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16. Abstract

Over the years, funding for maintenance, rehabilitation, restoration, and resurfacing activities has not kept pace with the needs of highway agencies. Consequently, it has become more and more necessary to develop a system for managing the pavement network and, in particular, for assisting highway agencies in the efficient allocation of their resources so as to make the best possible use of the limited funds available. An integral component of any pavement management system is a prioritization procedure for establishing rehabilitation and maintenance activities.

The material reported herein primarily documents a methodology for formulating a prioritization procedure using a method that it is hoped will lead to a more realistic and rational way of establishing candidate projects for priority programming at the network level pavement management system. The method presented is based on a factorial design involving a set of candidate decision variables, such as distress and present serviceability index. For this reason, it has been termed the rational factorial rating method; and its development is presented herein. In addition, the actual application of the method to the formulation of a preliminary prioritization procedure is discussed, together with the results obtained. It is felt that the method may provide a better understanding of how decisions on priorities are made in practice. The method can be applied in a controlled study by the Texas SDHPT or any other agency to develop a prioritization index which represents the ideas and experience of the group being surveyed.

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DEVELOPMENT OF A PRIORITIZATION PROCEDURE FOR THE NETWORK LEVEL PAVEMENT MANAGEMENT SYSTEM

by

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W. R. Hudson

Research Report Number 307-2

Implementation of a Pavement Management System for Texas
Research Project 3-8-81-307

conducted for

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

PREFACE

This is the second report produced under Research Study 307, "Implementation of a Pavement Management System for Texas." The long-range goal of this project is to assist the Texas State Department of Highways and Public Transportation in developing a rational pavement management system (PMS) for all pavement types and to provide for updating the system with continued input of the latest research findings.

This report presents a method for formulating an index for establishing rehabilitation and maintenance priorities at the network level PMS. The method is based on a factorial design involving a set of candidate decision variables, such as distress and present serviceability index. For this reason, it has been termed as the rational factorial rating method, and its application to the problem of formulating a prioritization index is presented herein.

Many people have contributed significantly to this work, and the authors are grateful to them all. In particular, we would like to thank Dr. P. W. John of the Mathematics Department of The University of Texas at Austin for his invaluable assistance in the development of the factorial designs and in the statistical analysis phase of the study. The authors are also grateful to Dr. B. F. McCullough and graduate students at the Center for Transportation Research, particularly David Luhr and Manuel Gutierrez de Velasco, for the valuable comments they have provided. Many thanks are also extended to the numerous highway engineers who participated in the study. In particular, the authors wish to thank Messrs. Robert Mikulin, Richard Rogers, and Robert Guinn for arranging the meetings with Highway Department personnel. Finally, thanks to Lyn Gabbert for her help in typing the manuscript and to Ana Aronofsky for drawing the figures.

E. G. Fernando

W. R. Hudson

LIST OF REPORTS

Report No. 307-1, "Development of an Initial Pavement Management System for Texas," by W. Ronald Hudson, R. D. Pedigo, and E. G. Fernando, describes current PMS experience, presents a recommended structure for the Texas PMS Release 1.0, and suggests areas for future improvement.

Report No. 307-2, "Development of a Prioritization Procedure for the Network Level Pavement Management System," by E. G. Fernando and W. R. Hudson, describes existing methods for formulating a prioritization index, documents the development of the rational factorial rating method as an alternative procedure for formulating an index, and presents a prioritization procedure established through application of the rational factorial rating method.

ABSTRACT

Over the years, funding for maintenance, rehabilitation, restoration, and resurfacing activities has not kept pace with the needs of highway agencies. Consequently, it has become more and more necessary to develop a system for managing the pavement network and, in particular, for assisting highway agencies in the efficient allocation of their resources so as to make the best possible use of the limited funds available. An integral component of any pavement management system is a prioritization procedure for establishing rehabilitation and maintenance activities.

The material reported herein primarily documents a methodology for formulating a prioritization procedure using a method that it is hoped will lead to a more realistic and rational way of establishing candidate projects for priority programming at the network level pavement management system. The method presented is based on a factorial design involving a set of candidate decision variables, such as distress and present serviceability index. For this reason, it has been termed the rational factorial rating method; and its development is presented herein. In addition, the actual application of the method to the formulation of a preliminary prioritization procedure is discussed, together with the results obtained. It is felt that the method may provide a better understanding of how decisions on priorities are made in practice. The method can be applied in a controlled study by the

Texas SDHPT or any other agency to develop a prioritization index which represents the ideas and experience of the group being surveyed.

KEYWORDS: Pavement management systems, pavement management, rehabilitation and maintenance, prioritization index, prioritization procedure, factorial design.

SUMMARY

The establishment of priorities for rehabilitation and maintenance activities is a major function of any network level pavement management system. In connection with this task, the selection of projects for inclusion in a work program is normally made through the use of a procedure that quantifies the degree of adequacy or acceptability of pavement sections on the basis of a set of decision criteria. The ratings obtained may then be used for making decisions on priorities for rehabilitation and maintenance work.

Various methods for priority programming of highway improvements are currently in use, and a review and evaluation of existing procedures for formulating a prioritization index is presented herein. In addition, a comprehensive method of index formulation, known as the rational factorial rating method, is developed. This method is based on a factorial design involving the following variables: (1) degree of distress, (2) present serviceability index, (3) traffic, (4) amount of rainfall, and (5) amount of freeze-thaw. Because the effects of the independent variables can be studied simultaneously, the method may provide a better insight as to how decisions on priorities are affected by each of the variables considered.

The application of the method to the formulation of a preliminary prioritization procedure is presented. Numerous pavement engineers were consulted from both office and field positions in the north and the south,

and a statistical analysis of the responses obtained is made herein. A prioritization procedure is then developed from the results of the analysis. It is recommended that the procedure presented be further tested in order to verify that priority listings obtained from it agree reasonably well with the opinions of engineers who are responsible for establishing priorities for rehabilitation and maintenance work.

This methodology can be applied in a number of ways to assist in devloping priority indices. It is suggested that a comprehensive index be developed by a more complete rating experiment for establishing maintenance programming priorities and also rehabilitation programming priorities.

IMPLEMENTATION STATEMENT

This document presents the development of a method for formulating a procedure for establishing rehabilitation priorities at the network level for Pavement Management. The method, known as the rational factorial rating method, was used to quantify the opinions of numerous pavement engineers from Texas and New York on establishing priorities for rehabilitation work. The raters represented both field and office personnel. A statistical analysis of the responses obtained is presented herein, and a preliminary prioritization procedure is established from the results of the analysis. It is recommended that a trial implementation of the suggested prioritization procedure be made in the near future. Then the methodology should be used on a broader scale within the Texas SDHPT to produce a definitive index for use in pavement evaluation.

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CHAPTER 1. INTRODUCTION

BACKGROUND

The development of systematic procedures for scheduling maintenance and rehabilitation activities is one of the major concerns of state and federal highway agencies today. This is primarily due to the fact that, over the years, funding for maintenance, rehabilitation, restoration, and resurfacing activities has not kept pace with the needs of highway agencies throughout the U.S., resulting in a backlog of projects for many of these agencies. This problem is further compounded by the reduced buying power of the U.S. dollar due to inflation, as a consequence of which the amount of work that can be accomplished with a given amount of money has been significantly reduced. In addition, recent concerns for energy consumption and costs have initiated reconsideration of the direct effect of pavement condition on vehicle operating costs (Ref 1).

These problems that confront highway engineers today demand good management of existing road networks and have led to increased interest in the development and implementation of pavement management systems (PMS) methodology. Broadly defined, pavement management includes the body of systematic and organized procedures and activities for providing and maintaining pavements. These activities range from the initial planning and programming of investments to the design, construction, in-service monitoring, evaluation, maintenance, and rehabilitation of pavements (Ref 1). Basic features of an implemented pavement management system are shown in Fig 1.1. As can be seen, pavement management operates at two levels, the network level and the project level. Activities at the network level are mainly the responsibility of administrators and are primarily connected with the establishment of decisions covering large groups of projects or an entire highway network. On the other hand, activities at the project level are concerned with more specific technical management decisions for individual projects.

Although pavement management, in its present state, is characterized by two distinct levels, it was oriented mainly towards project level activities during the early phases of its development, with design being the focal point (Ref 2). At that time, highway engineers were primarily concerned with providing the best design for each individual project, and network level pavement management consisted only of coordinating the individual projects for the particular program year. With sufficient funds available, this approach to managing pavements worked reasonably well. However, as funding became more limited in the 1970's, and with the shift in emphasis from new construction to the preservation of the existing pavement network, it soon became apparent that evaluation of needs should be made not on a simple project-by-project basis but from considerations of the road network as a whole. Consequently, the network level component became a major, identifiable function in pavement management systems. At this level, inventory data are used to assess network level status and needs, and decisions are made as to which rehabilitation and maintenance projects to include in the coming work program. The selection of candidate projects for rehabilitation and maintenance work is handled through a priority analysis in

NETWORK

- INVENTORY DATA BASE
- ASSESSMENT OF STATUS AND NEEDS
- PRIORITY PROGRAMS OF CAPITAL & MAINT. WORK
- FUNDING LEVEL EVALUATION

PROJECT

- DESIGN METHOD
  - TESTS, MODELS, CRITERIA
  - ECON. ANAL. & OPTIMIZATION
- CONSTR. CONTROL PROCED.
- MAINT. STANDARDS
- AS-BUILT & MAINT. DATA FILES

DOCUMENTATION OF METHODS AND PROCEDURES

Fig 1.1. Key features of an implemented pavement management system (Ref 2).

which inventory data are used to assess the adequacy of pavement sections versus a set of decision criteria. In order to quantify the degree of adequacy or acceptability and to facilitate comparisons between pavement sections, ratings, or scores, are generally calculated for each pavement section using a procedure established within the particular agency involved. The scores so obtained can then be used for establishing priority listings for rehabilitation and maintenance work.

SCOPE OF THE REPORT

The development of a prioritization variable is, a necessary ingredient in the pavement management process, and highway agencies have set up various procedures for determining prioritization indices. This report primarily documents efforts made to formulate a prioritization index using an approach that is expected to lead to a more realistic and rational way of establishing candidate projects for priority programming at the network level PMS. Chapter 2 is a review and an evaluation of several approaches to formulating a prioritization index, made in order to provide background information on existing practices.

Then, the development of a method, known as the rational factorial rating method is discussed (Chapter 3). Essentially, the formulation of an index using this method was based on a fractional factorial design consisting of the following factors: (1) degree of pavement distress, (2) present serviceability index, (3) traffic, and (4) environmental conditions of rainfall and freeze-thaw. The development of the method involved the participation of numerous highway engineers who were asked to give their opinions regarding the establishment of rehabilitation priorities. The responses obtained were then evaluated (Chapter 4) with the hope of gaining a better understanding of the way pavement engineers establish priorities in actual practice. In addition, a prioritization procedure was developed based on the results of the surveys made. A sample application is provided to illustrate how the procedure may be used (Chapter 5). Finally, the conclusions of the study are presented, together with recommendations for future research activities (Chapter 6).

CHAPTER 2. REVIEW AND EVALUATION OF ALTERNATIVE APPROACHES TO FORMULATING A PRIORITIZATION INDEX

INTRODUCTION

An important phase of rehabilitation programming is the establishment of candidate projects for road repair work. In order to carry out this function, numerous highway agencies have developed pavement rating systems to quantify the condition of each road segment in the network. In most cases, a combined rating, or score, is used to express the overall condition of the pavement in terms of a combination of selected attributes. However, there are also rating systems which utilize only a single attribute to quantify pavement condition. As an example, the pavement rating system of New York utilizes only pavement serviceability.

Early efforts at developing pavement rating systems began in 1946, when the Highway Research Board established a Committee on Pavement Condition Surveys in the Department of Design (Ref 3). The work of this committee culminated in the publication in 1957 of HRB Special Report 30, "Pavement Condition Surveys - Suggested Criteria." This report listed the various types of condition surveys and suggested items of information to be recorded for both preliminary and final type surveys. In addition, a comprehensive list of definitions of terms pertinent to pavement condition surveys was published. Then, in 1960, the staff of the AASHO Road Test developed an altogether new concept, the Present Serviceability Index (PSI), which is widely used by many highway agencies today (Ref 4). Finally, in 1962, the Highway Research Board published a procedure for rating the condition of flexible pavements. This procedure assigned numerical deduct values for specific distress types, depending on their extent and severity. A numerical pavement score was computed for a specific road segment by adding up the deduct values and subtracting the sum from an assumed perfect score of 100. This procedure has been adopted by several highway agencies throughout the country and Reference 5 documents pavement rating systems where the procedure is used.

Several other approaches have been used to formulate indices or scores for quantifying pavement condition and for establishing candidate projects for rehabilitation and maintenance programs. The objective of this chapter is to briefly document other studies that were made to formulate a pavement index or score for the purposes stated previously.

REVIEW OF NCHRP RESEARCH REPORT NO. NA - 3/1

Introduction

Research Report No. NA - 3/1, "Simplified Pavement Management at the Network Level," (Ref 6) presents a simplified pavement management system at the network level and provides an example illustrating how the framework can be applied to produce a priority ranking on a network basis. Emphasis herein is placed on describing the procedure used to quantify the adequacy of a pavement section for establishing priorities for rehabilitation work.

Methodology for Formulation of Prioritization Index (PINDEX)

In Research Report NA - 3/1, a methodology for developing an index that can be used to establish rehabilitation priorities at the network level PMS was presented. This index, which was called PINDEX in the report, was developed using a procedure that involved the following steps:

(1) selection of pavement attributes to include in PINDEX,

(2) categorization of the selected pavement attributes,

(3) establishment of numerical values for each category of the pavement attributes, and

(4) establishment of weighting factors with which to adjust calculated values of PINDEX.

In order to illustrate the methodology, the example provided in Research Report No. NA - 3/1 is discussed here.

For simplicity, the set of pavement attributes selected was PSI and severity and extent of fatigue cracking. In actual practice, additional variables may be incorporated in the formulation of PINDEX, depending on particular agency circumstances. However, it should also be kept in mind that the methodology discussed herein is to be applied for programming purposes only and not for any specific rehabilitation design. Consequently, the selection of a few essential pavement attributes (such as PSI and cracking) can be justified.

The next step in the procedure is the categorization of the selected pavement attributes. The categories used are shown in Table 2.1. It is emphasized that the categories established in the table are merely illustrative. In actual practice, the categories are decided upon by a group of experienced highway engineers group within a department.

TABLE 2.1. CATEGORIES OF PAVEMENT ATTRIBUTES USED IN EXAMPLE PROBLEM AND CORRESPONDING NUMERICAL VALUES (Ref 6)

(a) Serviceability

Category	PSI Range	Assigned Numerical Value
Very Good	3.8 - 5.0	6
Good	2.8 - 3.7	20
Fair	2.0 - 2.8	40
Poor	below 2.0	80

(b) Fatigue Cracking

Category	Severity	Extent (Percent)	Assigned Numerical Value
Excellent	Slight	10	2
Very Good	Slight	10 - 25	6
	Moderate or Severe	10	
Good	Slight	25 - 49	20
	Moderate or Severe	10 - 25	
Fair	Slight	50	40
	Moderate or Severe	25 - 49	
Poor	Moderate or Severe	50	80

Following the categorization of the selected pavement attributes, numerical values are assigned to each category. This procedure is very similar to using deduct values except that for this case "additive" values are employed, as shown in Table 2.1. Again, it is noted that those values are assigned on the basis of the subjective judgments of a group of pavement engineers. Using the condition survey information for a particular highway segment, a PINDEX value is computed by summing the pertinent numerical values for that particular road segment. For example, if a pavement belongs to the "Very Good" category in terms of both serviceability and fatigue cracking, the calculated PINDEX value would then be: 6 + 6 = 12. Other possible values of PINDEX for the example problem are summarized in Table 2.2. It should be noted that the higher the value of PINDEX, the higher the priority assigned to a pavement.

