	IH45	MP167	MP156	114	DEC84
	63	2	17	3	1	4	IH45	MP151	MP148	114	DEC84
	85	1	12	1	1	3	SH35	SH288	Culvert	122	MAR85
	91	2	19	4	1	3	IH20	MP599	MP603	123	MAR85
	95	1	12	4	1	3	LP610	ELLIA BLD.	YALE BLD.	127	MAY85
	97	4	13	4	1	3	IH10	MP678	MP681	130	MAY85
	100	1	13	3	1	4	IH10	MP714	MP718	132	JUN85
	101	1	12	4	1	4	IH10	MP730	MP732	132	JUN85
	102	1	12	1	1	3	US290	TELGE DR.	SH6	132	JUN85
	119	1	12	1	2	3	MH49	SECTION A	SECTION B	140	AUG85
	120	1	20	4	1	4	US90	MP2	MP6	140	AUG85
	141	4	13	1	1	3	SH71	ST. MARK 972	ST. MARK 1079	150	FEB86
	144	4	13	3	1	3	LP175	MP4 (SB)	MP6 (SB)	150	FEB86
	145	4	13	4	1	3	LP175	MP4 (NB)	MP6 (NB)	150	FEB86

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
2	1	5	17	3	1	1	SH36	FM2269	STA790	71	APR84
	2	4	15	3	1	1	IH35	MP225	MP252	72	APR84
	3	4	15	3	1	1	IH35	223 EXIT	225A EXIT	72	APR84
	9	4	15	3	1	1	SH16	FM1604	TWIN RISE	89	APR84
	10	4	15	3	1	1	IH37	MP109	MP105	89	APR84
	11	2	9	4	1	1	SH14	MP6	E. POLE (MP2)	90	JUN84
	12	5	14	1	1	1	SH71	SMITHVILLE	CR127	94	MAY84
	13	5	13	3	1	1	SH71	CR127	CR126	94	MAY84
	16	5	9	2	1	1	IH35	MP340	MP354	95	JUL84
	17	2	1	1	2	2	ROAD 3	SEC A1	SEC B2	96	JUL84
	19	5	6	3	1	1	IH20	SH158	MP137	97	JUL84
	20	5	6	3	1	1	IH20	MP98	MP92	97	JUL84
	21	5	6	3	1	1	IH20	MP90	MP89	97	JUL84
	22	5	6	3	1	1	IH20	MP88	MP87	97	JUL84
	23	5	6	3	1	1	IH20	PECOS EAST	PECOS WEST	98	JUL84
	26	2	11	1	1	1	US59	US259	CENTRAL FREI	99	AUG84
	29	4	16	4	1	1	SH359	FM1554	FM1554+	100	AUG84
	30	4	16	3	1	1	SH359	ROAD 20	FM1554	100	AUG84
	31	4	16	1	1	1	SH77	SEC 1	SEC 5	100	AUG84

P	Sec	R	D	C	H	S	Road	From	To	LOG	Date
2	32	4	16	3	1	1	IH37	MP18	MP40	100	AUG84
	35	1	12	3	1	1	FM1092	HAMPTON DR.	COUNTY PL.	106	OCT84
	36	1	12	3	1	1	SH6	DALLAS DR.	MP0	106	OCT84
	37	1	12	3	1	1	SH6	MP0	MP10	106	OCT84
	38	1	12	4	2	1	FM359	BLAIS RD.	MP10	106	OCT84
	40	2	9	1	1	1	LP340	US77	FM3400	107	OCT84
	41	2	9	3	1	1	SH14	MP6	MP2	107	OCT84
	49	5	25	3	2	2	FM592	FM1906	MP12	109	NOV84
	50	5	25	3	1	1	US83	MP0	MP4	109	NOV84
	51	5	25	3	1	1	US82	DICKENS	MP26	109	NOV84
	52	5	25	4	1	1	US82	MP26	MP30	109	NOV84
	53	5	8	1	2	2	FM18	MP12	MP14	111	DEC84
	54	5	8	1	2	2	US277	MP14	N. HASKEL	111	DEC84
	55	5	3	1	1	1	US287	FM1288	MP0	111	DEC84
	56	5	3	3	1	2	US82	MP26	MP22	111	DEC84
	57	5	8	3	1	1	IH20	MP198	MP205	112	DEC84
	58	5	8	3	1	1	IH20	MP230	MP234	112	DEC84
	59	5	8	4	1	1	IH20	MP248	MP243	112	DEC84
	60	5	8	3	1	1	IH20	MP254	MP250	112	DEC84

