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16. Abstract

This report presents the development and application of a scheme, in the form of a computer program, for prioritizing and scheduling a set of rigid pavements for rehabilitation within a specified time frame and budget constraints. The program is intended to provide the Texas State Department of Highways and Public Transportation with guidelines for generating decision elements for the management of road maintenance funds.

The prioritization and scheduling scheme is based on observed distress quantities; it makes use of distress indices and distress prediction equations, for which a detailed description is given.

The immediate application of the computer program is to generate lists of candidate pavements for rehabilitation. However, the use of the program is extended to analyze the effect of several different budget policies on the condition of the pavement network. Although availability of funds and managerial preferences play an important role in the budget selection procedure, the program can be used as an aid in the selection of a budget policy.

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RIGID PAVEMENT NETWORK REHABILITATION SCHEDULING USING DISTRESS QUANTITIES

by

Manuel Gutierrez de Velasco
B. F. McCullough

Research Report Number 249-5

Implementation of a Rigid Pavement
Overlay Design System
Research Project 3-8-79-249

conducted for

Texas State Department of Highways and
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in cooperation with the
U. S. Department of Transportation
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by the

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August 1983

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 fifth in a series of reports which describe work done on Project 249, "Implementation of a Rigid Pavement Overlay Design System." The study is being conducted at the Center for Transportation Research (CTR), The University of Texas at Austin, as part of a cooperative research program sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration.

Many people have contributed their help toward the completion of this report. Thanks are extended to Dr. W. R. Hudson for his continuous help and guidance and to all the CTR personnel, especially Jim Long, Ana Aronofsky, and Lyn Gabbert. Invaluable comments were provided by Gerald Peck and Richard Rogers, both from the Texas State Department of Highways and Public Transportation.

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LIST OF REPORTS

Report No. 249-1, "Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure," by Arthur Taute, B. Frank McCullough, and W. Ronald Hudson, presents certain improvements to the Texas Rigid Pavement Overlay Design Procedure (RPOD2) with regard to materials characterization and fatigue life predictions. November 1981.

Report No. 249-2, "A Design System for Rigid Pavement Rehabilitation," by Stephen Seeds, B. Frank McCullough, and W. Ronald Hudson, describes the developement, use and applicability of a Rigid Pavement Rehabilitation Design System, RPRDS, developed for use by the Texas State Department of Highways and Public Transportation. January 1982.

Report No. 249-3, "Void Detection and Grouting Process," by Francisco Torres and B. Frank McCullough, presents the results of an experiment and a theoretical analysis to determine an optimum procedure for detecting voids beneath CRC pavements. April 1983.

Report No. 249-4, "Effect of Environmental Factors and Loading Position on Dynaflect Deflections in Rigid Pavements," by Victor Torres-Verdin and B. Frank McCullough, discusses several of the factors that affect Dynaflect deflections in rigid pavements and provides a recommended procedure for Dynaflect deflection measurements which can be implemented on the rigid pavement overlay design procedures. Novemeber 1982.

Report No. 249-5, "Rigid Pavement Network Rehabilitation Scheduling Using Distress Quantities," by Manuel Gutierrez de Velasco and B. F. McCullough, presents the development and application of a computer program, PRP01, to prioritize and schedule a set of rigid pavements for rehabilitation within a specified time frame and budget constraints. August 1983.

ABSTRACT

This report presents the development and application of a scheme, in the form of a computer program, for prioritizing and scheduling a set of rigid pavements for rehabilitation within a specified time frame and budget constraints. The program is intended to provide the Texas State Department of Highways and Public Transportation with guidelines for generating decision elements for the management of road maintenance funds.

The prioritization and scheduling scheme is based on observed distress quantities; it makes use of distress indices and distress prediction equations, for which a detailed description is given.

The immediate application of the computer program is to generate lists of candidate pavements for rehabilitation. However, the use of the program is extended to analyze the effect of several different budget policies on the condition of the pavement network. Although availability of funds and managerial preferences play an important role in the budget selection procedure, the program can be used as an aid in the selection of a budget policy.

Key Words: Rigid pavements, Maintenance and Rehabilitation Management, prioritization, scheduling, budgeting, distress prediction, condition surveys.

SUMMARY

The main contribution of this report is a working scheme for prioritizing and scheduling maintenance and rehabilitation in a rigid pavement network. In additon to the procedure, other major contributions are the development of a failure criteria for rigid pavements using distress quantities and stressing the use of distress concepts in pavement management systems. The material in this report is part of an effort to develop a pavement maintenance and rehabilitation management system.

The prioritization and scheduling process starts by collecting field information to assess the current condition of the network. The information collected is the input to a computer program, PRP01, which helps management select rehabilitation candidates for the next year. Therefore, the collection and preparation of information for analysis is discussed in detail. The following topics are presented and discussed: the data processing procedure, the evolution of condition surveys carried out in the state, and the possibilities of sampling.

The scheme makes use of a distress index as a decision criterion to determine when a pavement has reached its terminal condition and to prioritize a group of pavements. The distress index is calculated by combining into a single number the various distress manifestations occurring in a pavement section. Several approximate methods aimed at developing a distress index are presented and discussed; i.e., subjective parameters,

regression analysis, factor analysis, and discriminant analysis. The latter was selected because it conformed better to the available data used in the analysis.

The initial pavement condition is determined from the field condition surveys, and the future condition is determined by means of prediction models. The development of distress prediction equations for rigid pavements and AC overlaid rigid pavements is presented. Regression analysis was used to obtain the equations for each type of distress considered.

The application of the distress indices and the distress prediction equations is presented in both the network and the project levels. At the network level, a program was develop to prioritize and/or schedule rigid pavements for rehabilitation. The program was tested using CRCP field data; similar runs are intended to help the SDHPT with future rehabilitaion decisions. At the project level, a design and maintenance evaluation program is presented, with illustrative examples. Guidelines are suggested for applying a program similar to that used in the derivation or improvement of the distress index equations.

The use of the prioritization and scheduling program, PRP01, is presented in detail (1) to generate a list of candidate pavements for rehabilitation within a design period and (2) as a tool in the analysis of alternatives to select budget policies. Conclusions are made on the impact of different budget levels, the time value of money, and the postponing of the date to overlay in the selection of a budget policy.

IMPLEMENTATION STATEMENT

A scheme for prioritizing a set of rigid pavement sections for rehabilitation and maintenance within a given time frame was developed and implemented into a compter program. As an application of the program, a list of candidate projects for rehabilitation for the next five years was generated using East Texas CRCP sections surveyed in 1980. In addition the program, PRP01, was used to analyze the impact on the future distress history of a pavement network of several different budgeting policies. It was concluded that the program is a very useful tool for selecting an adequate budgeting policy.

It is recommended that the Texas SDHPT implement the computer program using current information; that is, another condition survey is required in order to obtain an updated rehabilitation schedule and an estimate of budget requirements for rehabilitation of rigid pavements in the State in the near future.

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CHAPTER 1. INTRODUCTION

The expenditures required to rehabilitate and maintain pavements in the USA have been estimated to exceed $20 billion per year in the coming years (Refs 1 and 2). Because of the large amount of money involved, any improvements in management and technology for the rehabilitation and maintenance of pavements could result in significant savings.

So far, a relatively small amount of research effort has been directed toward the activities related to the restoration of old pavements as compared with the activities aimed at providing new facilities. One of the main reasons for this lack of attention is that most of the capital investments have been centered on procurement rather than the maintenance of roads. However, this trend is reversing and the effort is shifting toward the rehabilitation and maintenance of existing pavements.

This report deals with the use of distress concepts in Pavement Management Systems (PMS) for rigid pavements. Special emphasis is placed on the development of a Network Rehabilitation and Maintenance Scheme. This scheme, in the form of a computer program, is intended to help the Texas State Department of Highways and Public Transportation in the management of its road network. A detailed description of the derivation of the models which compose the scheme is presented.

BACKGROUND

This section presents an overview of recent developments in the area of pavement management and its application in Texas and defines rigid pavements.

PMS Developments

During the last decade, systems engineering has been successfully employed in various branches of civil engineering, including pavement management being one of them. The term Pavement Management System (PMS) is used to designate a technique aimed at achieving the best value possible for the public funds expended for pavements, by using a systems approach to pavement management. The concept of PMS can be considered a breakthrough in pavement technology because it provides a framework for integrating the activities associated with the planning, design, construction, maintenance, evaluation, and research of pavements into a comprehensive and coordinated set, in contrast to the traditional approach, which considers the various activities separately, without coordination (Refs 3, 4 and 5).

A PMS involves the application of systems engineering by decision makers to find optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The development of a PMS is a cyclic procedure leading toward an ideal system in which improvements are achieved by continuous upgrading of the schemes, the models, and the solution algorithms. An ideal system should be capable of predicting precisely the future condition of each pavement in a given network, the proper timing and type of maintenance required, the date to overlay, the costs, and the consumption of resources. Of course, the recommendations should represent the optimal solution for the constraints and the design period considered. However, it is important to realize that a perfect, or ideal, PMS is only an abstraction and that any working system will not be perfect at any stage of development. Nevertheless, such an ideal PMS provides guidelines to direct the research effort.

Because no PMS is yet perfected, it is now necessary to continuously evaluate the condition of the pavements in a network. Pavement condition involves five main components: riding quality, distress condition, load carrying capacity, safety, and aesthetics.

Although many schemes have been proposed, there is no completely operational PMS, and the existing systems are in the early stages of development. However, there is a growing interest in developing a reliable PMS, derived from the realization by highway agencies that sound management of the billions of dollars invested in roads is mandatory. The immediate need is for a simplified PMS that will assist in the planning and management of rehabilitation activities for existing pavements (Ref 5).

The management decisions involved in pavements can be considered, from the standpoint of pavement management, at two different levels: the network and the project. A network consists of a group of projects under the jurisdiction of an agency. A project is a pavement unit which, has similar characteristics throughout its length. The activities related to pavements at the network level are concerned with decisions on a group of projects. In the existing PMS schemes, each individual project is considered in detail once the decisions on the network have been reached. Coupling or interaction of the two levels is possible at the higher stages of PMS development, as is discussed later.