The last step in the procedure involves the establishment of weighting factors with which to adjust computed PINDEX values. In the field, conditions are not similar for all highway segments so that it would not be reasonable to compare pavements only on the basis of PINDEX values calculated using the procedure mentioned previously. For example, given two pavements with the same PINDEX value but with different traffic levels, it may not be logical to assign the same priority for both pavements. Instead, the highway segment with the higher traffic level should, be given a higher priority than the one with less traffic. As a consequence, weighting factors are established considering variables such as traffic, functional classification, and amount of rainfall. For the sample problem, prioritization factors (Table 2.3) were established considering functional class and average daily traffic (ADT). Again, it should be mentioned that these factors are established subjectively. A modified PINDEX is then computed by multiplying

TABLE 2.2. POSSIBLE VALUES OF PINDEX FOR SAMPLE PROBLEM (Ref 6)

Fatigue Cracking Category	PSI Category			
	Very Good	Good	Fair	Poor
Excellent	8	22	42	82
Very Good	12	26	46	86
Good	26	40	60	100
Fair	46	60	80	120*
Poor	86	100	120*	160*

*In this example, if PINDEX > 100, replace by PINDEX = 100

TABLE 2.3. EXAMPLE PRIORITIZATION FACTORS BASED ON FUNCTIONAL CLASSIFICATION AND AVERAGE DAILY TRAFFIC (ADT)*

Functional Classification	ADT	Factor
	high	1.00
Interstate	medium	0.95
	low	0.88
	high (> 15,000)	0.93
Principal Arterial	medium (5,000 - 15,000)	0.87
	low (< 5,000)	0.80
	high (>12,000)	0.83
Minor Arterial	medium (4,000 - 12,000)	0.75
	low (< 4,000)	0.68
	high (> 8,000)	0.73
Major Collector	medium (2,000 - 8,000)	0.65
	low (< 2,000)	0.60
	high (> 5,000)	0.60
Minor Collector	medium (1,000 - 5,000)	0.53
	low (< 1,000)	0.45
	high (> 3,000)	0.55
Local	medium (500 - 3,000)	0.45
	low (< 500)	0.35

*After Ref 6

the PINDEX value by the appropriate weighting factor. In addition, priority categories may be established by assigning relative priority rankings to specific ranges of the adjusted PINDEX. For the example, the following priority categories were used:

ADJUSTED PINDEX	PRIORITY CATEGORY
≥ 60	1
≥ 28 but < 60	2
< 28	3

In summary, a simple framework for establishing priority listings at the network level was presented. Because of its simplicity, the methodology may be readily implemented within a highway agency. The method is subjective, but this may be an advantage in that highway personnel can easily relate with it since the numerical values used reflect their own collective judgment. In addition, it is a procedure which can be applied in the absence of objective data with which to construct an index for establishing priority listings. In effect, the framework can be used as a first cut procedure toward establishing priority rankings within an initial PMS, pending the development of more complicated models.

UNIQUE SUMS APPROACH

The unique sums approach is characteristic of a rating system used in Sweden (Ref 7), in which classification of road sections are made with respect to the following variables: (1) pavement wear, (2) deformation (roughness and cracking), and (3) amount of treatment in routine maintenance.

For each variable, four levels were established which are indicative of the extent of distress, and, for each level, a class number and a rating are assigned, as shown in Table 2.4. Each road section is, therefore, characterized by three rating numbers, which are added together to give a composite rating. The rating numbers were chosen so that the sum of numerical values for every combination of variable levels is unique, i.e., each sum is different from the other sums. This characteristic differentiates this rating system from other procedures that assign numerical values to established categories of selected pavement attributes. In order to verify the uniqueness of the sums, Table 2.5 was set up using the rating numbers given in Table 2.4. Examination of the sums shows that each one is different from the rest. Because of this characteristic, any composite rating number can be readily broken down into its components. For example, given a composite rating of 30, one can easily identify the component variable levels as follows (refer to Table 2.5):

Component Variable	Variable Level	Rating
Wear	None or slight	12
Deformation	None or slight	17
Treatment in routine maintenance	None	1
	Composite Rating =	30

In summary then, the unique sums approach is another simple way of formulating an index for quantifying pavement condition. The procedure is also comparable to other rating systems that assign deduct values to specific categories of pavement attributes. However, the selection of numerical values is constrained by the requirement that their sums be unique. Because

TABLE 2.4. ESTABLISHED RATING NUMBERS FOR VARIOUS CATEGORIES OF PAVEMENT ATTRIBUTES USED IN THE SWEDISH ROAD INVENTORY SYSTEM (Ref 7)

Variable	Variable Level	Class Number	Rating
Wear	None or slight	1	12
	Obvious	2	18
	Considerable	3	48
	Serious	4	80
Deformation	None or Slight	1	17
	Obvious	2	24
	Considerable	3	55
	Large	4	93
Treatment in Routine Maintenance	None	1	1
	Isolated patches, sealing	2	5
	Considerable tear up	3	15
	Considerable patching	4	20

TABLE 2.5 TABLE OF COMPOSITE PAVEMENT RATINGS

Treatment in Routine Maintenance	Deformation	Wear: None or Slight (12)*	Wear: Obvious (18)	Wear: Considerable (48)	Wear: Serious (80)
None (1)	None or slight (17)	30	36	66	98
	Obvious (24)	37	43	73	105
	Considerable (55)	68	74	104	136
	Large (93)	106	112	142	174
Isolated patches, sealing (5)	None or slight (17)	34	40	70	102
	Obvious (24)	41	47	77	109
	Considerable (55)	72	78	108	140
	Large (93)	110	116	146	178
Considerable tear up (15)	None or slight (17)	44	50	80	112
	Obvious (24)	51	57	87	119
	Considerable (55)	82	88	118	150
	Large (93)	120	126	156	188
Considerable patching (20)	None or slight (17)	49	55	85	117
	Obvious (24)	56	62	92	124
	Considerable (55)	87	93	123	155
	Large (93)	125	131	161	193

*Numbers in parentheses beside variable levels are the assigned rating numbers shown in Table 2.4

of this characteristic, the composite rating number can be readily broken down into its components, and this is a desirable feature to have in a pavement rating system.

However, unless one has had experience using a rating system based on this approach, it may be difficult to identify the components of the composite ratings without also looking at some kind of a listing of unique sums and the corresponding variable categories for each. In addition, the numerical values obtained are highly non linear, allowing no meaningful comparisons to be made between different degrees of pavement condition.

UTILITY THEORY

The application of utility theory to develop a measure of overall pavement performance has been reported for Arizona and Texas (Refs 8 and 9). Basically, the procedure involves the assessment of utility functions which express a decision maker's preferences over different levels of selected attributes. These functions are primarily developed by soliciting expert opinion through interviews. An example, involving a utility function for money, is discussed herein to illustrate a procedure for constructing utility functions. However, some terms should be defined first. The definitions provided are based on the material reported in Reference 10.

In the succeeding discussion, any uncertain proposition is described as a lottery. For example, a person may be offered a lottery in which he receives $100 if a head comes up in the toss of a coin and nothing if a tail comes up. This coin tossing lottery is illustrated in Fig 2.1. Assuming that the coin is good, his probability of winning $100 is exactly 1/2. The expected value of the lottery is computed by multiplying the amount of each prize by its probability and summing over all prizes. As such, the expected value of the coin-tossing lottery is 1/2(\$100) + 1/2(\$0) = \$50. Now suppose that another individual offers to buy the lottery from the person to whom it was given. The minimum price with which that person is willing to part with his lottery is defined as the certain equivalent of the lottery. Below this minimum selling price, the person would rather play the lottery, and above it, he would choose to sell it. Figure 2.2 illustrates the meaning of certain equivalent. The symbol $\sim$ is used to indicate that the person is indifferent between playing the lottery or getting an amount of \$30 for it.

Several methods are available for assessing utility functions (Refs 11 and 12). For the example given here, a method known as the "standard gamble" is used. In applying this method, a decision maker is asked to choose between (1) the certainty of receiving a sum of money and or (2) a lottery in which there is a chance of receiving or, in some cases, losing one of two sums of money in which risk is expressed in terms of the probabilities associated with winning each amount. If the decision maker expresses a preference for one of the alternatives, the probabilities are changed successively until the alternatives appear as equally desirable to the decision maker. At this point of indifference, the alternatives are equal in terms of utility. Since a utility function reflects subjective evaluations of amounts of money in relative terms, the utilities for two of the dollar amounts in the initial lottery can be chosen arbitrarily, and the utilities of other dollar amounts can be determined in relation to these utility values.

Proceeding with the example then, suppose an individual is asked to choose between (1) the certainty of receiving \$3000 and (2) a lottery with a

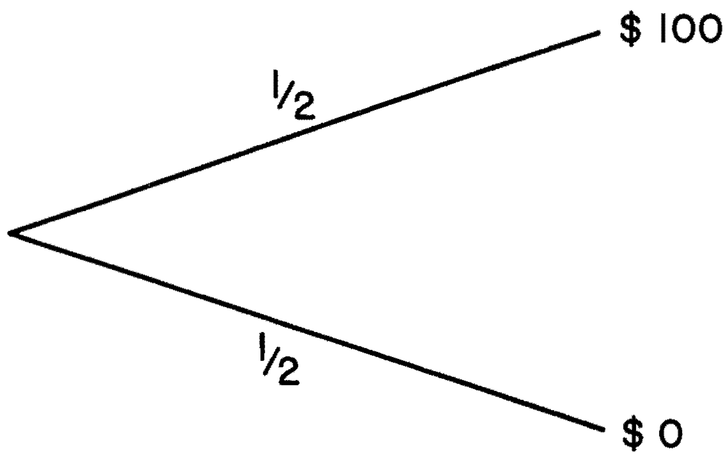

Fig 2.1. A coin tossing lottery.

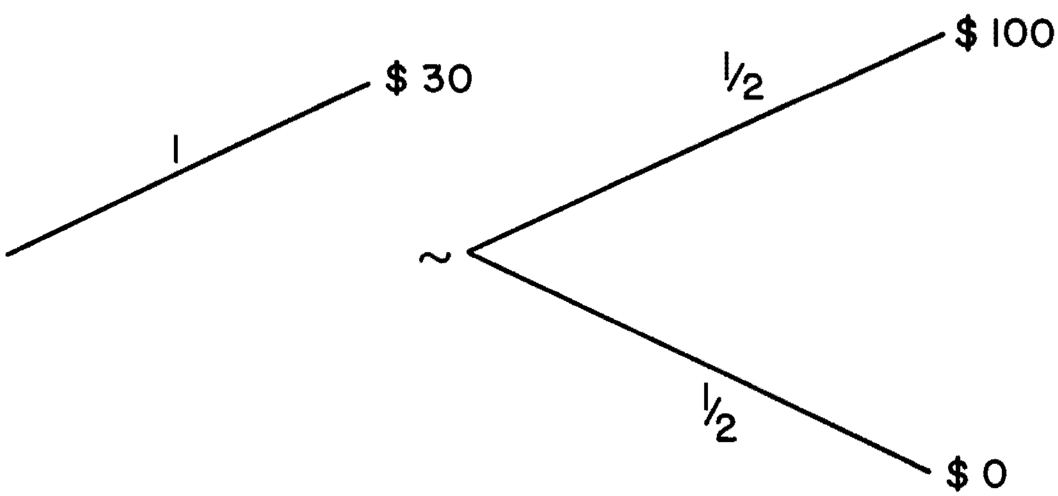

Fig 2.2. Certain equivalent of the coin tossing lottery.

probability p = 0.15 of receiving $10,000 and a probability (1 - p) = 0.85 of getting $1000. It is assumed for this first iteration that the individual prefers Alternative 1. This seems reasonable since the value of Alternative 1 is greater than the expected value of the lottery E(u) = 0.15($10,000) + 0.85($1000) = $2350. For the next iteration, assume that the probabilities for winning $10,000 and $1000 are changed to 0.25 and 0.75 respectively, and suppose that the individual still prefers Alternative 1. This would indicate risk aversion by the individual since the expected value of the lottery ($3250) with the revised set of probabilities is greater than the value of Alternative 1. The procedure is continued, and the probabilities are changed to p = 0.30 and (1 - p) = 0.70. Given these probabilities, the individual might now indicate equal preference for or indifference between the alternatives. At this point, the individual's utility for $3000 in Alternative 1 is equal to the utility for a 0.30 chance of receiving $10,000 and a 0.70 chance of getting $1000. To obtain utility values (in relative terms) for the monetary amounts in the alternatives, a utility value of zero for $1000 and a utility value of one for $10,000 can be assigned arbitrarily, and the utility value for $3000 can be found by solving the equation for the equal utility of the two alternatives. Thus:

$$\begin{aligned} U(\$3000) &= 0.3U(\$10{,}000) + 0.7U(\$1000) \\ &= 0.3(1) + 0.7(0) \\ &= 0.3 \end{aligned}$$

Therefore, with three points known, the individual's utility curve can already be constructed as shown in Fig 2.3.

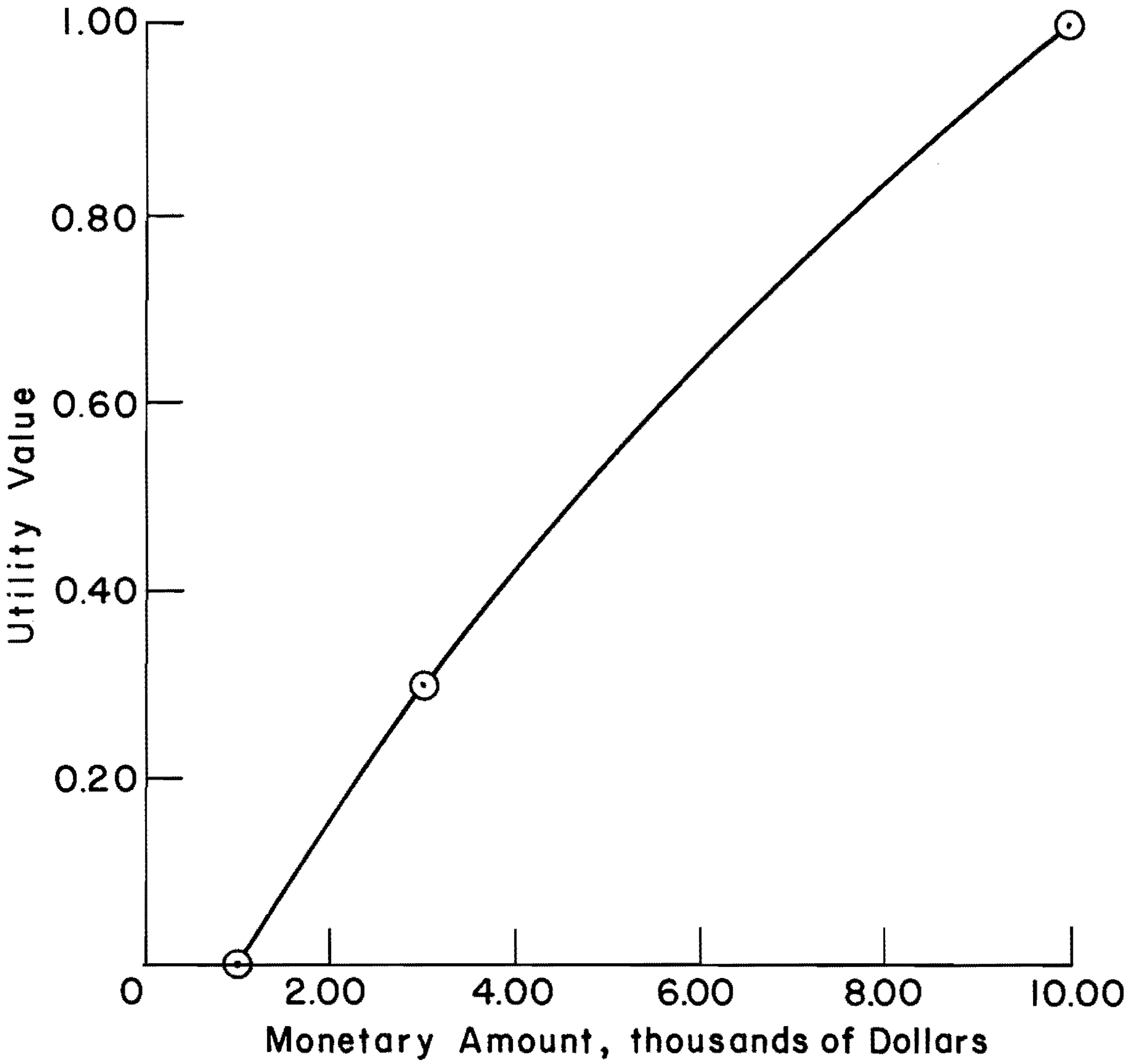

Fig 2.3. Example utility curve.