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
2	61	5	8	3	2	2	FM126	MP6	MP10	112	DEC84
	64	1	12	4	1	1	SH105	MP8	MP20	114	DEC84
	65	1	12	3	1	1	LP336	MP4	MP6	114	DEC84
	66	2	12	3	2	2	FM1485	MP8	MP2	114	DEC84
	67	2	12	3	2	1	FM2090	MP12	LIBERTY C/L	114	DEC84
	68	1	12	4	2	2	FM1942	MP8	MP2	114	DEC84
	69	1	12	3	2	1	FM646	MP6	MP8	115	DEC84
	70	4	15	4	1	1	LP453	NACODG.ST.	GARDEN ST.	116	JAN85
	71	4	15	4	1	1	SH16	ECKHERT RD.	C.BANDERO	116	JAN85
	72	4	15	4	2	2	FM2779	MP2	MP10	116	JAN85
	73	4	16	4	1	2	US59	MP30	MP16	116	JAN85
	74	4	21	3	1	1	US281	FALFURRIAS	BROOKS	117	JAN85
	75	4	21	2	2	1	FM510	LAGUNA VISTA	CULVERT	118	JAN85
	76	4	21	3	1	1	US83	McOULLUGH ST.	MP20	118	JAN85
	77	4	21	4	1	1	US83X	MP46	MP0	118	JAN85
	78	4	21	3	1	1	IH35	MP37	MP20	118	JAN85
	79	5	14	4	2	1	FM1325	HOWARD LANE	PARMER LANE	116	JAN85
	80	5	14	4	2	1	ATS	SEC 6	SEC 6 +	116	JAN85
	81	5	14	4	2	1	FM1431	AVENUE K	AVENUE N	116	JAN85

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
2	82	5	14	4	1	1	SH 29	MP18	MP10	116	JAN85
	83	2	12	4	2	1	FM1485	MP2	MP2 +	114	DEC84
	84	1	13	4	1	2	SH60	MP34	Magnet(MP30)	122	MAR85
	86	1	12	3	2	1	FM1128	Co. Rd. 91	Dogwood Ave.	122	MAR85
	87	5	14	4	1	1	US290	Geneva St.	Tara Ln.	125	APR85
	88	5	3	4	1	2	US287	MP10	FM174 (MP6)	123	MAR85
	89	2	19	4	1	1	US271	IH30	FM899	123	MAR85
	90	2	19	4	1	2	SH11	Hamilton St.	Hamilton St.	123	MAR85
	92	2	11	4	1	1	US59	MP18	MP10	123	MAR85
	93	2	11	3	1	1	US59	MP10	MP18	123	MAR85
	94	5	14	3	1	1	US183	RIVERA DR.	CEDAR PK.	126	MAY85
	96	4	13	4	1	1	IH10	MP681	MP679	130	MAY85
	98	4	13	3	1	1	IH10	MP701	MP718	130	MAY85
	99	5	14	4	2	1	SLAUGTHT ER	S. FIRST ST.	CHISHOLM ST.	131	JUN85
	103	5	9	4	1	1	SH53	MP0	MP8	136	JUL85
	104	5	9	4	1	1	LP491	FM2417	PARRISH ST.	136	JUL85
	105	2	18	4	1	1	US175	CTTNWOOD	FAIR RD.	136	JUL85
	106	2	10	4	1	2	US80	SH19	MP12	136	JUL85
	107	2	1	4	1	2	SH24	US64	FM64	136	JUL85

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
2	108	2	19	4	1	2	US67	SH8S	SH8N	136	JUL85
	109	2	10	4	1	2	US69	MP8	MP16	136	JUL85
	110	5	4	4	1	2	US287	MP12	MP20	136	JUL85
	111	5	4	3	1	1	US287	MP26	MP30	136	JUL85
	112	5	14	4	2	2	RM152	MP0	MP6	138	JUN85
	113	5	14	4	1	2	US290	MP18	MP24	138	JUN85
	114	4	15	4	1	2	IH35	MP40	MP47	139	AUG85
	115	4	15	4	1	1	IH35	MP43	MP53	139	AUG85
	116	4	21	4	1	1	IH35	MP20	MP37	139	AUG85
	117	1	13	4	1	2	US183	US90A	MP30	140	AUG85
	118	1	13	3	1	1	SH60	MP30	MP34	140	AUG85
	121	1	20	4	1	1	US90	MP2	MP12	140	AUG85
	122	2	17	4	1	2	SH6	MP2	MP12	140	AUG85
	123	5	13	3	1	2	US290	MP2	MP6	140	AUG85
	124	4	15	4	1	2	IH35	MP83	MP91	143	SEP85
	125	4	16	4	2	2	FM1545	MP2	MP3	143	SEP85
	126	4	21	4	1	1	US281	LOPEZ ST.	SH186	143	SEP85
	127	4	21	4	1	2	US281	MP0	MP14	144	SEP85
	128	4	21	3	1	1	US83	FM493	HUTTO RD	144	SEP85