Although a PMS is not a computer program per se, the amount of calculations necessary renders it essential to develop computer programs to transform the concepts into working reality. The key goal of any PMS is to move past the conceptual stage and develop an actual working system.

Developments in Texas

Since this report is part of a research effort on a rigid pavement overlay system, it is necessary to present past achievements in Texas specifically, the development of a condition survey approach for rigid pavements and the development of a pavement overlay design procedure. The rehabilitation prioritization and scheduling scheme presented in this report uses condition survey information for a pavement network to generate a list of candidates for rehabilitation within a certain design period. The selection of candidates for rehabilitation is preliminary to the design of an overlay; once the sections requiring overlay have been identified, the overlay design procedure is carried out for each pavement.

The condition survey approach for rigid pavements, which is covered in more detail in Chapter 3 and in Appendix A, was proposed by Strauss (Ref 52) and later implemented and modified by others (Refs 42, 43 and 72). The information collected in the condition surveys is used to develop the models in the scheme presented in this study. Part of such information is also used to demonstrate and test the capabilities of the scheme.

The pavement overlay design procedure evolved from a rationale presented by McCullough (Ref 53) using layered theory and the concept of the remaining life in the design procedure. Following this rationale, Schnitter et al (Ref 27) developed a computer program for designing overlays on rigid pavements. The models in this program were later improved by Taute et al (Ref 39). Seeds et al (Ref 21) extended the overlay design procedure into a "systems" design approach, i.e., a computer program to optimize the design of overlays on rigid pavements by selecting the best overlay alternatives from a great number of feasible strategies.

This report brings together the various research efforts mentioned and completes the picture of the PMS for rigid pavements developed in CTR Research Study 249.

Definition of Rigid Pavements

In this study, the pavement structure is considered as the upper portion of the road and includes all the layers resting on the subgrade. The two basic types of pavements are flexible, i.e., asphalt concrete pavements, and rigid, i.e. portland cement concrete pavements. The main concern of this report are the latter.

Rigid pavements are classified by whether or not they contain joints and reinforcement, as indicated in Table 1.1. The main purpose of the joints and the reinforcement is to control cracking in the concrete. Table 1.1 is a list of the possible combinations of joints, reinforcement, and prestressed reinforcement. The case not having steel and joints is not included. Some of the cases are only theoretical possibilities, i.e., pavements not actually built arising from the possible combinations of the variables. Of these combinations only JCP, JRCP, and CRCP have been studied at the Center for Transportation Research thus far.

TABLE 1.1. CLASSIFICATION OF RIGID PAVEMENTS IN TERMS OF THE POSSIBLE COMBINATIONS OF JOINTS AND REINFORCEMENTS

Rigid Pavements		Joints	Longitudinal Reinforcement: Reinforcing Bars	Longitudinal Reinforcement: Prestressed
JCP*		YES	NO	NO
JRCP*		YES	YES	NO
CRCP*		NO	YES	NO
JPCP	Total	YES	NO	YES
JPCP	Partial	YES	YES	YES
CPCP	Total	NO	NO	YES
CPCP	Partial	NO	YES	YES

*Currently used in Texas

Key:
- JCP - Jointed concrete pavements
- JRCP - Jointed and reinforced concrete pavements
- CRCP - Continuously reinforced concrete pavements
- JPCP - Jointed prestressed concrete pavements
- CPCP - Continuously prestressed concrete pavements

OBJECTIVES

This report focusses on the use of distress quantities for rigid pavements within a Pavement Management System. The main objective is the development of a working rehabilitation scheduling scheme. These are the specific objectives of the study:

(1) To present a detailed discussion of the data collection procedure and of the possibilities of sampling to collect information. The current state of technology in the pavement field is imperfect and requires upgrading on a continuing basis. This can best be accomplished by collecting feedback information from in-service pavement sections. However, the data collection needs to be carefully planned; the selection of the type, the amount, and the quality of the information to be gathered depends mainly on the specific future applications intended.

(2) To pinpoint the importance of distress as an output function to be used in PMS. A system output function in PMS should consider all the relevant pavement factors, such as riding quality, skid resistance, distress, structural capacity, traffic, and costs; nevertheless, riding quality has been prefered over the others. In the case of pavements with good periodic maintenance, distress appears to be a more relevant factor in the decision making process than riding quality.

(3) To develop a distress index for rigid pavements. A distress index combines into a single number several different distress quantities to facilitate comparison among projects. An approach different from the traditional ones is offered.

(4) To develop a terminal condition criterion for distress in rigid pavements. The failure of a pavement is not a catastrophic occurrence; but it indicates that the pavement did not meet the conditions which it was designed to fulfill. An excessive amount of distress can be considered as a terminal condition of the pavement due to its implications for the costs of maintenance or its effects on the riding quality of the pavement.

(5) To develop distress prediction models for rigid pavements. These models are intended to forecast the different distress quantities as functions of age, traffic variables, environmental conditions, and pavement material characteristics.

(6) To present the implementation of the models developed in the context of a PMS.

(7) To analyze the impact of several different budgeting policies using the rehabilitation scheduling scheme developed in this study and condition survey information collected in Texas during 1980.

RESEARCH APPROACH

The main issue of the report is the preparation of a working rehabilitation scheduling scheme to help the Texas SDHPT with decisions about maintenance and rehabilitation of rigid pavements at the network level. The development of such a scheme involves several steps, which are described in the following paragraphs.

The first step is the conceptual formulation of the problem. At this stage, the capabilities and limitations of the scheme to be developed are defined. Also, the availability of models for the scheme is studied; if models are required, data requirements are established.

The models in the system were developed using field data collected from Texas roads during the last decade. In addition, other data found in the literature were used. Although the field information used represents a unique set of data, it was not collected to fulfill the requirements for developing a PMS but to assess the condition of the roads; therefore, our models are limited by the availability of data.

The distress models in the system were developed using standard statistical techniques. Discriminant analysis was used to develop a distress index and the terminal condition criterion. For the distress prediction equations, regression analysis techniques were used.

A computer program was written integrating the distress models developed into the conceptual scheme of PMS. Using field data, sample runs were made to predict the maintenance requirements of the rigid pavements in the state of Texas.

SCOPE AND ORGANIZATION

The scheme developed represents a first stage in the development of a network level PMS for rigid pavements. Guidelines are provided for future developments.

Chapter 2 presents a conceptual formulation of the scheme developed and contains a brief description of PMS theory. In addition, it presents a justification for using distress quantities instead of other pavement attributes as an output function of the system.

In Chapter 3 the collection and preparation of condition survey information for analysis is discussed. The following topics are presented and discussed: the data processing procedure, the evolution of the condition surveys carried out in the state, other sources of information, and the possibilities of sampling.

The analysis of the data is presented in Chapters 4 and 5. Chapter 4 contains the development of a distress index and the terminal condition criterion through discriminant analysis. Other analysis techniques for developing index type equations are also investigated. Chapter 5 is dedicated to the development of distress prediction equations. Models are presented for Continuously Reinforced Concrete Pavements (CRCP), Jointed Unreinforced and Reinforced Concrete Pavements (JCP and JRCP), and for asphaltic concrete overlays on rigid pavements.

Chapter 6 is devoted to the description of the program written to implement the developed models in a PMS. In addition, sample applications are presented using field information.

Chapter 7 presents additional applications of the rehabilitation scheduling program presented in Chapter 6. The capabilities of the program are demonstrated by analyzing the effects of different budgeting policies using field data from a condition survey performed in 1980.

Conclusions and recommendations made throughout the report are summarized in Chapter 8. Guidelines for future developments are also given.

CHAPTER 2. CONCEPTUAL FORMULATION OF THE SYSTEM

This chapter contains a description of PMS concepts to provide a perspective of the problem. The principal objective is to present the conceptual formulation of the scheme developed in the following chapters. The concepts described in this chapter deal with the PMS decision levels: the network level, where decisions that affect the entire road network are made, and the project level, where decisions for specific projects are made. In addition, a justification for using distress quantities instead of other pavement characteristics as an output function is presented.

ANALYSIS AT THE NETWORK LEVEL

At the network level, the management system provides information to help decision makers in the development of agency-wide programs of new construction, maintenance, or rehabilitation which will optimize the use of available resources (Ref 5).

The basic inputs for a network level analysis are road need studies for new pavements, and periodic evaluations of existing pavements. Additional information is required, such as traffic studies and cost records, depending on the application intended and the sophistication of the system. The results of the analysis are a program for construction, maintenance, and rehabilitation of pavements within available resources.

Among the network PMS studies, the methods for planning maintenance and rehabilitation have become important in recent years. The desired result from this type of application is a maintenance and rehabilitation (M & R) schedule for each year during a period of several years. However, different degrees of complexity can be achieved, and an agency without PMS experience should start with a simplified version progress in a staged manner (Ref 6).

The following stages can be identified in the development of a maintenance and rehabilitation system; the stages are not intended to be unique, and several of the existing M & R systems fall within the stages presented:

(1) The first stage is a simplified version of the M & R system which considers planning one year at a time and provides a prioritized listing of projects to be rehabilitated for the next year. The requirements for this stage are some form of prioritization index, which may include several pavement outputs, for ranking the various projects; decision criteria for selecting the projects requiring rehabilitation; and costs, which, at least in an average form, can be included to help in the preparation of a budget or, in case the budget already exists, as another restraint in the selection of projects for rehabilitation.

(2) The next stage of development can follow two different paths; one includes the selection of maintenance alternatives and the other extends the design period to provide a prioritization listing for several years.

    (a) For the case including maintenance, the additional requirements are some rational determination of maintenance needs and maintenance costs.

    (b) To extend the design period, prediction equations are required for all the variables in the prioritization index in addition to the requirements listed in the first stage.

(3) The third stage is a combination of the two paths presented in the previous stage; that is, the system should consider a design period and several maintenance alternatives at the same time. This stage involves prediction models which account for different maintenance and rehabilitation possibilities, a procedure to select among

competing maintenance alternatives, and an algorithm to optimize the timing of M & R for the design period considered, within a budget and using available resources.