The application of utility theory may be extended to the problem of formulating measures of pavement performance by construction of utility curves for selected pavement attributes. A composite measure of pavement performance can then be obtained by combining the utility curves in a single equation. For example, the following simple model may be used:

$$U(\underline{X}) = \sum_{i=1}^{n} k_i \, U_i \, (X_i)$$

where

$U(\underline{X})$ = multi-attribute utility function scaled between 0 and 1,

$U_i(X_i)$ = individual utility function for the i^{th} attribute, scaled from 0 to 1, and

k_i = scaling constants with values between 0 and 1 such that

$$\sum_{i=1}^{n} k_i = 1.$$

This equation assumes mutual preferential independence between attributes. The intuitive meaning of this condition is that there is no interaction of preferences between attributes. Priorities can then be established by comparing the relative values obtained from the multi-attribute utility function $U(\underline{X})$.

DELPHI METHOD

One other approach to formulating a prioritization index is through the Delphi technique. This technique has been used previously in the development of a data base for Texas (Ref 13) and has recently been applied to develop a basis for evaluating highway surface condition in the State of Maine (Ref 14).

In this method, an attempt to achieve a consensus of opinion among a group of experts is made through cycles of intensive questioning interspersed with controlled opinion feedback. The technique avoids the direct confrontation of experts with one another which is the traditional method of pooling individual opinions. In this way, some of the serious difficulties inherent in face-to-face interaction are circumvented, such as (Ref 13):

(1) The spurious influence of a high status individual on the group - here, the status of an individual, which is often unrelated to his expertise on the question at hand, is given undue consideration in a face-to-face discussion.

(2) Ego commitment - after openly committing himself to a particular position, the individual is less likely to respond to facts and opinions advanced by other members of a face-to-face discussion group.

(3) Group pressure for conformity - in a face-to-face situation, the individual encounters great pressure to jump on the bandwagon and join the group.

The technique was applied by the Department of Transportation of the State of Maine in an effort to establish weights for various severity levels of selected distress categories. In connection with this, a rating form was developed, an example of which is shown in Fig 2.4. Numerous pavement experts within the Department were then consulted. Each expert was asked to establish the relative importance of selected distress categories for the

Attribute ____________

Distress Descriptions		Rural: Interstate	Rural: Arterial	Rural: Collector	Rural: Local	Rural: Traffic Factor	Urban: Interstate	Urban: Arterial	Urban: Collector	Urban: Traffic Factor
Cracking										
(1) Transverse	-Hairline									
(2)	< 1/4"									
(3)	> 1/4"									
(4) Longitudinal	-Hairline									
(5)	< 1/4"									
(6)	> 1/4"									
(7) Load Associated	-Initial									
(8)	Advanced									
(9)	Severe									
(10) Patching	-Good									
(11)	Fair									
(12)	Poor									
(13) Ruts	1/2"-1"									
(14)	> 1"									
(15) Crown	1"-2"									
(16)	2"-4"									
(17)	> 4"									
(18) Shoulder	Marginal									
(19)	Deficient									
(20)	None									

* Indicate with asterisk when you feel that high volume roads would warrant a higher rating

Significance Scale Guide

0	Unrelated or No Significance
-5	Somewhat Significant
-10	Moderately Significant
-15	Highly Significant
-20	Most Significant

N/A = In your opinion it does not apply or does not exist

Fig 2.4. Order of significance rating form (Ref 13).

following attributes: (1) overall surface condition, (2) roughness, (3) safety, (4) strength, and (5) maintenance need. Scores are assigned using a scale from 0 to 20, as shown in Fig 2.4, and functional classification and traffic level are also considered when assigning scores. Successive iterations of the Delphi process are then made. At each iteration, the means of the ratings obtained during the previous cycle for each distress category are fed back to the participants, who are invited to make changes in their ratings in the light of the information presented. The final output of this process then is a set of importance ratings reflecting the group consensus which may be used for establishing priorities.

CHAPTER 3. DEVELOPMENT OF THE RATIONAL FACTORIAL RATING METHOD

INTRODUCTION

As indicated previously, an important component of any pavement management system is a prioritization procedure for establishing rehabilitation and maintenance activities. In practice, one method of formulating such a procedure would be to select a number of pavement sections that are representative of a wide range of field conditions, and have a panel of engineers rate them on the basis of a selected set of attributes. The ratings obtained, together with physical measurements made on the pavement sections, can then be used to arrive at an equation for priority ranking of pavements. This approach is similar to the procedure used in developing the Present Serviceability Index at the AASHO Road Test.

However, as an alternative to actually selecting pavement sections and having a panel of engineers go out in the field, it may also be possible to quantify the opinions of these engineers on the subject of prioritization through a series of structured questions. These questions could consist of several scenarios that describe pavement sections under conditions in which they might exist in the field. These conditions could be defined by combinations of levels of selected pavement attributes such as distress and serviceability. By asking pavement engineers to indicate a rating of rehabilitation need for each of the pavement sections described to them, it would be possible to study, and perhaps to come out with a better understanding of, how highway engineers establish priorities for rehabilitation work. Efforts were therefore made to arrive at a factorial design through which the ideas presented above could be made concrete. The succeeding paragraphs document in more detail the development of the factorial designs.

DEVELOPMENT OF THE FIRST FACTORIAL DESIGN

The methods for developing a prioritization index presented earlier are comparable with one another because each of them attempts to quantify the subjective opinions of pavement engineers with regard to the establishment of priorities through the use of a numerical system of weights. An index is then constructed by aggregating the individual weights together. Inherent in this procedure, however, is the assumption that decisions on rehabilitation priorities are made considering the pavement variables to be independent of each other. In actual practice, this may not be an unreasonable assumption, and it may be worth finding out if this is so. Consequently, it was decided that some kind of a factorial design should most likely be used since this would allow the estimation of interaction effects between variables. In other words, the combined effect of independent variables (e.g., distress and PSI) on the particular dependent variable (e.g., rating of rehabilitation need) can be studied. This may be important since, in practice, it may be that combinations of pavement attributes significantly influence decisions on whether to rehabilitate or not.

Another advantage of using a factorial design is that the significant variables in the study can be identified, and the relative effect of each independent variable on the dependent variable can be estimated. In this way, the set of pavement attributes that should be included in the priority analysis need not be assumed off hand. Instead, a number of candidate attributes may be initially included as variables in the factorial design. The effect of each variable can then be estimated, and tests of significance can be made to identify the variables which are considered important. This would, therefore, represent an indirect procedure for establishing the set of pavement attributes to use as criteria for determining rehabilitation needs. In addition, should it be decided to include only the most important variables in order to simplify the priority analysis, the procedure could facilitate the selection of key variables. This is because the relative effect of each independent variable on the dependent variable can be estimated. Finally, by using a factorial base approach, a regression equation can be established that can be used to estimate how rehabilitation priorities are set by pavement engineers.

Because of the above advantages, a decision was made to use a factorial base procedure for formulating a prioritization index. Subsequent efforts were, therefore, primarily concerned with looking for a specific factorial design, and the studies conducted in this regard showed that a fractional factorial would be the most suitable design to use. Consequently, the factorial design shown in Fig 3.1 was selected. Each of the cells in the figure can be treated as a pavement section experiencing a particular and unique set of conditions of pavement distress, PSI, traffic level, and environment related factors. By asking highway engineers to rate each cell on the basis of the priority they would assign to each, it would be possible

Pavement Distress Evaluation			Significant		Moderate		Minimal	
PSI			2.4	3.5	2.4	3.5	2.4	3.5
		Traffic Level*						
Wet	Freeze Thaw	High	101 X	102	103	104 X	105 X	106
		Low	107	108 X	109 X	110	111	112 X
	No Freeze Thaw	High	113	114 X	115 X	116	117	118 X
		Low	119 X	120	121	122 X	123 X	124
Dry	Freeze Thaw	High	125	126 X	127 X	128	129	130 X
		Low	131 X	132	133	134 X	135 X	136
	No Freeze Thaw	High	137 X	138	139	140 X	141 X	142
		Low	143	144 X	145 X	146	147	148 X

* Low ≈ 6000 ADT
High ≈ 100,000 ADT

Fig 3.1. Initial factorial design.

to estimate how they establish rehabilitation priorities. However, it would not be practical to solicit the opinions of each pavement expert for all of the cells shown in the figure. Doing so would impose a heavy burden on each respondent and might just serve to confuse him. It is, therefore, this concern that led to the selection of a fractional factorial design based on a half-replicate of the full factorial shown in Fig 3.1. With this plan, a pavement engineer is asked to provide priority ratings only for certain selected combinations of the variables considered. In Fig 3.1, these combinations are the cells marked with an X.

A fractional factorial will not give as much information as a full factorial. However, the design shown in Fig 3.1 does enable one to estimate the main effects of each variable, and certain two-factor interactions, and it was felt that this information would be adequate enough for the purposes of the study. In addition, it was decided to include distress, PSI, traffic, freeze-thaw, and rainfall as variables in the design and to fix the distress factor at three levels and the remaining ones at two levels. The distress factor was fixed at three levels in order to check for non linearity of responses that may be associated with this variable.

PREPARATION AND ADMINISTRATION OF RATING FORM FOR THE FIRST FACTORIAL DESIGN

After the selection of the factorial design was made, a rating form was prepared for soliciting the opinions of pavement engineers on the matter of establishing priorities for rehabilitation work. This rating form is shown in Appendix A. The pavement sections included in the form represent the cells marked with an X in Fig 3.1. It was felt that a half-replicate of a

3×2^4 factorial (24 sections) was too much for a respondent to compare and rate all at once, and the decision was made to divide the half-replicate into two blocks consisting of 12 pavement sections each. Each pavement expert consulted was asked to assign priority ratings on a scale of 1.0 to 10.0, with 1.0 indicating a pavement section with a high rehabilitation priority and 10.0 a pavement section with a low rehabilitation priority. In addition, the respondents were instructed to assign ratings to twelve pavement sections at a time. Whenever possible, the respondents were given a break between rating sessions.

Dividing the half-replicate into two blocks may actually have an effect on the responses provided by the participants, and this possibility was recognized by the investigators. In particular, the responses for pavement sections included in one block may turn out to be different from those in the other block. Any difference in the responses between blocks would be hard to explain. However, it was felt that dividing the half-replicate into two blocks would not really have a significant effect, and this was later confirmed when the responses obtained were analyzed. (A detailed discussion of the results is presented in the succeeding chapter.) In addition, each respondent was asked to indicate on the rating sheet his major work area and the geographic region where he obtained most of his work experience. This instruction was given in order to investigate whether differences in responses could be associated with differences in backgrounds among respondents. Finally, for each priority rating assigned, the respondent was asked to indicate whether a pavement section at the present time, and in its present state, should be considered a candidate for rehabilitation work. This was done primarily to identify a pavement score at which rehabilitation work is considered to be necessary.

DEVELOPMENT OF THE SECOND FACTORIAL DESIGN

In addition to the development of the factorial design discussed above, a second factorial design was made to investigate whether pavement type has any significant influence on the way rehabilitation priorities are established. This variable was omitted from the initial factorial design, because it was felt that the establishment of priorities is not significantly affected by it and that, given two pavement sections under identical conditions (except that one is rigid and the other flexible), a pavement engineer would feel the same regarding the rehabilitation need for each pavement. However, in some of the meetings with the respondents, several of them wanted to know which of the pavement sections included in the rating form shown in Appendix A were flexible, and which ones were rigid. Consequently, it was realized that pavement type may be an important variable and it was decided to verify this.

Initially, the idea was simply to include another variable (pavement type) in the original research design. This variable would be fixed at two levels (rigid and flexible). However, this procedure immediately doubles the size of the factorial and the number of pavement sections which a respondent has to rate. Consequently, another factorial design had to be made which would allow the inclusion of pavement type as a variable and still be of a manageable size. In addition, the factorial design needed to provide at least as much information on main effects and two-factor interactions as the original design.

With the above guidelines in mind, efforts were made to come up with a suitable research design. In connection with this, one of the designs considered was a half-replicate of a 2^6 factorial consisting of the following factors each fixed at two levels: (1) pavement type, (2) degree of distress, (3) present serviceability index, (4) traffic, (5) amount of freeze-thaw, and (6) amount of rainfall. In effect, adopting this scheme would be just like fixing the distress factor in the original design at three levels rather than two levels and then simply adding the pavement type factor and fixing it at two levels, rigid and flexible. However, the question raised regarding this procedure was whether it was justifiable to fix the distress factor at three levels instead of two levels. As mentioned previously, this factor was set at three levels in order to check for non linearity of responses that may be associated with this variable. Therefore, an analysis was made of the data collected for the first research design in order to verify this. It was found out that there was no significant non linearity in the responses associated with the distress variable. Consequently, the idea of fixing distress at only two levels seemed reasonable, and a half-replicate of a 2^6 factorial was adopted as the research design.

The second fractional factorial design is illustrated in Fig 3.2, and the rating form prepared for this design is shown in Appendix B. Instructions for filling out the second rating form were essentially the same as those for the initial rating form. In the second factorial design, however, the 32 pavement sections were divided into 4 blocks of 8 sections each. This was done because it was again felt that to have a respondent rate the pavement sections all at the same time would be too much a burden on him. Consequently, participants were told to rate only 8 sections at a time, and, whenever it was possible, a break was given after half of the total number of sections were rated. The responses obtained for this factorial design are analyzed in the succeeding chapter.

Pavement Type			Rigid				Flexible			
Pavement Distress Evaluation			Significant		Minimal		Significant		Minimal	
PSI			2.4	3.5	2.4	3.5	2.4	3.5	2.4	3.5
Traffic Level*										
Wet	Freeze Thaw	High	201 X	202	203	204 X	205	206 X	207 X	208
Wet	Freeze Thaw	Low	209	210 X	211 X	212	213 X	214	215	216 X
Wet	No Freeze Thaw	High	217	218 X	219 X	220	221 X	222	223	224 X
Wet	No Freeze Thaw	Low	225 X	226	227	228 X	229	230 X	231 X	232
Dry	Freeze Thaw	High	233	234 X	235 X	236	237 X	238	239	240 X
Dry	Freeze Thaw	Low	241 X	242	243	244 X	245	246 X	247 X	248
Dry	No Freeze Thaw	High	249 X	250	251	252 X	253	254 X	255 X	256
Dry	No Freeze Thaw	Low	257	258 X	259 X	260	261 X	262	263	264 X

*Low ≈ 6000 ADT
High ≈ 100,000 ADT

Fig 3.2. Second factorial design.