P	Sec	R	D	C	H	S	Road	From	To	Log	Date
2	129	4	21	3	1	1	US281	US281-BUSS	SIUOX RD	144	SEP85
	130	4	21	3	1	1	US281	SIOUX RD.	US281-BUS.	144	SEP85
	131	4	16	4	1	2	SH285	MP2	MP10	144	SEP85
	132	4	16	3	1	1	US77	IH37	D.C.I. CO	144	SEP85
	133	4	16	4	2	1	PR22	ADMIRAL ST.	HUMBLE DR	144	SEP85
	134	1	12	4	2	2	SP28	CR530	MP0	144	SEP85
	135	1	12	4	2	1	LP197	11TH ST (WB)	19TH ST (WB)	144	SEP85
	136	1	20	4	2	1	FM1405	MP6	FM2354	144	SEP85
	137	1	20	4	1	2	SH124	MP4	MP8	144	SEP85
	138	1	20	4	2	2	FM787	MP12	MP14	144	SEP85
	139	4	15	4	1	1	LP453	NAGODGOCHES	GARDEN ST.	116	JAN86
	140	1	12	4	2	1	LP197	11TH (EB)	28TH (EB)	144	SEP85
	142	2	12	4	2	2	FM1314	MP2	MP10	150	FEB86
	143	2	12	4	2	2	FM3083	MP2	MP8	150	FEB86

APPENDIX B

ROUGHNESS INFORMATION OF THE SECTIONS

P	Sec	R	D	C	H	S	Obs	SI	C. V.
1	4	2	17	3	1	3	12	4.16	3.2
	5	2	17	4	1	3	12	3.82	7.92
	6	2	17	4	1	3	8	3.65	9.96
	7	2	18	1	1	4	6	3.27	7.85
	8	2	1	1	1	3	4	3.72	6.22
	14	2	1	1	1	4	9	3.93	5.68
	15	2	1	1	1	4	4	3.75	5.6
	18	2	1	3	1	3	16	3.74	3.52
	24	2	11	3	1	4	8	2.97	20.98
	25	2	11	3	1	3	6	3.76	2.56
	27	1	12	1	2	3	2	3.61	3.71
	28	1	12	1	1	3	5	4.07	5.7
	33	2	17	4	1	3	4	3.54	8.64
	34	1	12	4	1	4	11	3.55	7.58
	39	1	12	3	2	4	14	3.7	10.04
	42	5	5	1	1	3	66	3.98	5.29
	43	5	5	1	1	3	2	3.85	2.75
	44	5	4	4	1	4	9	4.09	7.5
	45	5	4	3	1	4	10	4.08	4.86
	46	5	4	4	1	4	9	4.14	5.81
	47	5	4	3	1	4	6	4.22	1.8
	48	5	4	1	1	4	6	3.98	3.61
	62	2	17	3	1	3	7	3.64	16.68
	63	2	17	3	1	4	4	3.96	2.31
	85	1	12	1	1	3	6	4.11	4.56
	91	2	19	4	1	3	6	3.67	1.97
	95	1	12	4	1	3	10	3.34	4.67
	97	4	13	4	1	3	3	3.89	2.08
	100	1	13	3	1	4	2	4.34	0.6
	101	1	12	4	1	4	2	2.77	0.26
	102	1	12	1	1	3	2	4.1	3.89
	119	1	12	1	2	3	8	2.68	17.59
	120	1	20	4	1	4	3	3.35	2.84
	141	4	13	1	1	3	39	4.04	3.09
	144	4	13	3	1	3	3	4.16	1.17