Existing M & R Schemes

Several schemes for maintenance and rehabilitation management have been presented in the literature or are currently in use by state agencies. The following review is not comprehensive but offers a sample to indicate the extent of development of network level PMS activities.

New York has developed a scheme to identify deficient pavement sections (Ref 12). A single response, pavement serviceability rating, is used to evaluate the complete network and to rank candidate projects. The procedure involves calculations with current values only and does not consider prediction models. After a project has been selected, it is necessary to perform a detailed evaluation, select the rehabilitation option, and calculate the cost of rehabilitation; that is, no attempt is made to evaluate the effects of single decisions in the overall network. The New York procedure includes both flexible and rigid pavements.

Pedigo and Hudson (Ref 6) developed guidelines for a simplified network level PMS and indicated how such a framework can be applied to produce a priority ranking. Among the guidelines presented, suggestions are given for formulating a Prioritization Index (PINDEX) using subjective information. This approach can be readily implementable even if objective data are not available.

The State of Washington combines roughness and distress into a single pavement rating (Refs 5 and 13). The future condition of the pavement is projected in terms of this rating, using prediction models based primarily on subjective data. Rehabilitation alternatives are considered whenever this index falls below a predetermined value, and rehabilitation is contemplated when the rating reaches a critical level.

Karan and Haas (Ref 14) have suggested a priority programming model which minimizes the loss in total net present value of annual benefits for all the projects in a network to determine the best timing for repairing each of the projects within a design period. This method was conceived for urban pavements and it makes use of a Urban Serviceability Index which can be forecast using a Markov process. In addition, a relation is given for determining average operating costs for different values of the Urban Serviceability Index.

Researchers from Texas A & M (Refs 15, 16, 17 and 18) developed a Rehabilitation and Maintenance System for the Texas flexible pavement network. The system contains several computer programs (a) identifying and scheduling effective strategies, (b) quantifying its benefits, (c) deriving working plans within system constraints, and (d) determining optimal policies. The sequence of activities involved in the optimization process can be summarized as follows:

(1) The first program in the series is used to check the field information collected by the districts before it is sent to the state authorities.

(2) An approximate strategy for the highway segments and the upper and lower budget limits for the districts are determined by a second program.

(3) The optimal rehabilitation and maintenance strategies and the benefits for one year planning horizons are determined by a third program for each district. In addition, a multi-period resource effective highway maintenance schedule can be obtained using a fourth computer program.

(4) The fifth computer program is capable of selecting the most promising set of budget levels for the districts under a fixed statewide budget. At the same time, another program, the sixth, is used to determine the best rehabilitation and maintenance strategy

for each section, and the resources and budget allocation district by district.

(5) The last program, which is basically the same as the sixth, optimizes the district fund allocations to its residencies by selecting the best strategy on each project.

The scheme developed by Texas A & M is a comprehensive system which involves activities at the network and project levels. The combined and sequential use of programs is aimed at helping management allocate money, men, equipment, and materials in an efficient manner. This system contributes several mathematical formulations which can be adopted by other agencies. The main drawbacks of the scheme are the costs and the prediction models therein which require further refinement.

Evaluation of Existing Network Level Schemes

A sample of the different degrees of complexity which can be found in existing network level maintenance and rehabilitation prioritization schemes has been presented. The existing schemes provide valuable information for the development of new schemes. However, the adoption of an already existing scheme is not possible without major modifications because the existing schemes have been conceived with specific needs in mind and under particular conditions.

A scheme which uses only serviceability index does not seem applicable to the rigid pavements in Texas since, according to information presented in Fig 2.4, this parameter does not indicate when a pavement with heavy maintenance is reaching terminal condition.

Optimization techniques based on user costs are not readily implementable because of the lack of cost information if an attribute other than PSI is used in the prioritization scheme.

It is the general consensus that, when developing a PMS, one should start from simplified schemes and evolve into more complicated forms as experience is accumulated (Ref 6). Therefore, a simplified scheme is formulated here with guidelines for its future development.

Proposed Network Level Scheme

The purpose of the scheme developed in this study is to provide maintenance management with a multi-period list of candidate rehabilitation projects. Figure 2.1 is a flow chart of the main steps involved in an M & R scheme. The scheme uses field information on the group of projects composing the network under analysis; the input information varies, depending on the models used within the program.

The first step in the program is the computation of a prioritization index for each project that transforms all of the pavement responses into a single number, which facilitates comparison among projects. In the program developed, only distress manifestations were considered in the prioritization index; although, in a more refined stage, the index should resemble the system output function described at the end of the chapter. With the prioritization index, the projects can be sorted out to define the priorities for rehabilitation and maintenance. After the priorities for the first year are defined, the next step involves the prediction of the future condition of the pavement sections in order to repeat the prioritization cycle for the following years. The cycle is repeated until the time frame of analysis is fully covered.

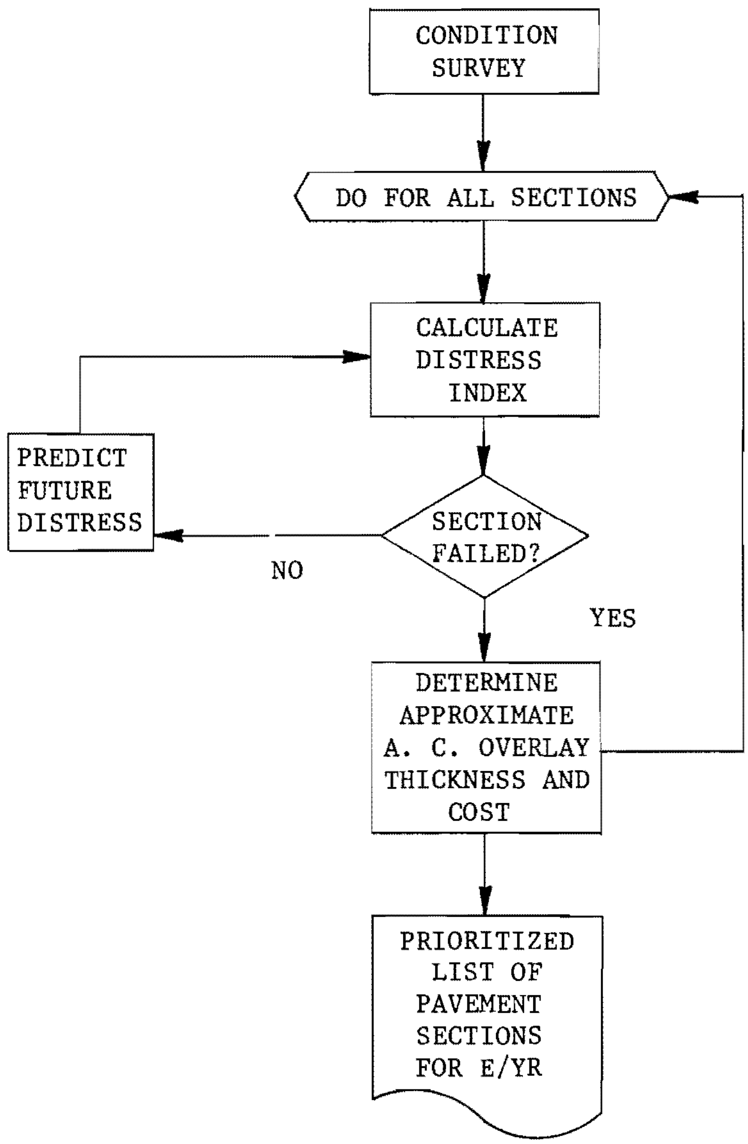

Fig 2.1. Basic steps in a rehabilitation and maintenance system at the network level.

ANALYSIS AT THE PROJECT LEVEL

At the project level, detailed consideration is given to alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within an overall program. The inputs for a project level analysis are load, environmental conditions, materials characteristics, construction and maintenance variables, and costs. The specific information varies, depending on the models in the system. The output of the analysis consists of a set of the best possible strategies to provide, maintain, or rehabilitate a pavement structure. The selection of alternatives is made from a detailed design, which includes the prediction of some or all of the pavement responses, and an economic evaluation of the alternatives under consideration.

Most of the research effort on PMS has been centered on project level analysis to provide new facilities. Progress in this area transformed the design concept from the one shot design approach into the selection of an optimum strategy.

Existing Design Systems

The first major working systems were developed during the late 1960's and early 1970's; among them is the Rigid Pavement System (RPS), the only working program for rigid pavements, which was developed by Kher et al (Refs 19 and 20). There are several highly developed design systems for flexible pavements and descriptions of them can be found elsewhere (Refs 3 and 5); this report is centered on rigid pavements.

The Rigid Pavement System (RPS) was developed at The University of Texas to design rigid pavements. RPS presents the designer with a set of best alternatives. The program utilizes 115 different input variables. All possible solutions, within the limits specified by the designer, are analyzed; costs incurred are calculated for each strategy and the optimal pavement strategies are selected primarily on the basis of minimum total overall costs. Other factors are utilized as constraints in the selection procedure, including availability of funds and minimum safety provisions. For those designs that reach the minimum level before completition of the analysis period, stage construction concepts are utilized.

The Rigid Pavement Rehabilitation Design System (RPRDS) recently developed by Seeds et al (Ref 21) to optimize the design of overlays on rigid pavements generates a number of feasible overlay design strategies based on user inputs, performs a present value cost analysis on each strategy, and then presents those which are optimal. The program considers several types of overlays, i.e., asphalt concrete, CRCP, and JCP.

Several M & R design systems can be found in the literature; of these, the one developed by Shahin et al (Refs 22 and 55) for the U. S. Air Force and the Army has the capability to account for jointed concrete pavements. This system uses a Pavement Condition Index (PCI) to evaluate the structural integrity of the pavement sections. Depending on the PCI level, several categories of M & R are indicated. On the basis of the results of the evaluation and the guidelines for M & R selection, the engineer may want to consider several alternatives for restoring the structural integrity and operational condition of the pavement. The selection of the best alternative involves performing an economic analysis to compare the costs of all feasible alternatives. The optimum alternative is selected from the economic analysis results, the mission of the pavement, and the policies of the management.