CHAPTER 4. EVALUATION OF PRIORITY RATINGS OBTAINED THROUGH APPLICATION OF THE RATIONAL FACTORIAL RATING METHOD

INTRODUCTION

In the previous chapter, a factorial-based procedure for formulating a prioritization index was presented. The method, known as the rational factorial rating method, was used to quantify the opinions of numerous pavement engineers on the matter of establishing priorities for rehabilitation work.

In this chapter, a statistical analysis of the responses obtained from the surveys conducted is presented. The discussion is divided into two main parts. In the first part, an evaluation of the responses gathered using the initial factorial design is made. The second part presents the analysis of responses for the second factorial design. From the results obtained, a procedure is developed which may be used for establishing rehabilitation priorities at the network level PMS.

EVALUATION OF RESPONSES FOR THE FIRST FACTORIAL DESIGN

In this part of the chapter, the variables which have a significant influence on the priority ratings obtained are determined, and an analysis is made to verify whether there are any interactions between the variables considered. In addition, an evaluation is made to see whether there are any differences in responses that may be associated with differences in backgrounds among respondents. Finally, the ratings are analyzed to obtain an estimate of a cut-off score at which rehabilitation work is considered to be necessary.

Determination of Significant Variables

Summary statistics calculated for the priority ratings are shown in Table 4.1. In order to determine which of the variables significantly influenced the responses obtained, a regression equation of the average responses shown in Table 4.1, as a function of the independent variables included in the study, was calculated. The regression equation which was obtained is expressed as Eq 4.1 below. This equation has a value of $R^2 = 97.1$ percent, and a standard error of the estimate (SEE) equal to 0.31.

$$Y = 5.26 + 0.46X_1 + 0.396X_2 + 0.601X_3 + 0.749X_4 + 1.66X_5 - 0.0568X_6 - 0.0036X_7 \quad (4.1)$$

The dependent variable Y in Eq 4.1 is used to represent the predicted priority rating. The first five independent variables, X_1 to X_5, represent respectively the following variables:

(1) rainfall,

(2) freeze-thaw,

(3) traffic,

(4) PSI, and

(5) distress (linear component).

TABLE 4.1 MEANS AND STANDARD DEVIATIONS OF PRIORITY RATINGS, AND CONFIDENCE INTERVAL ESTIMATES OF MEAN RATINGS FOR THE INITIAL FACTORIAL DESIGN

Section No.	Mean Rating	Standard Deviation	Confidence Interval Estimate of Mean Rating (95% Level)
123	6.61	1.78	6.08 - 7.14
130	7.65	1.55	7.18 - 8.11
137	3.39	1.36	2.99 - 3.80
122	6.42	1.63	5.93 - 6.91
135	6.52	1.79	5.98 - 7.05
118	7.54	1.47	7.10 - 7.98
108	4.19	1.47	3.75 - 4.63
134	6.53	1.32	6.13 - 6.92
101	1.40	0.84	1.15 - 1.65
127	3.85	1.29	3.66 - 4.05
144	5.30	1.65	4.81 - 5.80
115	3.67	1.19	3.32 - 4.03
105	4.44	1.92	3.86 - 5.01
131	3.94	1.52	3.49 - 4.39
104	4.16	2.07	3.54 - 4.77
145	5.93	1.68	5.42 - 6.43
140	6.21	1.50	5.76 - 6.66
148	9.28	0.98	8.99 - 9.57
119	3.71	1.33	3.31 - 4.11
141	6.26	1.72	5.74 - 6.77
112	7.50	1.58	7.03 - 7.97
114	3.55	1.62	3.06 - 4.03
109	4.41	1.49	3.96 - 4.85
126	3.79	1.70	3.28 - 4.30

In the analysis, values of these independent variables were coded in the following manner. A value of +1 was assigned when a variable was at its best level, and a value of -1 was used when it was at its worst level. For the distress factor, which was fixed at three levels, a value of 0 was used to indicate a pavement with a moderate degree of distress. The remaining two variables are explained as follows. Variable X_6 is used to represent the quadratic component of the distress factor. As mentioned in Chapter 3, this factor was set at three levels in order to verify whether there is a significant non linearity of responses that may be associated with this variable. The X_6 factor in Eq 4.1 is therefore used to verify that a significant non linearity does exist. In the analysis, values for this variable were coded in the following manner. A value of -1 corresponded to the minimal and significant levels of distress, and a value of +2 corresponded to the moderate level of distress. Variable X_7 is the factor which is used to check whether or not responses differed significantly between the component blocks in which the design was divided. For this factor, a value of +1 was used to represent pavement sections belonging to the first block (i.e., the first twelve sections in the rating form shown in Appendix A), and a value of -1 was used to represent pavement sections belonging to the second block.

In order to illustrate how well the equation fits the ratings obtained, a plot of the residuals versus the predicted priority ratings is shown in Fig 4.1. The residual is the difference between the actual and predicted priority ratings. As can be seen from the figure, most of the observed residuals are not more than 0.50 in absolute magnitude and plot near enough the horizontal line representing a value of the residual equal to zero. This indicates how well the equation fits the average priority ratings obtained.

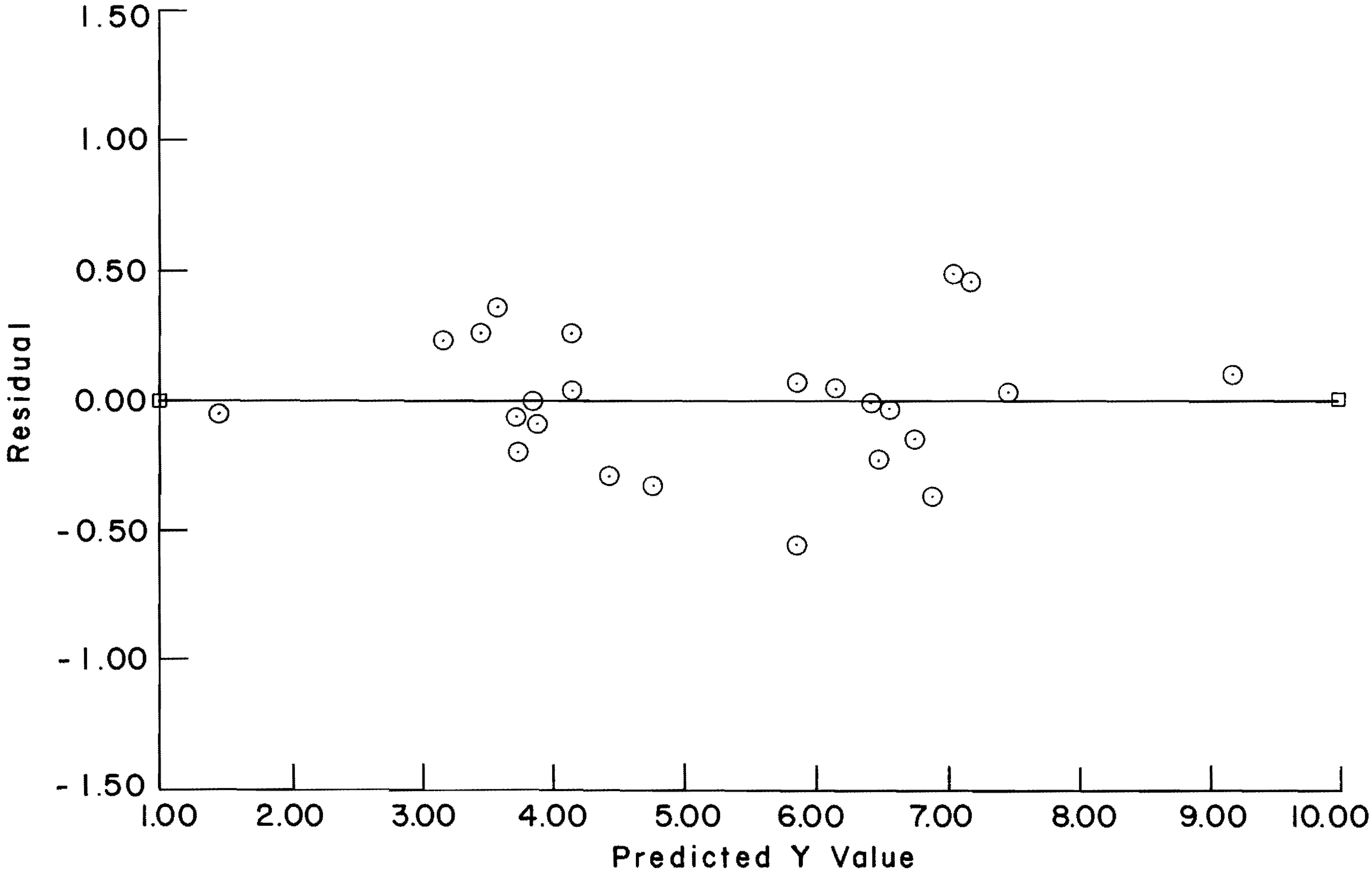

Fig 4.1. Plot illustrating the goodness-of-fit of equation 4.1 to the average priority ratings obtained for the first factorial design.

In addition, the plot does not indicate any dependence of the residuals on the magnitudes of the equation values. There is no curvilinearity in the scatter of the residuals, and they seem to plot more or less along the horizontal line representing a value of the residual equal to zero.

A test for the strength of the functional relationship between each independent variable and the dependent variable was made to determine the significant factors. Specifically, the coefficient of each factor in Eq 4.1 was tested for significance by calculating the statistic

$$t = \frac{b}{\sigma_b} \tag{4.2}$$

where

b = coefficient of independent variable to be tested,

σ_b = standard deviation of b .

The value calculated from Eq 4.2 is then compared with the value of t for (24-8) = 16 degrees of freedom and for an assumed confidence level. In the analysis, a 95 percent confidence level was selected, and a value of $t = \pm 2.12$ was obtained from a t-distribution table. This particular value is compared with the statistic calculated from Eq 4.2 for each variable coefficient. If the computed statistic t for a particular variable is less than -2.12 or greater than +2.12, a significant relationship exists between the particular independent variable and the dependent variable.

A summary of the computed t-statistics is shown in Table 4.2. From the table, it can be seen that each of the first five variables in Eq 4.1 has a significant relationship with the dependent variable, as evidenced by the

TABLE 4.2. COMPUTED t-STATISTICS FOR THE COEFFICIENTS OF EQ 4.1

Variable	Coefficient	t - Statistic
1. Rainfall (X_1)	0.460	7.22
2. Freeze-thaw (X_2)	0.396	6.21
3. Traffic (X_3)	0.601	9.43
4. PSI (X_4)	0.749	11.75
5. Distress		
a. Linear component (X_5)	1.656	21.22
b. Quadratic component (X_6)	-0.057	-1.26
6. Block Effect (X_7)	-0.004	-0.06

fact that the t-statistic for each of these variables is greater than +2.12. However, variables X_6 and X_7 do not show a significant relationship since their t-statistics lie between the interval [-2.12, +2.12]. The analysis, therefore, indicates that there is no significant non linearity of responses associated with the distress variable. In other words, the priority ratings obtained vary more or less linearly with the degree of distress. In addition, the analysis indicates that the division of the factorial into blocks did not have a significant effect on the responses obtained.

The results, therefore, indicate that the variables rainfall, freeze-thaw, traffic, PSI, and distress are significant factors influencing the establishment of priorities for rehabilitation work. In order to determine the relative importance of each of the variables, a standardized regression equation of the priority ratings as a function of the above variables was calculated. In this equation, the dependent and independent variables are standardized to mean zero and unit standard deviation. The relative significance of each variable can then be determined by comparing directly the coefficients of the variables in the regression equation.

The standardized regression equation obtained is shown as Eq 4.3 below, where the variables are as defined previously.

$$Y = 0.252X_1 + 0.217X_2 + 0.329X_3 + 0.410X_4 + 0.757X_5 \qquad (4.3)$$

$$R^2 = 97.7 \text{ percent} \qquad SEE = 0.17$$

By comparing directly the coefficients of the variables in this equation, it is readily seen that distress is the most significant of the five factors considered, followed in importance by PSI, traffic, rainfall and freeze-thaw. The relative importance of each variable is further illustrated by studying the statistical data summarized in Table 4.3. From the table, it can be seen that the variable distress explains a substantial portion of the variation in the responses obtained, accounting for 57.3 percent of the total variation. The table also shows the improvement in R^2 associated with the inclusion of each variable in the standardized regression equation. It can be seen that a substantial amount of the total variation (86.2 percent) can already be explained by the variables distress, PSI, and traffic. As such, it is felt that, should a simpler network level prioritization procedure be desired, the use of the preceding three variables as criteria in the analysis might be adequate. However, it should also be mentioned that the variables rainfall and freeze-thaw contribute significantly to explaining the total amount of variation in the responses obtained. As can be seen from Table 4.3, the coefficient of determination R^2 improves from 86.2 to 92.8 percent with the inclusion of the rainfall variable, and increases from 92.8 percent to 97.7 percent with the inclusion of the freeze-thaw variable.

Estimation of Interactions Between Variables

In the succeeding paragraphs, the responses are evaluated to check for interactions between the variables included in the factorial design. In the analysis, only two-factor interactions are considered. Three-factor and higher order interactions are used for estimating the residuals.

To facilitate the discussion of the analysis, each of the main variables is represented by a letter:

TABLE 4.3 RESULTS OF THE REGRESSION ANALYSIS OF THE VARIABLES IN EQ. (4.3)

Source of Variation	Degrees of Freedom	Sum of Squares	R^2 (%)	Change in R^2 (%)
Distress	1	13.18	57.3	57.3
PSI	1	4.04	74.9	17.6
Traffic	1	2.60	86.2	11.3
Rainfall	1	1.53	92.8	6.6
Freeze-thaw	1	1.13	97.7	4.9
Residuals	18	0.52	–	–
Total	23	23.00		

VARIABLE	SYMBOL
Rainfall	A
Freeze-thaw	B
Traffic	C
PSI	D
Distress	E

In order to determine whether there are any significant interactions between variables, a regression equation using the average responses as a function of the main variables and selected two-factor interactions was calculated. These two-factor interactions are AC, AD, AE, BC, BD, BE, CE, and DE. It was not possible to include AB and CD in the analysis since these interactions were confounded in the fractional factorial design. The calculated regression equation is shown below:

$$\begin{aligned} Y = {} & 5.26 + 0.46A + 0.396B + 0.601C + 0.749D + 1.66E \\ & -0.073AC + 0.0068AD + 0.0021AE - 0.0508BC \\ & + 0.0033BD + 0.06BE - 0.062CE + 0.235DE \end{aligned} \qquad (4.4)$$

R^2 = 99.3 percent SEE = 0.23

The strength of the relationship between each two-factor interaction and the dependent variable was evaluated using the procedure described in the previous section in order to determine which of the two-factor interactions are significant. In connection with this, t-statistics computed for the coefficients of the interaction terms in the regression equation are summarized in Table 4.4. They were compared with the value of $t = \pm 2.228$ for 10 degrees of freedom (d.f.), and a 95 percent confidence level. The results

TABLE 4.4 COMPUTED t - STATISTICS FOR THE TWO - FACTOR INTERACTIONS INCLUDED IN EQ. (4.4)

Two - factor Interaction	Coefficient	t-Statistic
AC	-0.0731	-1.47
AD	0.0068	0.14
AE	0.0021	0.04
BC	-0.0508	-1.02
BD	0.0033	0.07
BE	0.0600	1.04
CE	-0.0620	-1.08
DE	0.2350	4.09

indicate that a significant interaction exists between PSI and distress. This interaction is illustrated in Fig 4.2, where the average responses were plotted as a function of the two variables. As can be seen in the figure, lines fitted to the data are not quite parallel, indicating that an interaction does exist. An increase in the level of the distress factor at PSI = 2.4 does not quite produce the same change in the responses as at PSI = 3.5.