P	Sec	R	D	C	H	S	Obs	SI	C. V.
1	145	4	13	4	1	3	3	2.62	7.48
2	1	5	17	3	1	1	14	2.82	19.47
	2	4	15	3	1	1	12	4	7.84
	3	4	15	3	1	1	7	3.85	9.51
	9	4	15	3	1	1	8	3.65	4.55
	10	4	15	3	1	1	10	4.04	2.56
	11	2	9	4	1	1	8	3.03	11.82
	12	5	14	1	1	1	4	4.11	2.68
	13	5	13	3	1	1	4	4.16	0.82
	16	5	9	2	1	1	14	4.13	5.25
	17	2	1	1	2	2	4	2.16	10.55
	19	5	6	3	1	1	18	4.07	2.4
	20	5	6	3	1	1	8	4.24	3.05
	21	5	6	3	1	1	2	4.37	0.11
	22	5	6	3	1	1	4	4.33	3.06
	23	5	6	3	1	1	26	4.24	2.99
	26	2	11	1	1	1	6	3.99	7.99
	29	4	16	4	1	1	1	3.16	
	30	4	16	3	1	1	10	4.19	2.97
	31	4	16	1	1	1	5	3.84	3.44
	32	4	16	3	1	1	20	4.13	2.79
	35	1	12	3	1	1	6	3.96	2.94
	36	1	12	3	1	1	2	3.84	0.82
	37	1	12	3	1	1	9	4.09	4.16
	38	1	12	4	2	1	10	3.17	14.88
	40	2	9	1	1	1	8	4.25	4.01
	41	2	9	3	1	1	8	3.88	6.73
	49	5	25	3	2	2	6	3.48	4.34
	50	5	25	3	1	1	6	4.08	2.47
	51	5	25	3	1	1	4	3.91	9.01
	52	5	25	4	1	1	2	2.72	15.58
	53	5	8	1	2	2	4	2.81	9.83
	54	5	8	1	2	2	6	3.92	4.31
	55	5	3	1	1	1	6	3.73	4.28
	56	5	3	3	1	2	6	3.01	10.01

P	Sec	R	D	C	H	S	Obs	SI	C. V.
2	57	5	8	3	1	1	8	4.21	3.13
	58	5	8	3	1	1	6	4.11	5.02
	59	5	8	4	1	1	8	3.19	5.58
	60	5	8	3	1	1	6	4.14	2.99
	61	5	8	3	2	2	5	2.74	13.04
	64	1	12	4	1	1	6	3.96	8.03
	65	1	12	3	1	1	6	4.05	2.32
	66	2	12	3	2	2	6	2.44	11.75
	67	2	12	3	2	1	4	3.79	9.31
	68	1	12	4	2	2	8	3.62	14.46
	69	1	12	3	2	1	4	3.99	4.17
	70	4	15	4	1	1	2	1.8	56.26
	71	4	15	4	1	1	6	3.88	8.09
	72	4	15	4	2	2	14	2.99	7.39
	73	4	16	4	1	2	16	3.22	8.88
	74	4	21	3	1	1	6	4.15	3.09
	75	4	21	2	2	1	6	3.73	2.44
	76	4	21	3	1	1	4	3.76	1.8
	77	4	21	4	1	1	28	3.63	7.71
	78	4	21	3	1	1	14	3.96	5.26
	79	5	14	4	2	1	3	3.38	21.1
	80	5	14	4	2	1	1	2.29	
	81	5	14	4	2	1	4	2.84	18.51
	82	5	14	4	1	1	8	3.61	4.29
	83	2	12	4	2	1	2	3.73	13.97
	84	1	13	4	1	2	8	3.74	21.41
	86	1	12	3	2	1	9	4.27	1.84
	87	5	14	4	1	1	2	3.52	5.98
	88	5	3	4	1	2	8	3.59	6.99
	89	2	19	4	1	1	6	2.97	5.75
	90	2	19	4	1	2	2	2.77	14.59
	92	2	11	4	1	1	5	3.46	10.47
	93	2	11	3	1	1	5	3.98	3.7
	94	5	14	3	1	1	6	3.79	2.53
	96	4	13	4	1	1	2	3.55	19.3