Evaluation of Existing Models at the Project Level

The model used in RPS to determine pavement thickness is based on the results of the AASHTO Road Test (Refs 23, 24, and 25) and, therefore, the main factor in the analysis is the serviceability versus traffic relationship. On the other hand, RPRDS uses elastic layered theory coupled with a fatigue-like equation to determine overlay thicknesses. The fatigue equation, in the case of rigid pavements, is related to the occurrence of severe cracking in jointed pavements (Ref 26). The two programs were developed using the best state-of-the-art information; however, neither of them is useful in predicting distress quantities for maintenance management purposes.

The distress index developed by Shahin et al was developed from the collective judgement of experienced pavement maintenance engineers, and it seems to render acceptable results. However, it was developed to be applied to airport pavements.

Using more refined equations in a network level prioritization as opposed to the project level may result in more data requirements, more computer time, and, therefore, more money without affecting considerably the results of the procedure. One way to improve the procedure without excessively increasing the requirements is by developing approximate equations through computer simulation using a project level program. One such program was developed in this study to illustrate how to improve the prioritization equations. This program is conceptual rather than a working program since cost models as a function of distress are not available. However the program can be used to evaluate the design of existing projects.

In conclusion, a specific overlay can be designed more accurately using programs like RPRDS; however, the fact that it is not oriented to the prediction of distress quantities, plus the extensive input data and running time required, prevent the use of such programs at the network level.

Proposed Project Level Scheme

In rigid pavements, the derivation of an optimum maintenance or rehabilitation strategy, by means of economic analysis, is difficult due to the lack of cost and prediction models. Furthermore, the serviceability performance concept, which has been successfully used in flexible pavements, may be an inappropriate model for rigid pavements. Therefore, a rehabilitation and maintenance design approach is presented which replaces the serviceability performance concept with the distress history of the pavement.

The scheme proposed is not intended to replace more sophisticated schemes, such as RPRDS, but to illustrate its applications for future developments as better information becomes available. Among these applications, the scheme is suggested as an alternative approach for developing or improving distress index equations.

Figure 2.2 presents the basic steps in the proposed scheme. The design life and costs are calculated for several feasible alternatives, the purpose being to define the most effective rehabilitation and maintenance strategy from several under consideration. If user costs related to distress are not

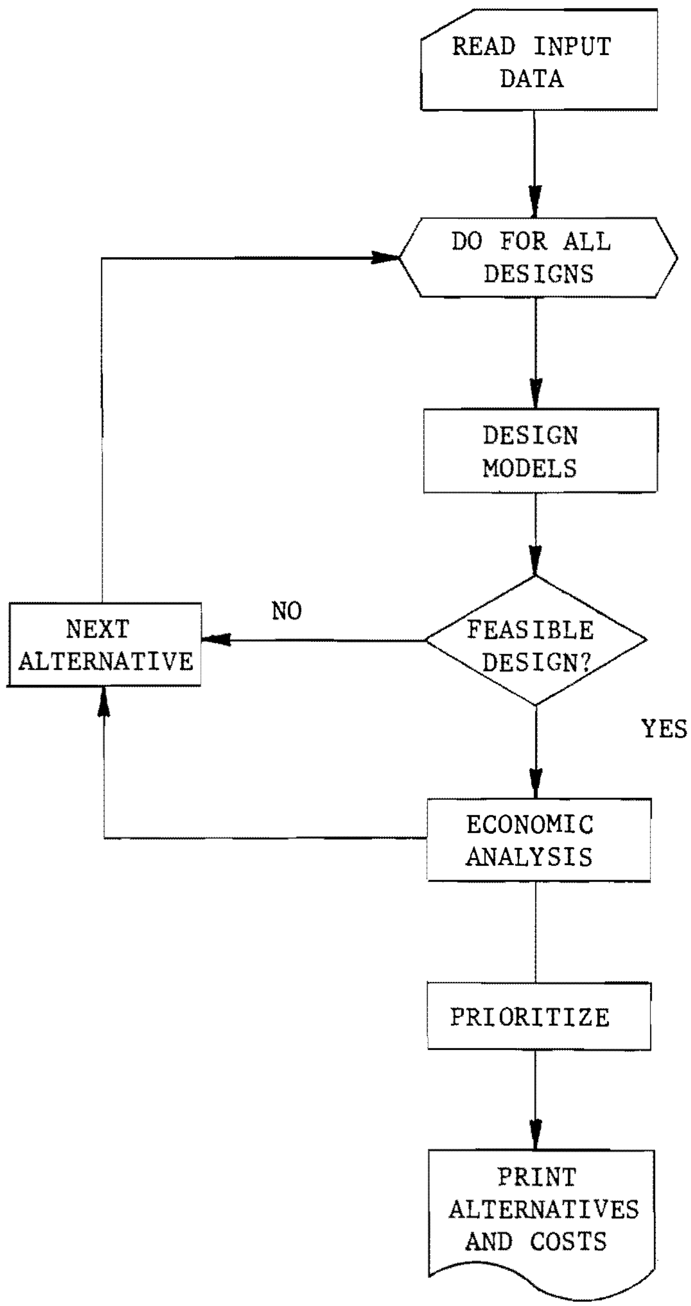

Fig 2.2. Basic steps in a design system at the project level.

available, rehabilitation is optimized not from the standpoint of economic analysis but from the results of a distress index.

INTERFACED ANALYSIS

A coupled or interfacing PMS is the combination of the two levels described before. Network and project decisions interact with one another. A good estimate of the resources to be used at the network level requires information on maintenance and rehabilitation for individual projects. On the other hand, timing of rehabilitation for an individual project depends on the network decisions.

This may be better explained using Fig 2.3, which presents a matrix of the allocation of certain resources among competing projects within a certain time frame. The columns in the figure are for the years considered in the analysis while the rows represent each of the projects. The amount of resources consumed in each block depends on the maintenance strategy selected for that project in that year. The purpose of the anlaysis might be to minimize the amount of resources consumed in each project and at the same time not exceed the available budget. The interaction between projects and network is evident if one considers that, in order to match the budget for each year, it is necessary to modify the sequence of maintenance alternatives and the rehabilitation timing of the projects until a best solution is obtained.

At the present time, the coupling of project and network level analysis is possible only in a simplified manner. The coupling of the two levels is deterred because

Proj \ Yr	1	2	3	...	n	Project Cost
1	C_{11}	C_{12}	C_{13}		C_{in}	$\sum_{j=1}^{n} C_{1j}$
2	C_{21}	C_{22}	C_{23}		C_{2n}	
3	C_{31}	C_{31}	C_{33}		C_{3n}	
4						
...				...		
m	C_{m1}	C_{m2}	C_{m3}		C_{mn}	
Required Investment	$\sum_{i=1}^{m} C_{i1}$	...				$\sum\sum_{ij} Cij$
Budget	B_1	...				

Network

Time Frame

Fig 2.3. Matrix of allocation of resouces among competing pavement rehabilitation projects in various years.

(1) the data collection requirements at the project level are very detailed and expensive when compared to the network level requirements;

(2) due to the lack of accurate prediction equations, two different sets of models are employed at the two levels; and

(3) the computer costs would be excessive if detailed models were to be used at the network level.

A simplified form of an interfaced system is currently being used by agencies which have a multi-period network level analysis.

SYSTEM OUTPUT FUNCTION

Among the important developments required in PMS is an output function involving the various parameters which affect decision making in pavements, such as riding quality, skid resistance, distress, traffic, and costs. The problem is not only the determination of the output function but the capability to predict each of the output parameters in the equation under variable conditions. Generally, riding quality has been the most important factor considered, primarily because of the influence of the AASHTO Road Test, where the concept of Present Serviceability Index (PSI) was developed.

Distress Types

Since the report focusses on the use of distress quantities in PMS, an overview of what distress is must be given. In Ref 7, the following definition is given: "Any indication of poor or unfavorable performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure." Another definition, given in Ref 3, considers distress as "a limiting response of the pavement when one of the primary responses, i.e., stress, strain, or deflection, is taken to a limit."

Distress is commonly grouped into three modes or categories: (a) fracture, (b) distortion, and (c) disintegration. Table 2.1 presents a schematic summary of the distress groups. For each mode, individual distress manifestations can be identified; detailed definitions of each individual manifestation are provided by Smith et al (Ref 9). Some of the distress mechanisms are also presented in Table 2.1.

Serviceability vs. Distress

In a large number of the cases observed in practice, the pavement serviceability history does not appear to change with time or traffic, while the distress condition does. Figures 2.4 and 2.5 show how serviceability and distress vary with traffic for Texas pavements. Each point represents a surveyed section of CRCP in Texas (Refs 11 and 37). The serviceability index was derived from roughness data obtained using profilometer measurements. The traffic figures were provided by the Planning Survey Division of the Texas SDHPT. The number of failures (punchouts and patches) per mile was obtained from the records of the CRCP condition surveys peformed in the State of Texas in 1974 and 1978 and described in the next chapter. From the figures, it appears that the serviceability index is independent of the traffic, i.e., the serviceability index value does not vary. One likely reason for having a constant serviceability is the continuous repair of the highway performed by the District's staff. Although from a structural or economics standpoint the section is approaching the end of its life, the riding quality remains unchanged. Thus, the use of distress measures may be

TABLE 2.1. DISTRESS MODES, MANIFESTATIONS AND MECHANISMS (Ref 8)

Distress Mode	Distress Manifestation	Examples of Distress Mechanism
Fracture	Cracking	Excessive loading Repeated loading (i.e., fatigue) Thermal changes Moisture changes Slippage (horizontal forces) Shrinkage
	Spalling	Excessive loading Repeated loading (i.e., fatigue) Thermal changes Moisture changes
Distortion	Permanent deformation	Excessive loading Time-dependent deformation (e.g., creep) Densification (i.e., compaction) Consolidation Swelling Frost
	Faulting	Excessive loading Densification (i.e., compaction) Consolidation Swelling
Disinte-gration	Stripping	Adhesion (i.e., loss of bond) Chemical reactivity Abrasion by traffic
	Raveling and scaling	Adhesion (i.e., loss of bond Chemical reactivity Abrasion by traffic Degradation of aggregate Durability of binder