It may also be noted that for each level of distress and PSI, there is an observation that seems to plot quite differently from the rest. These points represent ratings for pavement sections where the values of the other variables, rainfall, freeze-thaw, and traffic (which are not accounted for in Fig 4.2), are either all at their best levels or all at their worst levels. It is for this reason that such observations seem to plot either much higher or lower than the other observations corresponding to a particular level of distress and PSI.

In order to determine the relative significance between the main variables and the DE interaction, a standardized regression equation of the average responses as a function of the main variables and the DE interaction was calculated. The regression equation is shown below; the variables are as defined previously.

$$Y = 0.252A + 0.217B + 0.329C + 0.411D + 0.757E + 0.107DE \quad (4.5)$$

R^2 = 98.9 percent SEE = 0.12

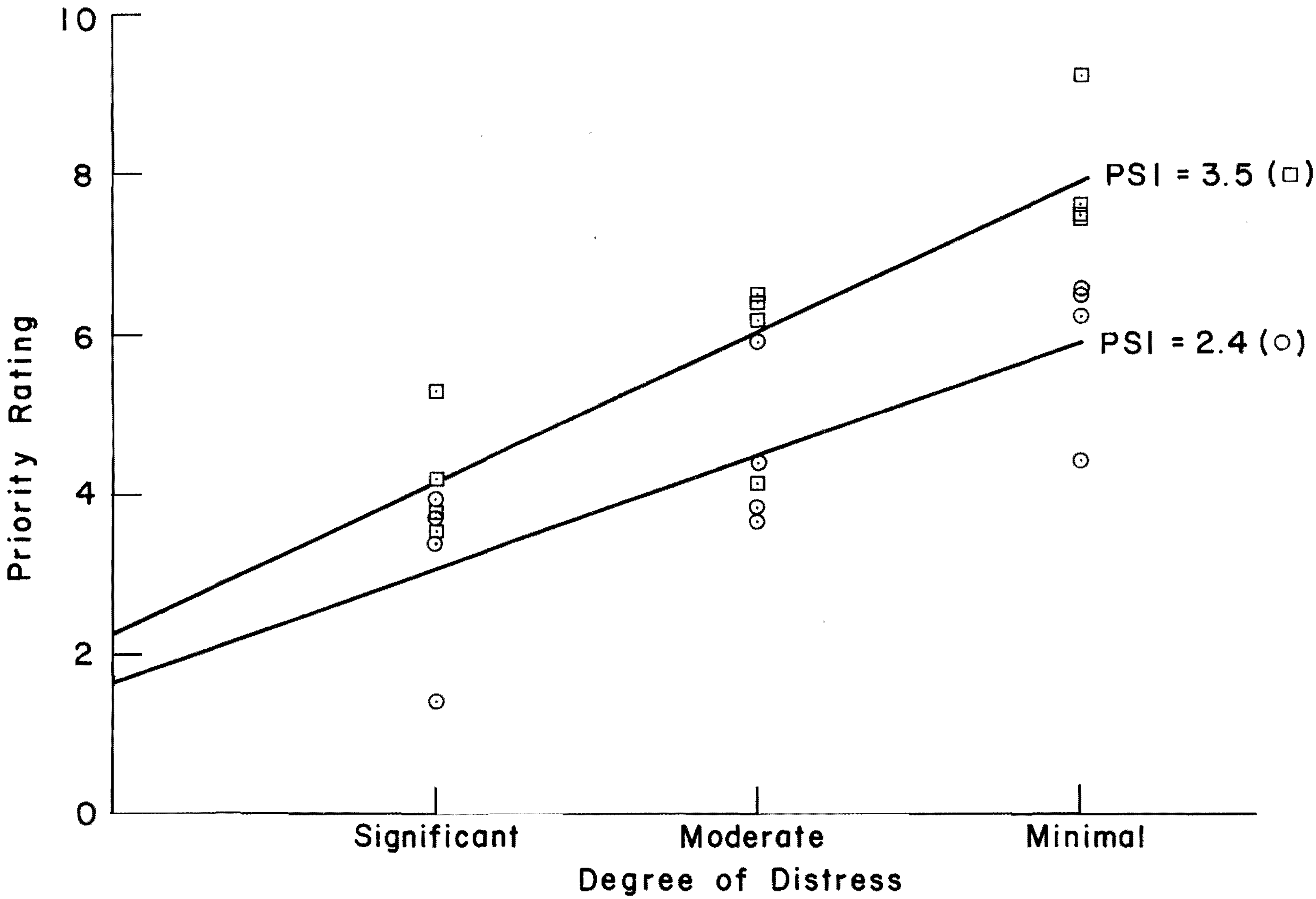

Fig 4.2. Graph illustrating the dependence of the effect of distress on the variable PSI.

By directly comparing the coefficients in Eq 4.5, it is seen that the DE interaction is the least important of the variables included in the equation. In addition, the sums of squares associated with the variables are summarized in Table 4.5. It can be seen from the table that the sum of squares associated with the DE interaction is 0.27 or only 1.2 percent of the total variation. As such, although the inclusion of DE as a variable in Eq 4.5 does result in a statistically significant improvement in R^2 from 97.7 to 98.9 percent , it may be argued that, for practical purposes, a sufficient amount of the total variation in the priority ratings obtained can already be explained by the five main variables. Consequently, the assumption that variables are considered independently of each other when priorities are established is, for practical purposes, quite reasonable.

Evaluation of the Effect of Differences in Backgrounds on the Responses Obtained

This approach can be used on any cross section of personnel and the differences of personnel background can be evaluated. In the two studies outlined here to test the methodology we took advantage of meetings in Texas and New York to get participants. The groups represented a balanced sample of people with field experience in the districts and from Office Division staff.

Each respondent who took part in the survey was asked to provide information on his major work area and the region where he obtained most of his work experience. The following were the various work groupings included in the survey: (1) Administrative, (2) Design, (3) Maintenance, (4) Construction, (5) Materials and Testing, and (6) Others. Respondents who did

TABLE 4.5 RESULTS OF THE REGRESSION ANALYSIS OF THE VARIABLES IN EQ. (4.5)

Source of Variation	Degrees of Freedom	Sum of Squares	R^2 (%)	Change in R^2 (%)
Distress (E)	1	13.18	57.3	57.3
PSI (D)	1	4.04	74.9	17.6
Traffic (C)	1	2.60	86.2	11.3
Rainfall (A)	1	1.53	92.8	6.6
Freeze-thaw (B)	1	1.13	97.7	4.9
DE	1	0.27	98.9	1.2
Residuals	17	0.25	—	—
Total	23	23.00		

not fall in any of the first five categories were classified under the Others group. In addition, the various geographical regions considered, together with information on the general environmental conditions prevalent in each region, are summarized in Table 4.6.

The above information was solicited from each respondent in order to analyze whether differences in responses can be associated with differences in backgrounds among respondents. In connection with this, the regression equation of priority ratings obtained from each individual was calculated and examined in order to verify whether respondents within a particular group were similar in the way they established priority ratings. The results obtained do not indicate any consistent pattern associated with responses from any particular group. As the information in Table 4.7 illustrates, the responses obtained reflect differences in what each respondent perceives to be the significant variables to consider in the establishment of priorities. Some respondents considered all of the variables to be significant in the establishment of their priority ratings, while others considered only certain factors as significant. However, it could be said that the variables traffic, PSI, and distress were considered to be significant by most respondents.

The results, therefore, indicate that each individual has his own opinion or way of thinking regarding how priorities are to be set. No particular characteristics were identified that clearly defined how priorities are established by members of any particular work group or regional category. As such, it is felt that the average responses (Table 4.1) best represent the overall opinions of the persons surveyed.

TABLE 4.6 GEOGRAPHICAL REGIONS CONSIDERED IN THE FACTORIAL DESIGNS (Ref. 5)

Geographical Region	General Environmental Characteristics
I	Wet, no freeze
II	Wet, freeze-thaw cycling
III	Wet, hard freeze
IV	Dry, no freeze
V	Dry, freeze-thaw cycling
VI	Dry, hard freeze

TABLE 4.7 LISTING OF THE SIGNIFICANT VARIABLES FOR EACH RESPONDENT

Respondent Number	Major Work Category	Regional Category	Variables				
			Rainfall	Freeze-thaw	Traffic	PSI	Distress
1	Others (Research)	—	YES	YES	YES	NO	YES
2	Others (Research)	—	YES	NO	YES	YES	YES
3	Others (Research)	V	NO	NO	YES	YES	YES
4	Others (Research)	—	NO	NO	NO	YES	YES
5	Others (Research)	V	NO	NO	NO	YES	YES
6	Others (Research)	V	NO	YES	YES	YES	YES
7	Others (Research)	V	YES	NO	NO	YES	YES
8	Others (Research)	V	YES	YES	YES	YES	YES
9	Others (Research)	—	NO	NO	YES	YES	YES
10	Others (Research)	III	YES	NO	NO	NO	YES
11	Others (Planning)	III	NO	NO	NO	YES	NO
12	Others (Planning)	III	YES	NO	YES	YES	YES
13	Others (Planning)	III	NO	NO	YES	YES	YES
14	Others (Soils)	III	NO	YES	NO	YES	YES
15	Others (Soils)	III	NO	YES	NO	NO	YES
16	Others (Air Quality)	V	YES	NO	YES	YES	YES
17	Materials & Testing	III	YES	YES	YES	YES	YES
18	Materials & Testing	III	NO	YES	NO	YES	YES
19	Materials & Testing	III	NO	YES	YES	YES	YES
20	Materials & Testing	III	YES	YES	NO	YES	YES

(continued)

TABLE 4.7. (Continued)

Respondent Number	Major Work Category	Regional Category	Variables				
			Rainfall	Freeze-thaw	Traffic	PSI	Distress
21	Materials & Testing	III	NO	NO	YES	NO	YES
22	Materials & Testing	III	YES	YES	YES	YES	YES
23	Materials & Testing	II	YES	NO	YES	YES	YES
24	Maintenance	III	YES	NO	YES	YES	YES
25	Maintenance	III	NO	NO	YES	YES	YES
26	Maintenance	III	YES	YES	NO	NO	YES
27	Maintenance	V	YES	YES	NO	NO	YES
28	Maintenance	V	YES	NO	YES	NO	YES
29	Maintenance	V	NO	YES	NO	NO	YES
30	Construction	III	NO	NO	YES	NO	YES
31	Construction	III	NO	YES	NO	YES	YES
32	Construction	III	YES	YES	YES	NO	YES
33	Construction	III	YES	NO	NO	YES	YES
34	Construction	III	NO	NO	NO	YES	YES
35	Design	II	NO	NO	YES	YES	YES
36	Design	II	NO	NO	YES	YES	NO
37	Design	_	YES	NO	YES	YES	YES
38	Design	_	YES	NO	YES	NO	YES
39	Design	V	YES	NO	YES	YES	YES

(continued)

TABLE 4.7. (Continued)

Respondent Number	Major Work Category	Regional Category	Variables				
			Rainfall	Freeze-thaw	Traffic	PSI	Distress
40	Design	V	NO	NO	NO	YES	YES
41	Administrative	V	YES	YES	YES	NO	YES
42	Administrative	V	YES	NO	NO	NO	YES
43	Administrative	II	YES	YES	YES	YES	YES

Legend:

YES - variable is significant at 95% level of confidence

NO - variable is not significant

_ no information given

Determination of a Cut-off Score For Rehabilitation Work

As mentioned in the previous chapter, each respondent was also asked to indicate on his rating sheet whether or not a pavement section needs to be considered a candidate for rehabilitation. This was done primarily to identify a cut-off score at which road repair work is considered to be necessary.

In order to obtain an estimate of a cut-off score, the responses were grouped into several rating intervals, as shown in Table 4.8. A count of the number of observations falling within a particular interval was made. Each observation was associated with either a "YES" or a "NO" response to the question of whether a particular pavement section should be considered a candidate for rehabilitation. For each rating interval, the percentage of the number of observations that was associated with a "YES" response was calculated, and these percentages are recorded in Table 4.8. A plot of the distribution of "YES" responses for each rating interval was then made, and a smooth curve was fitted through the midpoints of the intervals, as illustrated in Fig 4.3. An estimate of a suitable cut-off score can then be made using this figure. For the analysis, the point on the Y-axis corresponding to equal percentages of "YES" and "NO" responses (i.e., Y = 50 percent) was used to estimate the cut-off score. By entering Fig 4.3 at Y = 50 percent , an estimate of the cut-off score equal to 5.6 is obtained, as illustrated in the figure.

TABLE 4.8 PERCENTAGE OF "YES" OBSERVATIONS IN EACH RATING INTERVAL

Rating Interval	Number of Observations	% of "YES" Observations
1 - 2	52	100.0
2 - 3	90	100.0
3 - 4	133	98.5
4 - 5	167	88.6
5 - 6	144	53.5
6 - 7	138	33.3
7 - 8	116	11.2
8 - 9	100	7.0
9 - 10	89	0.0

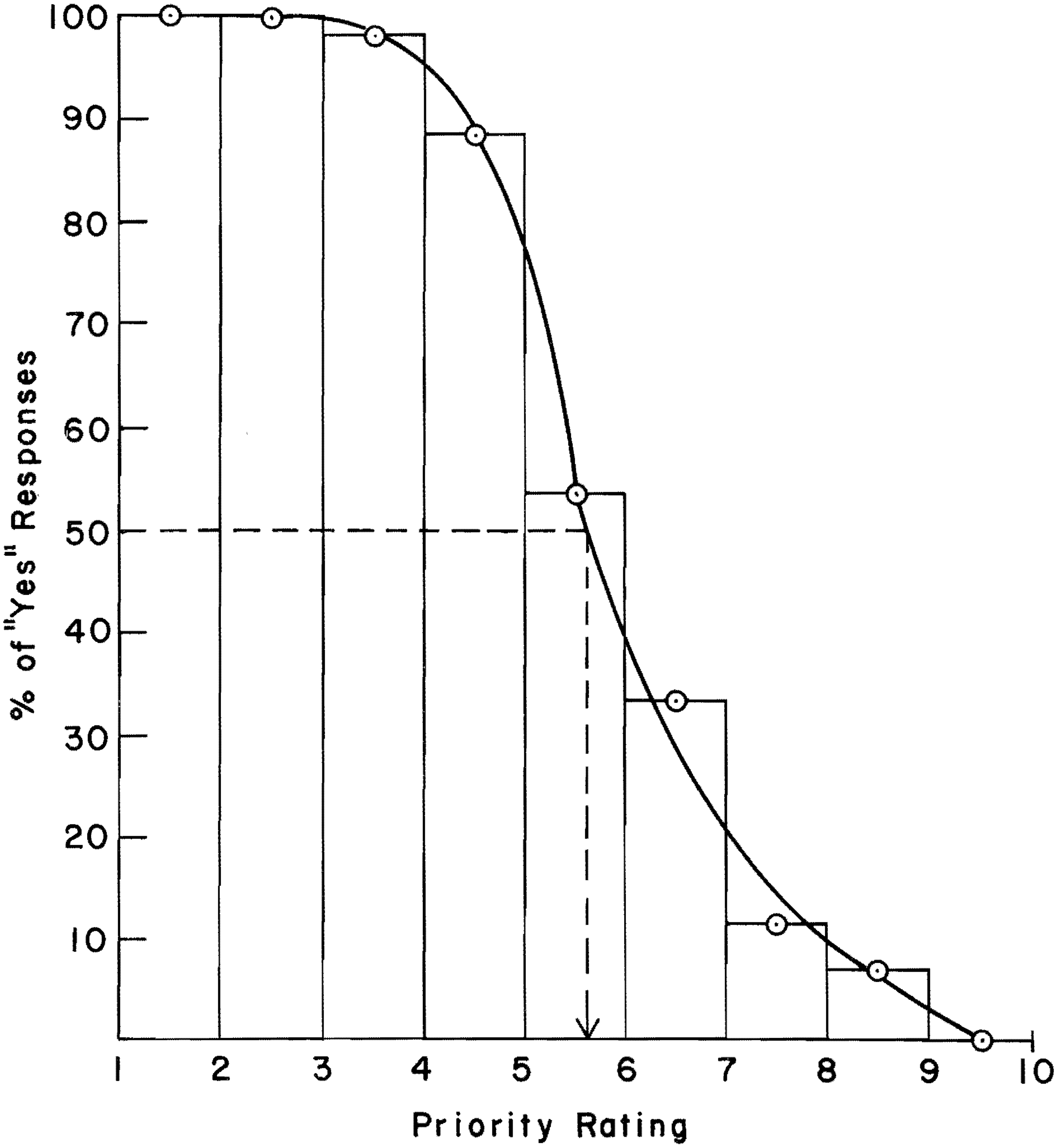

Fig 4.3. Distribution of "Yes" responses for each rating interval.