P	Sec	R	D	C	H	S	Obs	SI	C. V.
2	98	4	13	3	1	1	20	4.28	2.35
	99	5	14	4	2	1	2	0.91	42.25
	103	5	9	4	1	1	11	3.69	11.65
	104	5	9	4	1	1	6	3.93	5.18
	105	2	18	4	1	1	7	3.66	7.61
	106	2	10	4	1	2	6	3.43	9.84
	107	2	1	4	1	2	4	1.8	44.1
	108	2	19	4	1	2	6	1.82	43.71
	109	2	10	4	1	2	10	2.68	14.83
	110	5	4	4	1	2	8	2.92	15.73
	111	5	4	3	1	1	8	4.29	3.43
	112	5	14	4	2	2	4	2.91	4.98
	113	5	14	4	1	2	8	3.43	5.68
	114	4	15	4	1	2	8	3.78	2.53
	115	4	15	4	1	1	6	3.65	8.83
	116	4	21	4	1	1	14	3.89	4.07
	117	1	13	4	1	2	2	2.14	21.6
	118	1	13	3	1	1	8	4.21	1.32
	121	1	20	4	1	1	3	2.99	10.89
	122	2	17	4	1	2	10	3.76	6.29
	123	5	13	3	1	2	7	2.67	4.94
	124	4	15	4	1	2	7	2.8	19.62
	125	4	16	4	2	2	6	2.84	11.84
	126	4	21	4	1	1	3	3.17	6.98
	127	4	21	4	1	2	15	3.39	11.14
	128	4	21	3	1	1	8	3.93	4.59
	129	4	21	3	1	1	8	3.85	5.02
	130	4	21	3	1	1	8	3.83	6.54
	131	4	16	4	1	2	10	2.41	9.91
	132	4	16	3	1	1	14	3.65	8.09
	133	4	16	4	2	1	10	3.35	9.88
	134	1	12	4	2	2	4	1.86	25.23
	135	1	12	4	2	1	4	2.99	30.91
	136	1	20	4	2	1	6	2.33	26.06
	137	1	20	4	1	2	8	2.38	32.38

P	Sec	R	D	C	H	S	Obs	SI	C. V.
2	138	1	20	4	2	2	6	3.08	15.04
	139	4	15	4	1	1	2	3.63	8.24
	140	1	12	4	2	1	3	1.88	42.43
	142	2	12	4	2	2	12	2.89	12.71
	143	2	12	4	2	2	10	2.55	26.14

APPENDIX C

TABLE OF ABBREVIATIONS

TABLE OF ABBREVIATIONS

α	Probability of Making a Type I Error
α^*	The a used in the Bonferroni Multiple Comparison Test
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACP	Asphalt Concrete Pavement
ANOVA	Analysis of Variance
A&M	Agricultural and Mechanical
β	Probability of Making a Type II Error
BPR	Bureau of Public Roads
C	Category of Use (variable used in the analysis)
CRCP	Continous Reinforce Concrete Pavement
CTR	Center for Transportation Research
C.V.	Coefficient of Variation
D	District Number
d.f.	Degree of Freedom
ΔSI	Difference Between the Initial and the Terminal SI
EMS	Expected Mean Square
FPS	Flexible Pavement Design System
GMR	General Motor Road (Profilometer)
H	Highway Classification (variable used in the analysis)
Ident.	Identification used in the Interaction Plots

IPSR	Individual Present Serviceability Rating
MS	Mean Square
NID	Normally and Independently Distributed
Obs.	Number of Observations
p	Number of Cells to be Compared in the Q-Homog. Test
P	Pavement Type (variable used in the analysis)
PCA	Portland Cement Association
PCC	Pavement Concrete Cement
PES	Pavement Evaluation System
p_i	Initial Serviceability Index
PMS	Pavement Management System
p_o	Serviceability Index after Overlay
p_t	Terminal Serviceability Index
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
q	Test Statistics for the Q-Homogeneity Test
q_c	Critical value for "q"
R	Climatic Region (variable used in the analysis)
Ref.	Reference
RMSVA	Root Mean Square Vertical Acceleration
RPS	Rigid Pavement Design System
s	Standard Deviation
S	Surface Type (variable used in the analysis)
SS	Sum Square
SAS	Statistical Analysis System

SDHPT	State Department of Highway and Public Transportation
Sec	Section Number
SSec	Sub-Section Number
SI	Serviceability Index
v	Degree of Freedom
$\bar{\nu}$	Harmonic Mean of the Degree of Freedom
VA	Abbreviation for RMSVA
VERTAC	Computer Program to Calculate the RMSVA
w	Test Statistics for the W-Normality Test (Wilk)
W	Relative Displacement Between the Following Road Wheel and the Vehicle Body
w_c	Critical value of "w"
W_f	Measured of the Pavement Profile
z	Displacement of the Vehicle Body
$\ddot{z}$	Acceleration of the Vehicle Body