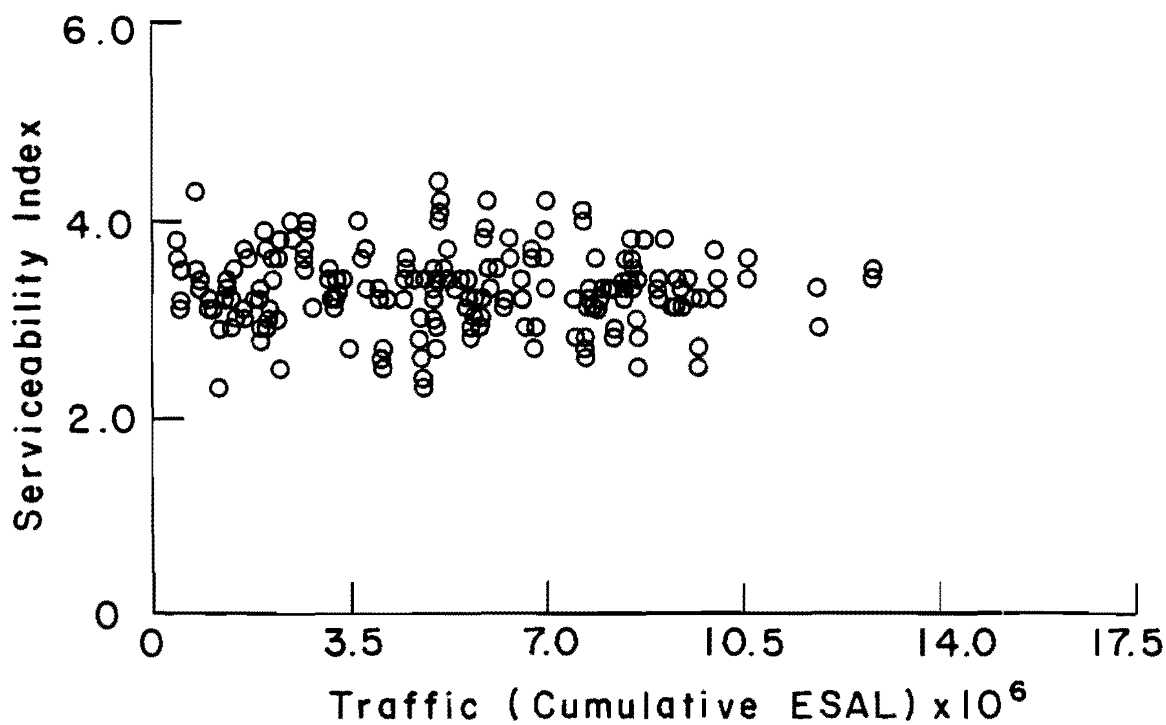

Fig 2.4. Serviceability index versus traffic applications (both directions) for Texas CRCP sections surveyed in 1974 and 1978.

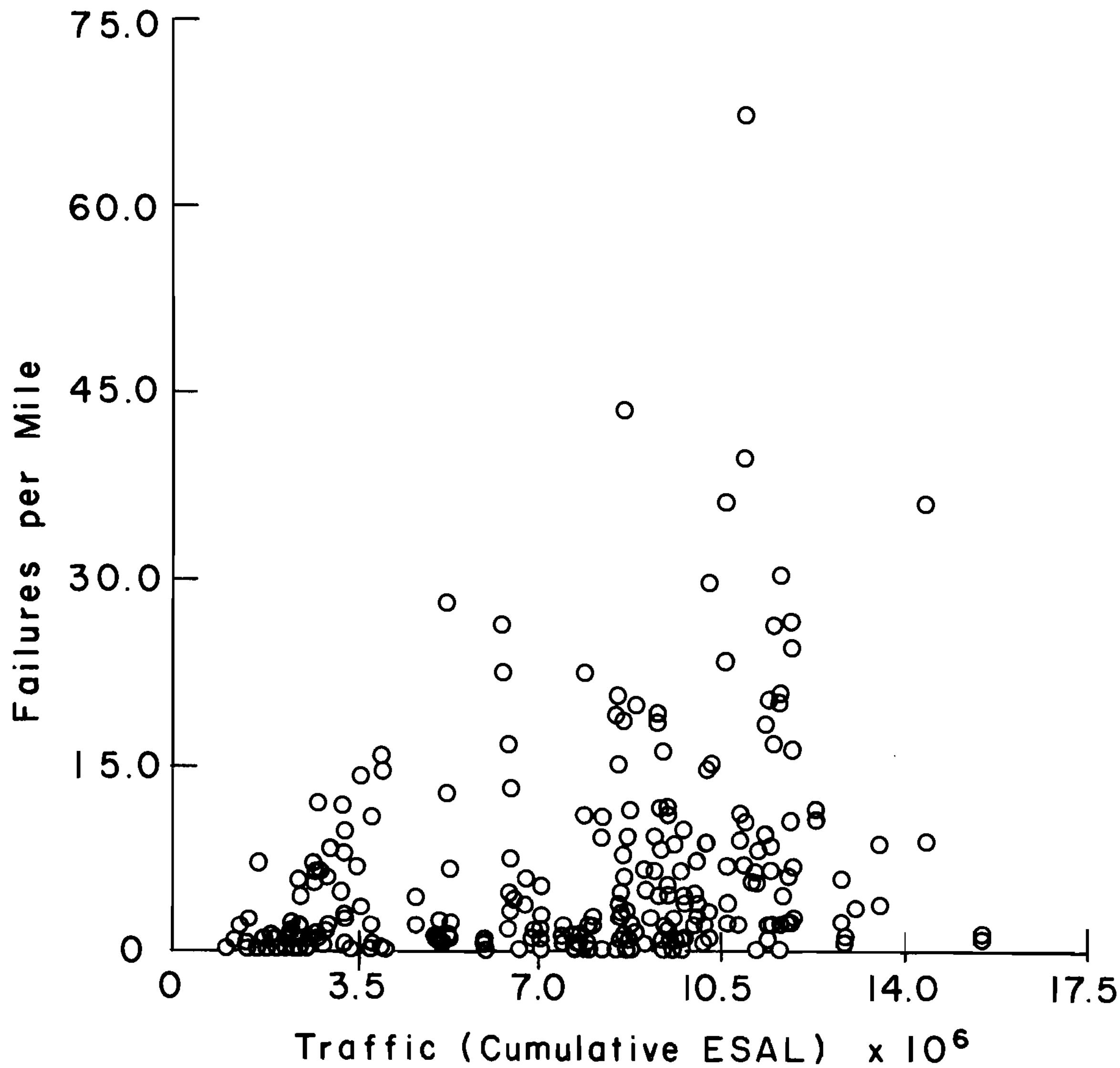

Fig 2.5. Number of failures per mile (punchouts and patches) versus traffic applications (both directions) for Texas CRCP sections surveyed in 1974 and 1978.

a more realistic way to evaluate a pavement's terminal condition. This statement is contrary to the AASHTO guide concepts (Ref 25); however, the AASHO concepts, which are based on the AASHTO Road Test results (Ref 23), do not consider pavement sections deteriorating without maintenance.

Therefore, it appears that distress manifestations, in this case failures per mile, are better indicators of the deterioration of a CRCP than the serviceability index as evidenced by the variability. In other words, in a CRCP with heavy maintenance, distress appears to be a more significant factor in the decision making process than the serviceability index. Other factors may seem more relevant in other cases, depending on the particular circumstances.

An additional advantage of using distress is that it relates directly to maintenance requirements and indirectly measures other pavement functional indicators, such as serviceability. Among the disadvantages of using distress manifestations is the lack of applicable cost equations since past research has made more extensive use of the PSI concept.

SUMMARY

This chapter presented the conceptual formulation of a rehabilitation prioritization scheme using distress quantities. These are the principal points presented in the chapter:

(1) It was decided that a simplified scheme should be formulated as a starting point and that some guidelines should be provided for future evolution into more complicated forms as experience is accumulated.

(2) The proposed scheme will provide maintenance management with a multi-period list of candidate projects for rehabilitation. The

prioritization procedure is based on a distress index and several distress prediction equations.

(3) It was suggested that a project level program be used as a simulation tool to generate improved prioritization or distress index models. This approach would be feasible if better prediction and cost models were available.

(4) From experience in Texas with rigid pavements, it is felt that distress is a better indicator of the condition of the pavements. Therefore, it is recommended that distress be used as the central factor to be considered in the prioritization scheme.

The main concern of this report is to develop a scheme for scheduling rehabilitation of rigid pavements based on distress quantities. A computer program is developed in the process. The program, a rehabilitation prioritization program presented in Chapter 6, produces a set of ordered candidate pavements for maintenance and rehabilitation. This program uses only distress quantities in the prioritization procedure. However, it appears reasonable to include in future versions the impact of other variables, such as traffic and climatic conditions, in the procedure. Also, in order to optimize the prioritization procedure, user and agency costs should be considered.

CHAPTER 3. DATA COLLECTION AND REDUCTION

The current technology in the pavement field is imperfect and requires information on a continuing basis. In addition, management decisions depend on supporting data. Therefore, the importance of collecting feedback information from in-service pavement sections is apparent. The objective of this chapter is to summarize and discuss the collection and processing of information, basically condition surveys, for analysis. The following topics are presented and discussed:

(1) the conceptual development of a data processing procedure,

(2) the sources of information used in this study,

(3) the possibility of collecting information through sampling within a project, and

(4) the programs used to report and summarize the information.

Additional information is presented in Appendix A, which deals with the evolution of the procedure and the recording forms used in the condition surveys performed by the CTR through the years.