EVALUATION OF RESPONSES FOR THE SECOND FACTORIAL DESIGN

In the succeeding paragraphs, the priority ratings from the second factorial design are analyzed. As mentioned in Chapter 3, it was decided to construct another factorial scheme in which the influence of pavement type can be examined. The second factorial design adopted is essentially a modification of the first factorial design. Based on the analysis presented in an earlier section, no significant non linearity of responses associated with the distress variable was found. Consequently, in the second factorial design, the distress variable was fixed at only two levels, and the final research design selected was a half-replicate of a 2^6 factorial.

Evaluation of the Influence of Pavement Type

A regression equation of the average priority ratings shown in Table 4.9 was calculated in order to verify whether pavement type has a significant influence on the ratings obtained. For the analysis, a value of -1 was used as the code for rigid pavements, and a value of +1 was used for flexible pavements. Values for the other five main variables were coded in the same way as was done for the analysis of priority ratings for the initial factorial design. The computed regression equation is

$$\begin{aligned} Y = {} & 5.43 + 0.389X_1 + 0.236X_2 + 0.735X_3 + 0.872X_4 \\ & + 1.37X_5 - 0.079X_6 - 0.0397X_7 + 0.0598X_8 \\ & - 0.0199X_9 \qquad (4.6) \end{aligned}$$

R^2 = 97.3 percent SEE = 0.37

TABLE 4.9 MEANS AND STANDARD DEVIATIONS OF PRIORITY RATINGS, AND CONFIDENCE INTERVAL ESTIMATES OF MEAN RATINGS FOR SECOND FACTORIAL DESIGN

Section Number	Mean Rating	Standard Deviation	Confidence Interval Estimate of Mean Rating (95% Level)
258	6.36	1.62	5.72 - 7.00
213	3.81	1.46	3.23 - 4.39
206	2.93	1.61	2.29 - 3.57
231	6.23	1.66	5.57 - 6.89
235	5.17	1.84	4.44 - 5.90
249	3.05	1.67	2.39 - 3.71
224	7.18	1.67	6.52 - 7.84
244	8.68	1.35	8.15 - 9.21
218	3.80	1.48	3.22 - 4.38
255	5.42	1.85	4.69 - 6.15
246	5.53	1.42	4.97 - 6.09
264	8.80	1.60	8.16 - 9.44
225	4.21	1.64	3.56 - 4.86
211	5.75	2.03	4.95 - 6.55
204	6.81	1.90	6.06 - 7.56
237	2.44	1.29	1.93 - 2.95
241	4.69	1.55	4.08 - 5.30
259	7.23	1.82	6.51 - 7.94
234	4.18	1.77	3.48 - 4.87
216	7.66	1.76	6.97 - 8.35
252	8.28	1.51	7.68 - 8.88
230	5.31	1.60	4.68 - 5.94
207	4.64	1.64	3.99 - 5.29
221	2.38	1.35	1.85 - 2.91
210	4.92	1.53	4.32 - 5.52
228	8.26	1.65	7.61 - 8.91
247	6.41	1.44	5.84 - 6.98
240	7.48	1.56	6.86 - 8.10
201	1.95	1.41	1.39 - 2.51
254	4.60	1.74	3.91 - 5.29
219	4.74	1.74	4.05 - 5.43
261	4.74	1.57	4.12 - 5.36

where

X_1 = rainfall variable,

X_2 = freeze-thaw variable,

X_3 = traffic variable,

X_4 = PSI variable,

X_5 = distress variable,

X_6 = pavement type variable, and

X_7, X_8 and X_9 = variables used for representing the various blocks into which the design was divided.

Tests of significance for the coefficients of the independent variables in Eq 4.6 were made to determine the strength of the relationship between each independent variable and dependent variable (priority rating). In connection with this, the calculated t-statistics for the coefficients are shown in Table 4.10. By comparing the values of each of these statistics with the value of $t = \pm 2.074$ for (32-10) = 22 d.f. and 95 percent confidence level, it is seen that only the first five main variables are significant. The results do not indicate differences in the responses obtained between blocks. This indicates that the division of the factorial design into four blocks was not arbitrary and that any other division would have yielded similar results.

In addition, the analysis seems to indicate that when decisions on priorities are made, consideration of whether a pavement is flexible or rigid is probably not as important as consideration of the other main variables, such as the degree of distress of a pavement section, its present serviceability index, and the volume of traffic passing over. Another interpretation may be that, given a flexible pavement and a rigid pavement

TABLE 4.10 COMPUTED t - STATISTICS FOR COEFFICIENTS OF THE VARIABLES IN EQ. (4.6)

Variable	Coefficient	t - Statistic
Rainfall (X_1)	0.389	5.94
Freeze-thaw (X_2)	0.236	3.60
Traffic (X_3)	0.735	11.22
PSI (X_4)	0.872	13.31
Distress (X_5)	1.370	20.91
Pavement Type (X_6)	-0.079	-1.21
X_7	-0.040	-0.61
X_8	0.060	0.91
X_9	-0.020	-0.30

under similar conditions, a highway engineer would feel the same regarding the rehabilitation need for both pavements. However, the ratings obtained may actually be indicative of how the respondents felt regarding the adequacy of each pavement section in its present state and not in any future state. If this is the case, then it is reasonable for the priority ratings to have been made more on the basis of the given levels of distress, PSI, traffic, rainfall, and freeze-thaw. Had the respondents been thinking also of the future state of a pavement section, then the influence of pavement type might have turned out to be significant since some highway engineers may feel that one pavement type deteriorates faster than the other.

However, it is probably desirable to point out that determining which pavement type deteriorates more rapidly is really quite difficult. Rate of deterioration could be a function of many variables, such as pavement structure, traffic, and environmental conditions, and caution should be exercised before expressing any strong opinion regarding which pavement type deteriorates at a faster rate. As such, it may be better for priority ratings to be assigned on the basis of how a highway engineer feels about the adequacy of a pavement section in its present state and not in any future state.

Determination of the Relative Significance Between Variables

An effort to determine the relative significance between variables was made to investigate whether respondents for the second factorial design felt the same way regarding the relative importance of the variables as the respondents for the initial factorial design. In connection with this, the standardized regression equation of the priority ratings was calculated as a function of the five significant variables, namely, (1) distress, (2) PSI, (3) traffic, (4) rainfall, and (5) freeze-thaw. The equation obtained is

$$Y = 0.205X_1 + 0.124X_2 + 0.387X_3 + 0.459X_4 + 0.722X_5 \qquad (4.7)$$

$$R^2 = 97 \text{ percent} \qquad SEE = 0.19$$

where

X_1 = rainfall factor,

X_2 = freeze-thaw factor,

X_3 = traffic factor,

X_4 = PSI factor, and

X_5 = distress factor.

By comparing directly the coefficients of the above regression equation, one can obtain the relative order of significance among the variables considered. The result of the comparison indicates that participants in the second survey (i.e., those who filled out the second rating form) felt the same way as the participants in the initial survey felt regarding the relative significance of the variables. Both sets of participants felt that distress is the most important variable, followed by PSI, traffic, rainfall, and freeze-thaw, in order of importance.

Estimation of Interaction Effects Between Variables

The significance of each of the following two-factor interactions was also evaluated: AB, AC, AD, AE, BC, BD, BE, CD, CE, and DE. The results obtained show that the CD, CE, and DE interactions are statistically significant while the remaining ones are not. However, as with the case of the previous analysis, a substantial amount of variation (97 percent, as shown in Eq 4.7) can already be explained by the five main variables. Consequently, it is again felt that although the CD, CE, and DE interaction terms are statistically significant, the use of only the five main variables in the priority analysis is sufficient for practical purposes.

Evaluation of the Effect of Differences in Backgrounds Among Respondents

An effort was also made to evaluate whether differences in priority ratings can be associated with differences in backgrounds among respondents. The results of the analysis mirror those obtained previously. As before, no particular characteristics were identified that clearly define how priorities are established by members of any particular work group or regional category. The findings again indicate that each individual has his own opinion or way of thinking regarding how rehabilitation priorities are to be established.

Comparison of the Regression Equations From Both Surveys

In order to check for similarity in the results of the first and second factorial designs, a comparison of the regression equations calculated for both surveys is made herein. For the analysis, pairwise comparisons of the beta coefficients of Eqs 4.3 and 4.7 are made using a t - test. For each pair of coefficients, the t - statistic expressed as Eq 4.8 is calculated:

$$t = \frac{\beta_{i,1} - \beta_{i,2}}{\sigma_{\beta_{i,1} - \beta_{i,2}}} \qquad (4.8)$$

where

$\beta_{i,1}$ = beta coefficient for the i^{th} independent variable in the standardized regression equation for the first survey (Eq 4.3),

$\beta_{i,2}$ = beta coefficient for the i^{th} independent variable in the standardized regression equation for the second survey (Eq 4.7), and

$\sigma_{\beta_{i,1}-\beta_{i,2}}$ = standard error of the difference between the beta coefficients.

In the analysis, an estimate of the standard error is made using Eq 4.9:

$$\sigma_{\beta_{i,1} - \beta_{i,2}} = \sqrt{S_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} \qquad (4.9)$$

where

S_p^2 = pooled estimate of variance,

n_1 = number of observations for the first factorial design (equal to 24), and

n_2 = number of observations for the second factorial design (equal to 32).

Initially, a comparison of the mean squares of the residuals was made using an F-test. The result of the comparison indicates that it is reasonable to assume equal variances in the ratings obtained from the two surveys. A pooled estimate of variance can therefore be made by adding the sums of squares of the residuals for the two regression equations and dividing the sum by the total number of degrees of freedom for both equations.

The t-statistics calculated using Eq 4.8 are summarized in Table 4.11. By comparing the computed t-statistics with the value of $t \approx \pm 2.017$ corresponding to a 95 percent confidence level and (18 + 26) = 44 degrees of freedom, it is seen that the beta coefficients of the regression equations are not significantly different from each other. Consequently, the analysis seems to indicate that the first and second surveys yielded similar results.

PRIORITIZATION PROCEDURE FOR A SIMPLIFIED NETWORK LEVEL PMS

Based on the results of the preceding analyses, it is felt that the variables distress, PSI, traffic, rainfall, and freeze-thaw form an adequate set of criteria to use for a network level prioritization procedure. Since the results of the two surveys conducted are quite similar, the responses obtained from either one may be used to establish an equation for calculating priority ratings as a function of the five variables mentioned previously. Using the average responses obtained from the initial survey, the following regression equation is established:

$$Y = 5.26 + 0.46X_1 + 0.396X_2 + 0.601X_2 + 0.749X_4 + 1.66X_5 \qquad (4.10)$$

R^2 = 97.8 percent SEE = 0.31

TABLE 4.11 COMPUTED t - STATISTICS FOR PAIRWISE COMPARISONS OF THE BETA COEFFICIENTS OF EQS. 4.3 and 4.7

Variable	$\beta_{i,1}$	$\beta_{i,2}$	t
Rainfall (X_1)	0.252	0.205	0.97
Freeze-thaw (X_2)	0.217	0.124	1.93
Traffic (X_3)	0.329	0.387	-1.20
PSI (X_4)	0.410	0.459	-1.02
Distress (X_5)	0.757	0.722	0.72

where

X_1 = rainfall factor,

X_2 = freeze-thaw factor,

X_3 = traffic factor,

X_4 = PSI factor, and

X_5 = distress factor.

In this equation, each of the independent variables takes on values in the range of -1 to +1. As mentioned earlier, -1 was used to code values of the variables that correspond to their worst levels and +1 was used to code values of the variables corresponding to their best levels.

In order to use Eq 4.10, therefore, categories of the independent variables corresponding to values within the range of -1 to +1 should be established. This could probably be done through consultation with highway engineers. Tentatively however, the categories shown in Table 4.12 for each of the factors considered may be utilized. It is emphasized that the categories listed are subject to modifications, depending on the opinions of highway engineers within the department.

Alternatively, a regression equation can also be established which would allow input of the values of the independent variables directly. In connection with this, the average priority ratings were regressed with the values of the independent variables shown below:

VARIABLE	"BEST" LEVEL	"WORST" LEVEL
Rainfall (X_1)	5 inches/year	40 inches/year
Freeze-thaw (X_2)	0 cycles/year	60 cycles/year

TABLE 4.12 SUGGESTED CATEGORIES OF THE VARIABLES IN EQ 4.10

A. Rainfall - inches/year

Categories	Numerical Value
≤10	+1.0
>10 but ≤20	0.5
>20 but ≤30	0.0
>30 but <40	-0.5
≥40	-1.0

B. Freeze-thaw - cycles/year

Categories	Numerical Value
≤15	+1.0
>15 but ≤30	0.5
>30 but ≤45	0.0
>45 but <60	-0.5
≥60	-1.0

C. Traffic, ADT

Categories	Numerical Value
≤1000	+1.0
>1000 but ≤8000	0.5
>8000 but ≤15,000	0.0
>15,000 but <23,000	-0.5
≥23,000	-1.0

D. Present Serviceability Index

Categories	Numerical Value
<2.5	-1.0
≥2.5 but <3.0	-0.5
≥3.0 but <3.5	0.0
≥3.5 but <4.0	+0.5
≥4.0	+1.0

(continued)

TABLE 4.12. (Continued)

E. Distress

Categories	Numerical Value
1. Rigid Pavements	
a) Minimal Distress - 5 or fewer failures per mile, some minor spalling, little or no pumping at edges and longitudinal joints	+1.0
b) Moderate Distress - 6-13 failures per mile, fair percentages of minor spalling in pavement section, some severe spalling, moderate pumping at edges and longitudinal joints	0.0
c) Significant Distress - 14 or more failures per mile, fair to substantial amounts of severe spalling, moderate to extensive pumping at edges and longitudinal joints	-1.0
2. Flexible Pavements	
a) Minimal Distress - slight cracking, little or no rutting and slight alligatoring in a few areas	+1.0
b) Moderate Distress - intermittent moderate cracking with some spalling, frequent slight cracking, and intermittent slight or moderate alligatoring and rutting	0.0

(continued)

TABLE 4.12. (Continued)

Categories	Numerical Value
c) Significant Distress - extensive moderate cracking and rutting, frequent moderate alligatoring	-1.0

Traffic (X_3)	100 ADT	100,000 ADT
PSI (X_4)	4.0	2.0
Distress (X_5)	+1.0	-1.0

The regression equation obtained from the analysis is

$$Y = 5.4 - 0.0263X_1 - 0.0132X_2 - 0.4LOG_{10}X_3 + 0.749X_4 + 1.66X_5 \qquad (4.11)$$

$$R^2 = 97.8 \text{ percent} \qquad SEE = 0.31$$

The values used for the first four variables are felt to be representative of the conditions that might exist in the field. For the distress variable, the numerical values are the same as those used for computing Eq 4.10, and the categories listed in Table 4.12 for this variable may also be used as a guide in the determination of the appropriate numerical values to use for various degrees of distress.

The categories for the distress variable are those which appear in the initial survey form shown in Appendix A. Although the categories are expressed in terms of word descriptions, it is also possible to use some quantified distress score should this be desired. A uniform set of verbal descriptions that characterizes qualitatively the degree of distress may, however, serve as a practical guide for evaluating pavement condition. In particular, since pavement condition is expressed in terms which are familiar to a field engineer, the use of a uniform set of word descriptions may be something that he can easily relate to. In addition, verbal descriptions may help to guide the choice of maintenance or rehabilitation treatments. As such, their use, in conjunction with quantified measures of distress, is also worth considering. Finally, it may be noted that Eqs 4.10 and 4.11 do not yield an exact value of 1.0 or 10.0 when all of the variables are at their lowest or highest levels. This may be expected because there is still some amount of variation that is not explained by the regression equations. It is felt however that the results obtained using either equation can still be used directly for establishing priority rankings.

SUMMARY

In this chapter, the opinions of numerous highway engineers regarding the establishment of rehabilitation priorities were evaluated. Statistical analyses made indicate that, overall, the variables distress, PSI, traffic, rainfall, and freeze-thaw significantly influence decisions on priorities. In addition, certain two-factor interactions were found to be statistically significant. However, it was recognized that the five main variables mentioned previously can already account for a very substantial portion of the total variation in the responses obtained. Consequently, it is felt that the two-factor interactions can be ignored, and that the assumption of independence among variables seems reasonable. In addition, the following results were obtained:

(1) There was no significant non linearity of responses associated with the distress variable.

(2) No particular characteristics were identified that clearly defined how priorities are established by members of any particular work group or regional category.

(3) Pavement type did not turn out to be a significant factor in the analysis.

Finally, a procedure was presented which may be used for establishing priorities for a simple network level PMS. Using results from the initial survey, two regression equations were established, either of which may be used for prioritizing projects. The variables distress, PSI, traffic, rainfall, and freeze-thaw were used as the independent variables in the regression equations.

CHAPTER 5. SAMPLE APPLICATION OF THE PRIORITIZATION PROCEDURE

In the previous chapter, a prioritization procedure was developed that can be used for establishing rehabilitation priorities at the network level PMS. In this chapter, an application of the procedure is briefly presented.

To illustrate how the procedure is used in establishing priorities for rehabilitation work, a number of hypothetical pavement sections were set up, as shown in Table 5.1. For simplicity, the sections listed are assumed to be rigid pavements in the example. Each section is represented by a project number, and data on the amount of rainfall, amount of freeze-thaw, traffic level, PSI, and distress rating are given for each pavement section. The categories listed in Table 4.12 for the distress variable may be used as a guide for defining the distress ratings given in Table 5.1.

By using Eq 4.11, developed in the previous chapter, a prioritization index was calculated for each of the sections listed in Table 5.1. The computed indices can then be used for assigning priority rankings to the given sections (Table 5.2).

The results show that the section with project number 9-6189-NB has the highest priority for rehabilitation work, followed by section 3-6352-EB. Although both of these sections have the same distress ratings, section 9-6189-NB has twice as much traffic as the other section, and it is in an area with a greater amount of freeze-thaw cycling. As such, a higher priority ranking was assigned to section 9-6189-NB.

TABLE 5.1. HYPOTHETICAL DATA USED IN THE ILLUSTRATIVE EXAMPLE AND CALCULATED PRIORITIZATION INDICES

Project Number	Amount of Rainfall (inches/year)	Amount of Freeze-Thaw (cycles/year)	Traffic Level (ADT)	PSI	Distress Rating	Prioritization Index
8-2340-NB	30	25	20,000	3.4	+1.0	6.77
10-1029-EB	15	20	30,000	3.1	0.0	5.27
2-3471-WB	25	35	60,000	3.2	0.5	5.60
9-6189-NB	20	40	40,000	2.7	-1.0	2.87
12-5309-SB	29	28	50,000	3.6	+1.0	6.74
14-3070-WB	15	20	75,000	2.5	-0.5	3.83
7-6571-NB	35	36	38,000	3.0	0.0	4.42
3-6352-EB	23	18	20,000	2.5	-1.0	3.05

TABLE 5.2. PRIORITY RANKINGS OF PAVEMENT SECTIONS BASED ON THE CALCULATED PRIORITIZATION INDICES

Project Number	Prioritization Index	Ranking
9-6189-NB	2.87	1
3-6352-EB	3.05	2
14-3070-WB	3.83	3
7-6571-NB	4.42	4
10-1029-EB	5.27	5
2-3471-WB	5.60	6
12-5309-SB	6.74	7
8-2340-NB	6.77	8

The results obtained for sections 8-2340-NB and 12-5309-SB are also worth considering. Both of these sections have the same distress rating and are located in areas with similar environmental characteristics. In addition, the PSI's for both sections are not very much different from each other. However, section 12-5309-SB carries a significantly larger volume of traffic than section 8-2340-NB. Consequently, a higher priority ranking was assigned to section 12-5309-SB.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

As highway budget levels shrink in the face of growing inflation and traffic levels increase, the development of systematic procedures for providing and maintaining pavements will become more and more of a necessity for highway agencies. In essence, this body of systematic procedures, structured to meet the needs of the implementing agency, is what constitutes a pavement management system. An integral part of any pavement management system is a subset of procedures for establishing priorities for rehabilitation work. In this particular pavement management activity, inventory data are used to assess network level status and needs, and decisions are made as to what rehabilitation and maintenance projects to include in the coming work program. The objective, of course, of this activity is to establish a work program that will make the best use of the available funds. Using a set of decision variables established within the particular agency, the adequacy of pavement sections is assessed, and a pavement score or index is generally calculated for each section to facilitate priority ranking for rehabilitation and/or maintenance work. The formulation of a prioritization variable is, therefore, one of the major tasks required in developing pavement management systems.

In this report and approach to, the formulation of a prioritization index using a rational factorial rating method was presented. The method is simple in concept, and, as the name implies, is based on a factorial design involving a set of candidate decision variables, such as distress and present serviceability index. It is also felt that the method is a rational way of formulating a prioritization procedure. Because the effects of two or more independent variables can be studied simultaneously in a factorial design, the method can provide a better insight as to how decisions on priorities are made by pavement engineers. In addition, the method allows for the estimation of the effects of the variables included in the design, thus making it possible to identify the key variables.

One major limitation of the method, however, is the problem associated with keeping the design to a manageable size. It is recognized that as the number of factors and/or number of variable levels increases, the size of the factorial also increases. Consequently, it may be harder to solicit opinions from pavement engineers. However, it is also felt that the problem could be overcome by judicious selection of a factorial design that keeps the number of variable combinations to a desirable limit and still allows sufficient information to be gained. In addition, it is recognized that for network level purposes, it may be sufficient to have information on only a few variables. This is because, at this level, only overall judgments on the needs of the road network are required and candidates which appear in the final program of work will, in general, require further scrutiny before any rehabilitation activity is performed (Ref. 6).

It is recognized that, since the rational factorial rating method is a fairly new approach to formulating a prioritization procedure, some experience with using it is probably required before any judgment can be made on whether it is good or not. Consequently, it is recommended that the prioritization procedure presented in the previous chapter be tested to verify whether priority listings obtained from it agree reasonably well with the opinions of pavement engineers who are responsible for establishing priorities for rehabilitation and maintenance work. This might also point out modifications which could be made in the procedure. In particular, it may be necessary to modify the categories of the variables suggested in the previous chapter (Table 4.12).

Finally, it is recommended that future research efforts be directed towards estimating changes in the prioritization variable resulting from the application of specific rehabilitation options. It is recognized that the selection of the best rehabilitation measure is also a pavement management activity. In addition, it is desirable for any pavement management system to continually improve, and for it to extend its functions from the relatively simple activity of providing priority listings to the more complex activity of providing estimates of the best rehabilitation measures for particular projects. In this regard, the development of models for estimating changes in the prioritization variable as a function of the particular rehabilitation option selected is probably required.

Models may be developed using multiple regression techniques or through a Markovian procedure. Each of the estimated changes resulting from the application of a particular rehabilitation option can then be divided by the cost associated with each option to obtain a measure of its "economic efficiency." The higher the expected improvement in the prioritization variable, and the lower the cost, the better the rehabilitation option. In this way, the various rehabilitation measures may then be ranked according to their "economic efficiencies". The option with the highest "economic efficiency" then corresponds to the best rehabilitation option.

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APPENDIX A

RATING FORM FOR FIRST FACTORIAL DESIGN

APPENDIX A. RATING FORM FOR FIRST FACTORIAL DESIGN

INTRODUCTION

We would like to request your assistance in a research project being undertaken by the Center for Transportation Research of The University of Texas at Austin for the Texas State Department of Highways and Public Transportation. A review and evaluation of alternative approaches to formulating a prioritization index has led to the development of a method called the rational factorial rating method that it is hoped will lead to a more realistic and rational way of establishing candidate projects for rehabilitation work. We would like to illustrate the application of the method to the formulation of an index for prioritizing rehabilitation projects.

In connection with this study we have prepared a rating sheet, and we request you to fill it out according to the instructions given. Your answers should be based solely on your personal opinion developed from your own experience. Please do not be influenced by other raters. You should neither look at their ratings nor show them yours. There are no right or wrong answers, and your responses will be strictly confidential. The information obtained shall be used in formulating an index considering the following factors: (1) pavement distress evaluation, (2) present serviceability of the pavement section, (3) traffic level, and (4) environmental conditions. The following verbal descriptions are taken to be indicative of the various levels considered for the pavement distress evaluation factor.

For Rigid Pavements

(1) Minimal Distress - 5 or fewer failures per mile, some minor spalling, little or no pumping at edges and longitudinal joints.

(2) Moderate Distress - 6 to 13 failures per mile, fair percentage of minor spalling in pavement section, some severe spalling, and moderate pumping at edges and longitudinal joints.

(3) Significant Distress - 14 or more failures per mile, fair to substantial amounts of severe spalling, moderate to extensive pumping at edges and longitudinal joints.

For Flexible Pavements

(1) Minimal Distress - slight cracking, little or no rutting, slight alligatoring in a few areas.

(2) Moderate Distress - intermittent moderate cracking with some spalling, frequent slight cracking, intermittent slight or moderate alligatoring and rutting.

(3) Significant Distress - extensive moderate cracking and rutting, frequent moderate alligatoring.

Instructions

Please fill out the rating sheet according to the following instructions:

(1) Examine carefully all sections with the given combinations of variables.

(2) Treat each combination as representing a pavement section experiencing a particular and unique set of conditions including (a) the stated pavement distress evaluation, (b) PSI, (c) traffic level, and (d) environmental related factors.

(3) Rate each of the sections described, using a scale from 1.0 to 10.0 (decimal ratings such as 3.2 are permitted), where 1.0 indicates a pavement with a high rehabilitation priority, and 10.0 includes a pavement with a low rehabilitation priority.

Bear in mind that the given combinations of variables are not exhaustive. Consequently, before writing down your ratings, think of the worst and the best possible combinations of the variables which might exist. A pavement under the worst possible combination(s) of variables, in your judgement, should receive a rating of 1.0 and a pavement under the best combination(s) a rating of 10.0.

(4) Assign ratings for the given sections described relative to the worst and the best sets of conditions you have established in step 3. Write your ratings in the spaces provided for them.

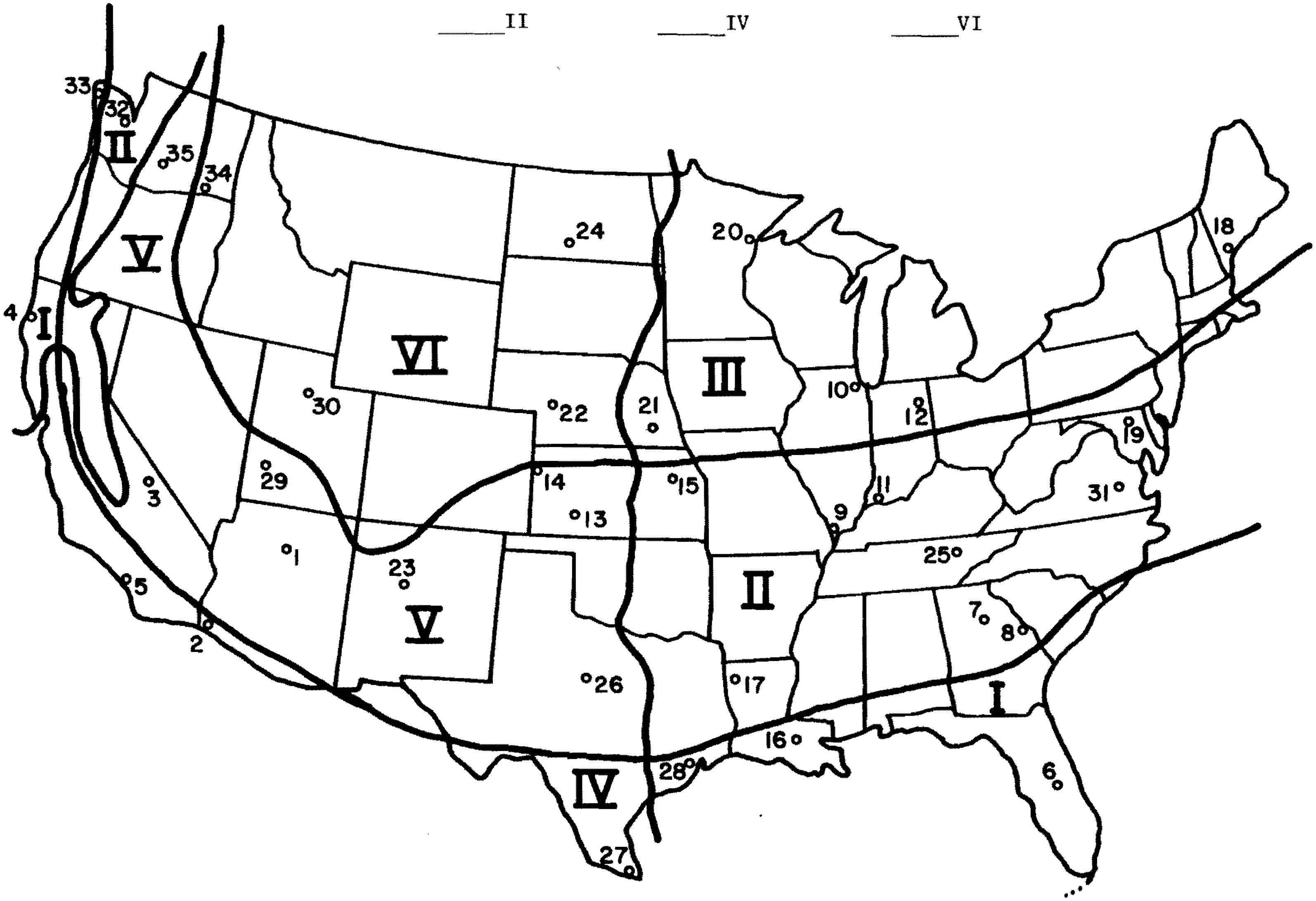
(5) For each combination of variables, indicate whether the pavement should at this time be a candidate for rehabilitation work, by placing an X in either the "YES" or "NO" blank provided for this purpose.

THANK YOU VERY MUCH FOR YOUR COOPERATION.