CONCEPTUAL DEVELOPMENT OF A DATA PROCESSING PROCEDURE

Figure 3.1 is a flowchart of the data processing procefure. The first step is the collection of data, which is followed by proper storage for future use. With the help of computer software, the step of data reduction and analysis yields results in the form of reports for the various agency

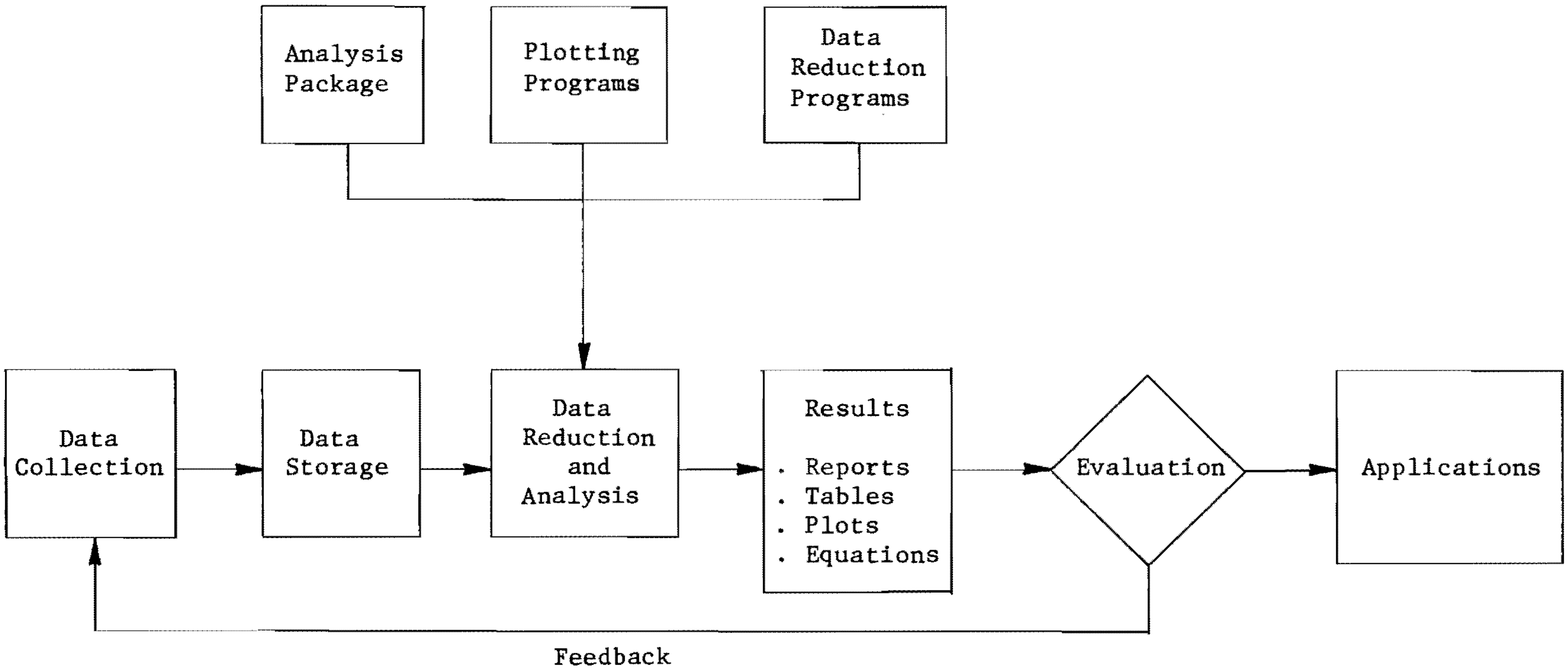

Fig 3.1. Conceptual data processing procedure.

departments which make use of this information. Before the information is used, it is necessary to evaluate the results and decide if more information is required. Once the information is evaluated, it will be applied in the different activities of the Pavement Management System. Of course, in order to upgrade the models and the information in the system, there is a continuing feedback procedure.

In the following paragraphs, a conceptual discussion of the various steps in the data processing procedure is presented. First, several possible information applications are mentioned to explain the purposes for collecting the data. Then, guidelines are provided for determining the quality and quantity of the data and deciding which information should be collected and how it should be collected. To complete the theoretical discussion, the data reduction and analysis step is also covered.

Applications: Purposes of Collecting the Data

A PMS consists of the comprehensive set of activities that go into planning, design, construction, maintenance, evaluation, and research of pavements. Pavement evaluation provides information to the rest of the activities; the information channelized through research is redirected, after further processing, to the other activities. The following is a partial list of PMS activities where the condition survey information is used:

(1) Planning

- (a) network evaluation,
- (b) prioritization of pavement sections,
- (c) short-term programming and budgeting, and
- (d) long-term programming;

(2) Design

- (a) information for overlay design,
- (b) evaluation of design in a pavement section, and
- (c) evaluation of design equations;

(3) Maintenance

(a) short term scheduling of maintenance,
(b) long term scheduling of maintenance, and
(c) evaluation of maintenance techniques and materials;

(4) Construction

(a) evaluation of construction in a new pavement section, and
(b) evaluation of construction techniques and materials.

All of the PMS activities depend on accurate information, obtained either from pavement surveys or from prediction models. At the present time the use of models to predict pavement responses is restricted by their imperfect state. Therefore, the importance of continuously obtaining information for the correct functioning of a PMS is apparent. Table 3.1 indicates activities which could make good use of distress prediction models. Those applications which appear not to require prediction models make use of "fresh" data.

Data Collection Considering Quality and Quantity

The quality and quantity of information varies in each of the PMS activities. Table 3.1 shows the types of condition survey required for each of such activities; in addition, it indicates whether or not distress models are used to process the data. Different types of condition surveys can be conducted, depending on the type of pavement and the application for which they are intended. For the purposes of this report, they have been divided in terms of their quality and quantity.

For quantity, the terms used in Table 3.1 are defined as follows:

(1) Census or mass survey. As the term implies, this type of condition survey involves surveying the complete network.

TABLE 3.1. TYPE OF CONDITION SURVEY RECOMMENDED FOR SEVERAL DIFFERENT PAVEMENT MANAGEMENT APPLICATIONS.

Application	Condition Survey		Distress Models
	Quantity	Quality	
PLANNING:			
. network evaluation	(1) or (2)	(a) or (b)	Yes
. prioritization	(1)	(b)	Yes
. short term planning	(1)	(b)	Yes
. long term planning	(1) or (2)	(b)	Yes
DESIGN:			
. information for design	(4)	(b) or (c)	Yes
. evaluation of design	(4)	(a) or (b)	No
. evaluation of equations*	(1) or (3)	(c)	No
MAINTENANCE:			
. short term scheduling	(1)	(b) or (c)	No
. long term scheduling	(1)	(b)	Yes
. evaluation of techniques and materials*	(3)	(b) or (c)	No
CONSTRUCTION:			
. evaluation of pavt. section	(4)	(a) or (b)	No
. evaluation of techniques and materials*	(3)	(b) or (c)	No

*Research activities

Quality

(a) Reconnaisance
(b) Tally or semi-detailed
(c) Detailed or photographic

Quantity

(1) Census
(2) Network sample (stratified)
(3) Experimental design
(4) Project

(2) Sampling. Sampling can be performed from the network by selecting representative sections or from each project by selecting representative subsections within a project. Sampling from the network has been used for quick evaluation of the network or to make a broad estimate of the long-term condition of the network (Refs 1 and 28). An attempt was made in this study to obtain samples within specific projects and from them to infer the condition of the whole project; the results were discouraging (Ref 29).

The quantity of information sampled by some state agencies appears to vary from 100 percent to 8 percent of the network. Sampling intervals range from 1000-sq-ft areas every 1/3 mile to 100-ft. long segments every mile within selected projects (Ref 30).

(3) Experimental design. A factorial design is mandatory in some of the condition surveys, as in the case of developing or evaluating design methods which need to be applicable to a variety of conditions. Furthermore, the factorial matrix should be specified in terms of "ranges" and not "points"; the reason being that, due to the scarce research resources, measurements and observations need to be made from existing in-service roads; the adoption of point levels would make the field search for test sections next to impossible (Ref 33).

In the case of evaluating maintenance or construction techniques, simpler experimental designs have been used. Usually test and control sections are monitored to detect differences in the overall performance among both types of sections and to assess the advantages or disadvantages of the technique under study.

(4) Project. When the information required is for designing an overlay or evaluating the design or construction of a pavement section, the condition survey refers only to that single section.

For quality, the terms used in Table 3.1 are as follows:

(1) Reconnaisance. These surveys consist of visual inspection and qualitative judgment of the pavement made by a qualified individual.

(2) Tally or semi-detailed. In this type of survey a pavement section is divided into subsections. The distress manifestations are tallied and, once the subsection has been completed, the quantities are transferred to the field sheets.

(3) Detailed or photographic. The exact location of each distress manifestation is recorded in this type of condition survey. Usually sketches or photographic techniques are used. The use of photographic techniques is not limited to detailed condition surveys; they can be used when the survey operation interferes to a large extent with the traffic, as in urban areas.

Additional Information. The information collected for pavement management activities can be classified as pavement responses or attributes (dependent variables) and additional information (independent variables). The pavement responses are dependent variables only if some form of forecasting is involved. The additional information can be further subdivided into fixed and variable, indicating if such information is constant or varies with time.

The selection of the type and quality of information to be gathered depends on the application intended. For instance, in order to evaluate the condition of a roadway network, only responses of the pavement such as riding quality, load response, distress, and safety are required. On the other hand, in the case of research activities, it may be worthwhile to collect all types of information.

Table 3.2 indicates which additional information may be required in several PMS activities. In Table 3.2, the quality of the information is not specified, although economics and the degree of accuracy required will dictate the quality of the information. Of course, there is a minimum quality for each application. For example, prediction equations derived through research require less accuracy at the network level than they do at the project level. Therefore, the quality of information used at the network can be different than that used at the project level.

Some applications make indirect use of the information, such as the ones that involve the use of prediction equations. These applications can be carried out even without the indirectly required information.

Data Reduction and Analysis

After the information has been collected, it must be organized, summarized, and documented. Due to the extensive amount of information, the

TABLE 3.2. ADDITIONAL INFORMATION TO THE CONDITION SURVEY REQUIRED FOR VARIOUS PMS ACTIVITIES

Application	Traffic	Materials	Construction	Maintenance	Costs	Environment
PLANNING						
Network evaluation	N	N	N	N	N	N
Prioritization	Y	N	N	N	Y	Y
Short term planning	Y	N	N	N	Y	N
Long term planning	Y	I	I	I	Y	I
DESIGN						
Information for design	Y	Y	Y	N	Y	Y
Evaluation of design	Y	Y	Y	Y	Y	Y
Eval. of design equations	Y	Y	Y	Y	N	Y
MAINTENANCE						
Short-term scheduling	I	N	N	Y	Y	N
Long-term scheduling	I	I	I	Y	Y	I
Eval. of maintenance techniques and matls.	I	Y	N	Y	Y	N
CONSTRUCTION						
Eval. of pavt. section	N	N	Y	N	Y	N
Eval. of construction techniques and matls.	I	Y	Y	N	Y	N
RESEARCH	Y	Y	Y	Y	Y	Y

Y = information required
N = information not required
I = information indirectly required

use of computer facilities is mandatory. By analyzing the information, future conditions may be inferred. As stated before, the models used in pavement technology are far from accurate, and continuous upgrading is necessary; these models are the result of the analysis of the information.

SOURCES OF INFORMATION

This section presents the sources of information used in this report. Field data were collected for CRCP and AC overlaid pavements, and literature information was collected for jointed pavements. The information has been used, first, to develop prediction models and, last but not least, to test and demonstrate the applications of the rehabilitation and prioritization program presented in Chapter 6.

The data collection procedure involves the following (Ref 30):

(1) determination of what attributes of the pavement should be measured and what type of information needs to be acquired;

(2) field measurement of attributes, such as structural capacity, ride quality, distress condition, and skid resistance, on a sample or mass inventory basis and to a degree of accuracy and frequency appropriate to the class of road, agency resources, use of the data, etc;

(3) collection of data from as built pavements and maintenance, including costs;

(4) traffic measurements;

(5) determination of environmental conditions;

(6) inventory of available resources (materials, equipment, manpower, budget, etc.).

In the following paragraphs a description is given of the distress information collected through condition surveys of the various types of pavements included in this report: CRCP, jointed pavement, and AC overlaid rigid pavement. The final part of this section describes the sources of additional information.

CRC Pavements Condition Surveys

Condition surveys, i.e., field measurements of distress aimed toward assessing the pavement condition, have been carried out by the CTR in rural and urban districts. The condition survey procedure in urban zones is different from the one used in rural zones due to the different traffic conditions.

Table 3.3 presents in condensed form the various condition surveys performed on CRCP in the state. The rural districts were surveyed in 1974, 1978, and 1980; the urban districts were surveyed in 1976 and 1981. Figure 3.2 shows the locations within the state of the districts surveyed. The distress manifestations measured were somewhat different in each condition survey, but the following are the manifestations measured: transverse cracking, localized cracking, spalling, pumping, punchouts, and patches. Detailed information on the condition survey procedure is given in Appendix A.

Table 3.4 presents a summary of the information collected in the rural condition surveys. The summary is organized by districts and by the year of the condition surveys. The information provided is length surveyed, length overlaid, age range, distress manifestitions (cracking, spalling, and failures), and average and standard deviation of the riding quality or serviceability index of the pavements surveyed.

Condition Surveys for Jointed Pavements

Although jointed pavements (JCP and JRCP) are not uncommon in the state, regular monitoring of this type of pavement has not been carried out

TABLE 3.3. SUMMARY OF CONDITION SURVEYS PERFORMED IN THE STATE OF TEXAS AND MEASURED DISTRESS MANIFESTATIONS

			Condition Survey*				
			Rural			Urban**	
Distress Manifestation		Intensity	74	78	80	76	81
Cracking	Transverse	Minor	•	•			
		Severe	•	•			
	Longitudinal		•				
	Localized	Minor	•				
		Severe	•				
Spalling		Minor	•	•	•	•	•
		Severe	•	•	•	•	•
Pumping		Minor	•	•	•		
		Severe	•	•	•		
Punchouts		Minor	•	•	•	•	•
		Severe	•	•	•	•	•
Patches	Asphalt		•	•	•	•	•
	PC Concrete		•	•	•	•	•

*Refer to Appendix A for details
**Not included in this study

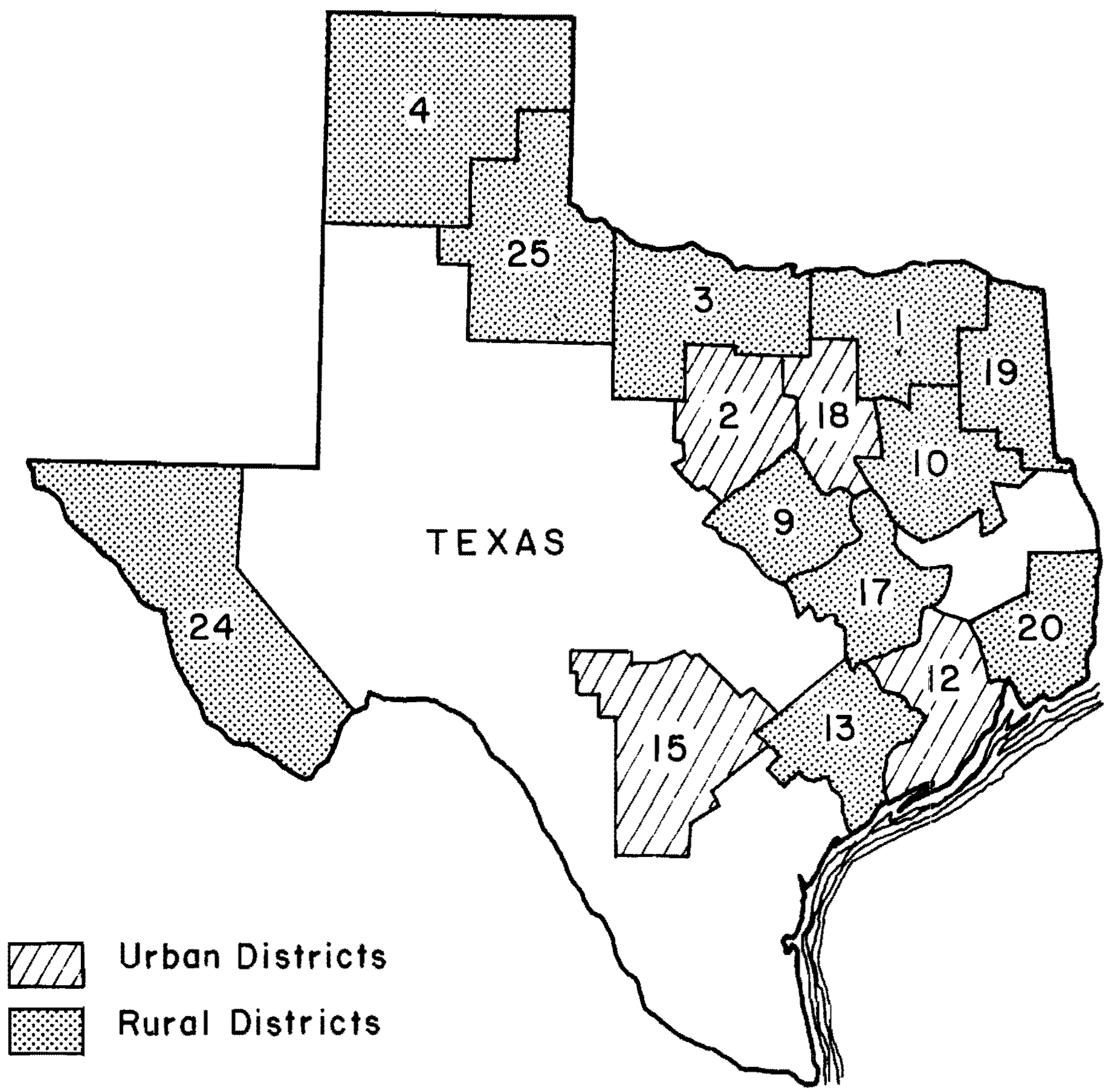

Fig 3.2. Location of rural and urban districts surveyed to collect CRC pavement information.

TABLE 3.4. SUMMARY INFORMATION OF CRC PAVEMENTS IN TEXAS FROM 1974, 1978, AND 1980 CONDITION SURVEYS

DISTRICT NO.	YEAR	LENGTH TOT (miles)	LENGTH OVL (miles)	AGE RANGE FROM (years)	AGE RANGE TO (years)	CRACK SPC MEAN (ft)	CRACK SPC SD (ft)	MIN SPALL MEAN (%)	MIN SPALL SD (%)	SEV SPALL MEAN (%)	SEV SPALL SD (%)	FAILURES MEAN (No)	FAILURES SD (No)	RQ MEAN	RQ SD
17	1980	238.0	51.2	8.2	16.9	4.0	2.5	14.2	5.7	1.1	2.1	3.6	3.7	---	---
17	1978	238.2	51.2	6.2	14.9	4.0	2.5	13.6	6.1	0.6	1.1	2.2	2.7	3.6	0.3
17	1974	238.3	0.0	2.2	13.0	4.0	2.5	---	---	---	---	6.9	16.3	3.6	0.3
19	1980	219.7	24.4	8.5	15.8	3.6	2.7	20.0	12.3	6.2	11.5	6.8	13.8	---	---
19	1978	219.3	24.4	6.5	13.8	3.6	2.7	19.8	12.5	5.7	10.9	4.0	8.3	3.6	0.4
19	1974	219.4	0.0	2.5	9.8	3.6	2.7	---	---	---	---	1.1	2.0	3.4	0.3
20	1980	78.8	22.2	8.4	17.4	4.2	3.0	7.5	7.0	6.0	8.3	1.6	4.2	---	---
20	1978	78.2	21.2	6.4	15.4	4.2	3.0	6.3	7.3	3.9	6.7	1.1	3.9	3.1	0.4
20	1974	75.6	0.0	2.4	11.4	4.2	3.0	---	---	---	---	0.8	2.4	3.0	0.3
24	1978	99.4	0.0	3.0	8.9	5.5	2.8	28.0	18.0	0.2	0.2	0.1	0.2	3.7	0.2
24	1974	88.9	0.0	0.2	4.9	5.5	2.8	---	---	---	---	0.0	0.1	---	---
25	1978	61.2	0.0	3.0	10.2	3.0	1.4	10.2	3.1	0.0	0.0	0.1	0.1	4.0	0.3
25	1974	59.4	0.0	1.2	6.2	3.0	1.4	---	---	---	---	0.0	0.0	3.7	0.2