Indicate the geographic region where you obtained most of your work experience by placing an X in the appropriate space below:

_____I _____III _____V

_____II _____IV _____VI



Indicate your major work area by putting an X in the appropriate space below:

____Administrative ____Construction Date: ____________

____Design ____Materials & Testing

____Maintenance ____Others (specify ____________)

Assign ratings for the following pavement sections:

Section No.	Environmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section Be Considered a Candidate for Rehabilitation?
123	Wet, No Freeze Thaw	Low	2.4	Minimal Distress	________	YES:____NO:____
130	Dry, Freeze Thaw	High	3.5	Minimal Distress	________	YES:____NO:____
137	Dry, No Freeze Thaw	High	2.4	Significant Distress	________	YES:____NO:____
122	Wet, No Freeze Thaw	Low	3.5	Moderate Distress	________	YES:____NO:____
135	Dry, Freeze Thaw	Low	2.4	Minimal Distress	________	YES:____NO:____
118	Wet, No Freeze Thaw	High	3.5	Minimal Distress	________	YES:____NO:____
108	Wet, Freeze Thaw	Low	3.5	Significant Distress	________	YES:____NO:____
134	Dry, Freeze Thaw	Low	3.5	Moderate Distress	________	YES:____NO:____
101	Wet, Freeze Thaw	High	2.4	Significant Distress	________	YES:____NO:____
127	Dry, Freeze Thaw	High	2.4	Moderate Distress	________	YES:____NO:____
144	Dry, No Freeze Thaw	Low	3.5	Significant Distress	________	YES:____NO:____
115	Wet, No Freeze Thaw	High	2.4	Moderate Distress	________	YES:____NO:____

*Low ∿ 6000 ADT

High ∿ 100,000 ADT

Indicate your major work area by putting an X in the appropriate space below:

____Administrative ____Construction Date:__________________

____Design ____Materials & Testing

____Maintenance ____Others (specify ________________)

Assign ratings for the following pavement sections:

Section No.	Enviornmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section Be Considered a Candidate for Rehabilitation?
105	Wet, Freeze Thaw	High	2.4	Minimal Distress	________	YES:____NO:____
131	Dry, Freeze Thaw	Low	2.4	Significant Distress	________	YES:____NO:____
104	Wet, Freeze Thaw	High	3.5	Moderate Distress	________	YES:____NO:____
145	Dry, No Freeze Thaw	Low	2.4	Moderate Distress	________	YES:____NO:____
140	Dry, No Freeze Thaw	High	3.5	Moderate Distress	________	YES:____NO:____
148	Dry, No Freeze Thaw	Low	3.5	Minimal Distress	________	YES:____NO:____
119	Wet, No Freeze Thaw	Low	2.4	Significant Distress	________	YES:____NO:____
141	Dry, No Freeze Thaw	High	2.4	Minimal Distress	________	YES:____NO:____
112	Wet, Freeze Thaw	Low	3.5	Minimal Distress	________	YES:____NO:____
114	Wet, No Freeze Thaw	High	3.5	Significant Distress	________	YES:____NO:____
109	Wet, Freeze Thaw	Low	2.4	Moderate Distress	________	YES:____NO:____
126	Dry, Freeze Thaw	High	3.5	Significant Distress	________	YES:____NO:____

*Low ∿ 6000 ADT

High ∿ 100,000 ADT

APPENDIX B

RATING FORM FOR SECOND FACTORIAL DESIGN

APPENDIX B. RATING FORM FOR SECOND FACTORIAL DESIGN

INTRODUCTION

We would like to request your assistance in a research project being undertaken to evaluate pavements for the Texas State Department of Highways and Public Transportation. A review and evaluation of alternative approaches to formulating a prioritization index has led to the development of a method called the rational factorial rating method that it is hoped will lead to a more realistic and rational way of establishing candidate projects for rehabilitation work. We would like to illustrate the application of the method to the formulation of an index for prioritizing rehabilitation projects.

In connection with this study we have prepared a rating sheet, and we request you to fill it out according to the instructions given. Your answers should be based solely on your personal opinion developed from your own experience. Please do not be influenced by other raters. You should neither look at their ratings or show them yours. There are no right or wrong answers, and your responses shall be strictly confidential. The information obtained will be used in formulating an index considering the following factors: (1) pavement distress evaluation, (2) present serviceability of the pavement section, (3) traffic level, and (4) environmental conditions. The following verbal descriptions are taken to be indicative of the various levels considered for the pavement distress evaluation factor.

For Rigid Pavements

(1) Minimal Distress - 5 or fewer failures per mile, some minor spalling, little or no pumping at edges and longitudinal joints.

(2) Significant Distress - 14 or more failures per mile, fair to substantial amounts of severe spalling, moderate to extensive pumping at edges and longitudinal joints.

For Flexible Pavements

(1) Minimal Distress - slight cracking, little or no rutting, slight alligatoring in a few areas.

(2) Significant Distress - extensive moderate cracking and rutting, frequent moderate alligatoring.

Instructions

Please fill out the rating sheet according to the following instructions:

(1) Examine carefully all sections with the given combinations of variables.

(2) Treat each combination as representing a pavement section experiencing a particular and unique set of conditions including, (a) the stated pavement distress evaluation, (b) PSI, (c) traffic level, and (d) environmental related factors.

(3) Rate each of the section described, using a scale from 1.0 to 10.0 (decimal ratings such as 3.2 are permitted), where 1.0 indicates a pavement with a high rehabilitation priority and 10.0 indicates a pavement with a low rehabilitation priority.

Bear in mind that the given combinations of variables are not exhaustive. Consequently, before writing down your ratings, think of the worst, and the best possible combinations of the variables which might exist. A pavement under the worst possible combination(s) of variables, in your judgement, should receive a rating of 1.0 and a pavement under the best combination(s) a rating of 10.0.

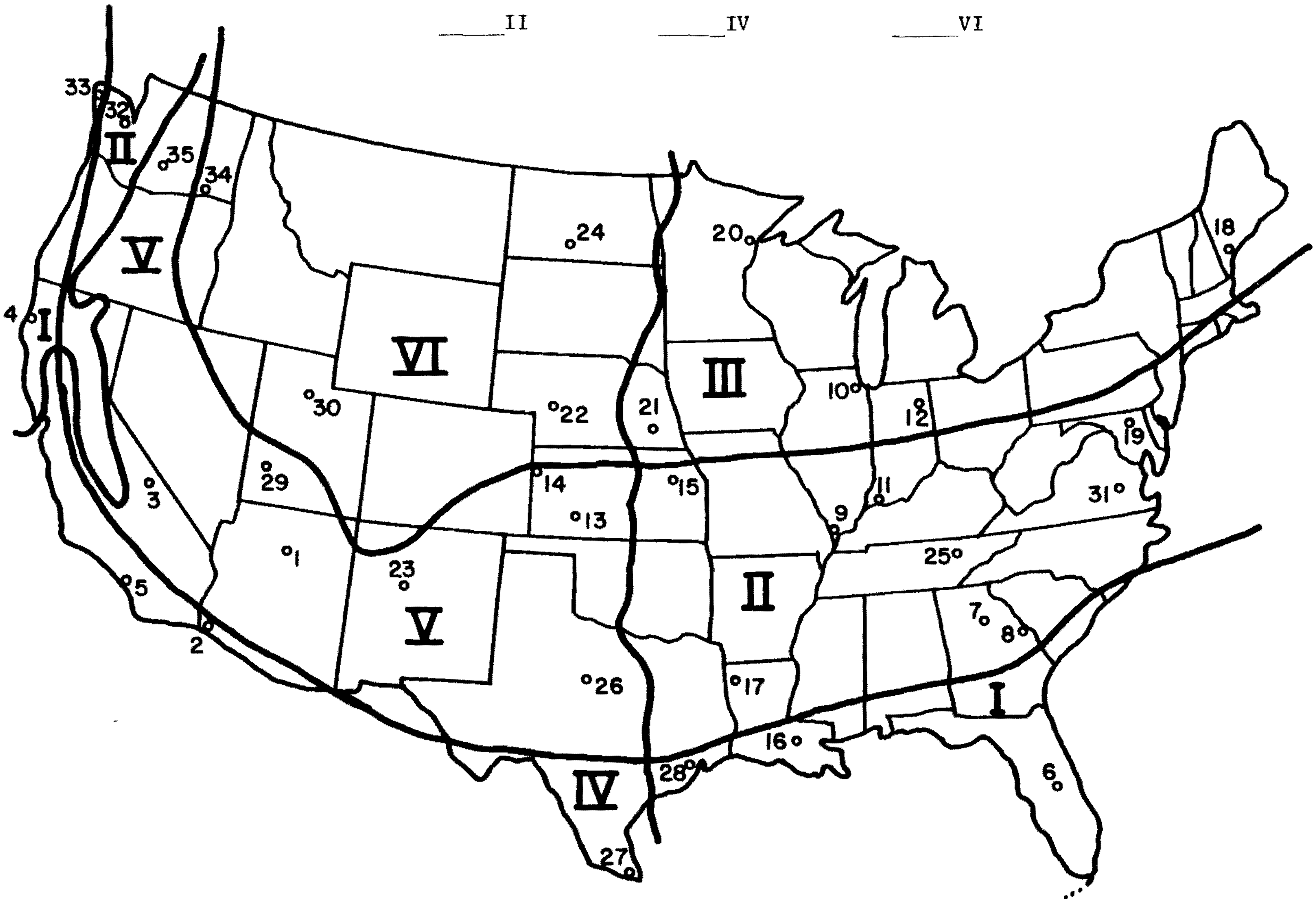
(4) Assign ratings for the given sections described relative to the worst and the best sets of conditions you have established in step 3. Write your ratings in the spaces provided for them.

(5) For each combination of variables, indicate whether the pavement should at this time be a candidate for rehabilitation work by placing an X in either the "YES" or "NO" blank provided for this purpose.

THANK YOU VERY MUCH FOR YOUR COOPERATION.

Indicate the geographic region where you obtained most of your work experience by placing an X in the appropriate space below:

_____I	_____III	_____V
_____II	_____IV	_____VI



Date:________________

INDICATE YOUR MAJOR WORK AREA BY PUTTING AN X IN THE APPROPRIATE SPACE BELOW:

___Administrative ___Construction

___Design ___Materials and Testing

___Maintenance ___Others (specify___________________________)

ASSIGN RATINGS FOR THE FOLLOWING PAVEMENT SECTIONS:

Section No.	Pavement Type	Environmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section be Considered a Candidate for Rehabilitation?	
258	Rigid	Dry, No Freeze Thaw	Low	3.5	Signif. Distress	____________	YES:_____	NO:______
213	Flexible	Wet, Freeze Thaw	Low	2.4	Signif. Distress	____________	YES:_____	NO:______
206	Flexible	Wet, Freeze Thaw	High	3.5	Signif. Distress	____________	YES:_____	NO:______
231	Flexible	Wet, No Freeze	Low	2.4	Minimal Distress	____________	YES:_____	NO:______
235	Rigid	Dry, Freeze Thaw	High	2.4	Minimal Distress	____________	YES:_____	NO:______
249	Rigid	Dry, No Freeze Thaw	High	2.4	Signif. Distress	____________	YES:_____	NO:______
224	Flexible	Wet, No Freeze Thaw	High	3.5	Minimal Distress	____________	YES:_____	NO:______
244	Rigid	Dry, Freeze Thaw	Low	3.5	Minimal Distress	____________	YES:_____	NO:______

*Low ∿ 6000 ADT
High ∿ 100,000 ADT

Date:________________

INDICATE YOUR MAJOR WORK AREA BY PUTTING AN X IN THE APPROPRIATE SPACE BELOW:

___Administrative　　　___Construction

___Design　　　___Materials and Testing

___Maintenance　　　___Others (specify____________________________)

ASSIGN RATINGS FOR THE FOLLOWING PAVEMENT SECTIONS:

Section No.	Pavement Type	Environmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section be Considered a Candidate for Rehabilitation?
218	Rigid	Wet, no Freeze Thaw	High	3.5	Signif. Distress	________	YES:____ NO:____
255	Flexible	Dry, No Freeze Thaw	High	2.4	Minimal Distress	________	YES:____ NO:____
246	Flexible	Dry, Freeze Thaw	Low	3.5	Signif. Distress	________	YES:____ NO:____
264	Flexible	Dry, No Freeze Thaw	Low	3.5	Minimal Distress	________	YES:____ NO:____
225	Rigid	Wet, No Freeze Thaw	Low	2.4	Signif. Distress	________	YES:____ NO:____
211	Rigid	Wet, Freeze Thaw	Low	2.4	Minimal Distress	________	YES:____ NO:____
204	Rigid	Wet, Freeze Thaw	High	3.5	Minimal Distress	________	YES:____ NO:____
237	Flexible	Dry, Freeze Thaw	High	2.4	Signif. Distress	________	YES:____ NO:____

* Low ∿ 6000 ADT
High ∿ 100,000 ADT

Date: ____________

INDICATE YOUR MAJOR WORK AREA BY PUTTING AN X IN THE APPROPRIATE SPACE BELOW:

___ Administrative ___ Construction

___ Design ___ Materials and Testing

___ Maintenance ___ Others (specify ____________________)

ASSIGN RATINGS FOR THE FOLLOWING PAVEMENT SECTIONS:

Section No.	Pavement Type	Environmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section be Considered a Candidate for Rehabilitation?
241	Rigid	Dry, Freeze Thaw	Low	2.4	Signif. Distress	________	YES:_____ NO:_____
259	Rigid	Dry, No Freeze Thaw	Low	2.4	Minimal Distress	________	YES:_____ NO:_____
234	Rigid	Dry, Freeze Thaw	High	3.5	Signif. Distress	________	YES:_____ NO:_____
216	Flexible	Wet, Freeze Thaw	Low	3.5	Minimal Distress	________	YES:_____ NO:_____
252	Rigid	Dry, No Freeze Thaw	High	3.5	Minimal Distress	________	YES:_____ NO:_____
230	Flexible	Wet, No Freeze Thaw	Low	3.5	Signif. Distress	________	YES:_____ NO:_____
207	Flexible	Wet, Freeze Thaw	High	2.4	Minimal Distress	________	YES:_____ NO:_____
221	Flexible	Wet, No Freeze Thaw	High	2.4	Signif. Distress	________	YES:_____ NO:_____

*Low ∿ 6000 ADT
High ∿ 100,000 ADT

Date:________________

INDICATE YOUR MAJOR WORK AREA BY PUTTING AN X IN THE APPROPRIATE SPACE BELOW:

___Administrative ___Construction

___Design ___Materials and Testing

___Maintenance ___Others (specify ________________________)

ASSIGN RATINGS FOR THE FOLLOWING PAVEMENT SECTIONS:

Section No.	Pavement Type	Environmental Condition	Traffic Level*	PSI	Pavement Distress Evaluation	Rating of Rehabilitation Need	Should Pavement Section be Considered a Candidate for Rehabilitation?
210	Rigid	Wet, Freeze Thaw	Low	3.5	Signif. Distress	__________	YES:_____ NO:_____
228	Rigid	Wet, No Freeze Thaw	Low	3.5	Minimal Distress	__________	YES:_____ NO:_____
247	Flexible	Dry, Freeze Thaw	Low	2.4	Minimal Distress	__________	YES:_____ NO:_____
240	Flexible	Dry, Freeze Thaw	High	3.5	Minimal Distress	__________	YES:_____ NO:_____
201	Rigid	Wet, Freeze Thaw	High	2.4	Signif. Distress	__________	YES:_____ NO:_____
254	Flexible	Dry, No Freeze Thaw	High	3.5	Signif. Distress	__________	YES:_____ NO:_____
219	Rigid	Wet, No Freeze Thaw	High	2.4	Minimal Distress	__________	YES:_____ NO:_____
261	Flexible	Dry, No Freeze Thaw	Low	2.4	Signif. Distress	__________	YES:_____ NO:_____

*Low ∿ 6000 ADT
High ∿ 100,000 ADT

THE AUTHORS

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E. G. Fernando was a Research Assistant at The University of Texas at Austin. He graduated with a Bachelor's Degree in Civil Engineering from the University of the Philippines in October 1978, and entered Graduate School at The University of Texas at Austin in September 1980. While in the University, he was involved with research work on Pavement Management Systems. He obtained his M. S. degree in Engineering from the University of Texas at Austin in August 1982.