(continued)

TABLE 3.4. (continued)

DISTRICT NO.	YEAR	LENGTH TOT	LENGTH OVL	AGE RANGE FROM	AGE RANGE TO	CRACK SPC MEAN	CRACK SPC SD	MIN SPALL MEAN	MIN SPALL SD	SEV SPALL MEAN	SEV SPALL SD	FAILURES MEAN	FAILURES SD	RQ MEAN	RQ SD
		(miles)		(years)		(ft)		(%)		(%)		(No)			
1	1980	90.2	1.6	5.5	16.5	6.5	4.2	30.8	15.4	1.1	1.1	2.0	2.7	---	---
1	1978	89.2	1.6	3.5	14.5	6.5	4.2	24.1	15.6	0.4	0.7	1.0	1.4	3.4	0.2
1	1974	79.6	0.0	3.5	10.5	6.5	4.2	---	---	---	---	0.6	0.7	3.1	0.3
3	1978	119.8	4.2	5.0	14.3	6.3	3.7	18.9	8.9	0.6	3.0	0.1	0.2	3.1	0.3
3	1974	120.8	0.0	1.0	10.3	6.3	3.7	---	---	---	---	0.1	0.3	3.1	0.3
4	1978	87.4	0.0	6.2	16.1	3.3	1.8	18.5	8.1	0.2	0.2	0.5	0.9	3.4	0.4
4	1974	87.3	0.0	2.2	12.1	3.3	1.8	---	---	---	---	0.2	0.6	3.2	0.4
9	1980	45.2	16.2	9.9	16.0	8.4	3.1	27.2	19.2	2.7	2.7	1.4	2.2	---	---
9	1978	45.2	16.2	7.9	14.0	8.4	3.1	27.2	19.2	1.8	2.0	0.9	1.3	2.9	0.3
9	1974	45.2	0.0	3.9	14.0	8.4	3.1	---	---	---	---	1.8	2.6	2.7	0.2
10	1980	166.9	0.0	13.3	17.2	6.8	4.2	53.8	12.6	1.9	2.2	7.3	5.7	---	---
10	1978	167.3	0.0	11.3	15.2	6.8	4.2	54.0	12.4	1.9	2.2	4.8	4.7	3.4	0.3
10	1974	170.4	0.0	7.3	11.2	6.8	4.2	---	---	---	---	1.6	1.6	3.2	0.2
13	1980	294.2	37.2	6.3	17.1	5.1	3.6	27.9	12.2	5.2	5.8	1.7	3.7	---	---
13	1978	293.2	11.6	4.3	16.1	5.1	3.6	15.3	9.0	3.3	4.2	1.1	2.3	3.4	0.3
13	1974	265.8	0.0	0.3	12.1	5.1	3.6	---	---	---	---	0.2	0.4	3.5	0.3

regularly in the field. Therefore, other sources of information were used in this study. Table 3.5 presents data used by Carey and Irick (Ref 34) to develop the serviceability-performance concept. The same information is used in this report to develop some of the distress models, as discussed in Chapter 4. Other models have been adopted from the literature (Refs 23, 35 and 36).

Condition Surveys for AC Overlaid Rigid Pavements

The monitoring of overlaid rigid pavements was only recently begun, and, therefore, the existing information does not present extensive time-histories of distress occurrence. Futhermore, only a few sections with the status of experimental sections are monitored. However, among these experimental sections there is one, known as Walker County, which represents one of the oldest, better monitored asphalt concrete overlays on rigid pavements in the state. Walker Co. contains several experimental sections, with varying AC overlay thicknesses, constructed on IH-45. The total project length is 11.4 miles. In order to monitor the distress condition of the overlay, condition surveys have been carried out before and at 20, 28, 55, and 71 months after the overlay was placed. Table 3.6 presents a summary of the information collected in such sections, including percentage of distress reflected in the various overlay thicknesses and the rut depths measured for the different overlay thicknesses.

Sources of Additional Information

In the following paragraphs, a description is presented of the sources of additional information, i.e., information other than distress quantities. Although the description is applicable to the three types of pavements included in this report, emphasis is placed on CRCP due to the fact that, so

TABLE 3.5. DATA FOR 49 SECTIONS SELECTED BY CAREY AND IRICK (REF 34) TO DEVELOP THE PRESENT SERVICEABILITY INDEX FOR RIGID PAVEMENTS USED IN THE AASHO ROAD TEST.

SECTION CODE	ACCEPTABILITY OPINIONS YES	ACCEPTABILITY OPINIONS NO	CRACKING (ft / 1000 sq ft)	SPALLING (ft / 1000 sq ft)	PATCHING (sq ft / 1000 sq ft)	FAULTING (in. / 1000 ft)	PSI
R1	0	.8	53.0	4.0	8.0	2.0	1.7
R2	1.0	0	4.0	0	0	0	3.7
R3	.2	.5	42.0	0	11.0	0	2.3
R4	0	.5	46.0	0	7.0	7.0	2.2
R5	0	1.0	102.0	0	28.0	1.0	1.4
R6	.2	.1	15.0	2.0	1.0	3.0	2.5
R7	1.0	0	0	0	0	0	4.5
R8	0	1.0	65.0	11.0	5.0	3.0	1.5
R9	0	1.0	74.0	19.0	85.0	1.0	.9
201	0	1.0	40.0	60.0	59.0	1.0	1.6
202	0	1.0	23.0	4.0	66.0	0	2.1
203	.1	.9	47.0	1.0	41.0	0	2.1
204	1.0	0	4.0	0	0	0	4.3
205	1.0	0	2.0	0	0	0	4.0
206	.6	.2	14.0	0	1.0	1.0	3.4
207	.4	.2	22.0	0	0	1.0	3.3
208	.3	.4	14.0	0	0	0	3.2
209	.1	.6	34.0	0	0	0	2.6
210	0	1.0	16.0	503.0	12.0	0	1.8
211	1.0	0	0	0	0	0	4.3
212	1.0	0	0	0	0	0	4.1
213	1.0	0	0	0	0	0	4.0
214	1.0	0	0	0	0	0	4.1
215	1.0	0	0	0	0	0	4.0
216	1.0	0	0	0	0	0	3.8
217	0	1.0	76.0	2.0	1.0	0	1.9
218	0	1.0	64.0	0	0	10.0	2.1
219	0	.9	97.0	0	1.0	4.0	2.0
220	1.0	0	0	0	0	0	4.1
401	1.0	0	0	1.0	0	2.0	3.8
402	1.0	0	11.0	1.0	0	4.0	3.5
403	.9	0	2.0	4.0	0	1.0	3.7
404	.6	.2	1.0	1.0	2.0	4.0	3.4
405	.3	.5	72.0	13.0	0	5.0	2.5
406	.4	.3	70.0	10.0	1.0	5.0	2.8
407	.1	.8	41.0	4.0	29.0	1.0	1.6
408	.1	.8	42.0	8.0	37.0	2.0	1.5
409	.2	.8	52.0	7.0	29.0	1.0	1.8
410	.2	.8	86.0	5.0	33.0	2.0	1.9
411	.1	.8	40.0	6.0	65.0	0	1.5
412	.4	.4	81.0	3.0	5.0	5.0	2.7
413	1.0	0	0	1.0	0	1.0	3.9
414	1.0	0	0	0	0	1.0	4.0
415	1.0	0	0	0	0	1.0	3.8
416	0	.9	54.0	1.0	219.0	8.0	.5
417	.1	.7	36.0	1.0	0	18.0	2.2
418	1.0	0	0	0	0	1.0	4.1
419	.5	.3	5.0	2.0	13.0	2.0	3.0
420	.1	.3	5.0	7.0	16.0	2.0	2.7

TABLE 3.6. PERCENT REFLECTED DISTRESS AND RUT DEPTH INFORMATION COLLECTED ON AN ASPHALT CONCRETE OVERLAY PROJECT IN WALKER COUNTY, TEXAS

OVERLAY THICKNESS (IN)	LENGTH (FT)	Z	PCT REFLECTED DISTRESS 20	28	55	71	RUT DEPTH (IN) 55	71	PCT REPAIRS
2.5	26275	1.01	0.01	0.11	1.15	1.49	0.07	0.11	68.
	5473	8.16	0	0.02	0.07	0.12	-	-	65.
	3796	0.46	0	0	1.02	1.04	-	0.11	80.
	8127	2.46	0	0.02	0.44	0.53	0.06	0.09	53.
	1073	0.32	0	0	0.06	0.12	-	-	0.
	627	1.13	0	0	0.50	0.50	-	-	50.
	274*	2.52	0	0	0	0	-	-	50.
	1550	0.44	0	0	0.62	0.67	-	0.01	50.
	500*	1.38	0	0	0.03	0.03	-	-	100.
	2175	0.48	0	0.35	0.84	1.59	-	-	67.
	4750	4.72	0	0.34	1.69	2.06	0.06	0.16	40.
	4275	0.72	0	0.14	1.01	1.35	-	0.14	33.
	58895		0	0.10	0.64	0.95	0.06	0.10	50.
4.0	125*	0.00	0	0	0	0	-	-	100.
	1000	1.83	0	0	0.01	0.11	0.10	0.11	56.
	850	2.43	0	0.01	0.40	0.62	-	-	67.
	2850	0.72	0	0.03	0.07	0.10	0.06	0.18	67.
	4700		0	0.01	0.16	0.28	0.08	0.15	63.
5.0	5152	2.48	0	0	0.02	0.09	-	0.17	92.
	2548	9.74	0	0	0.02	0.03	0.23	0.34	50.
	1000	0.69	0	0.09	0.27	0.33	-	-	50.
	8700		0	0.03	0.10	0.15	-	0.25	64.
6.0	3100	0.33	0	0	0	0	0.32	0.75	100.
	1900	0.18	0	0	0	0	-	0.34	100.
	9700	8.32	0	0	0	0	0.36	0.47	58.
	5189	2.19	0	0	0.18	0.19	-	0.48	42.
	3827	1.08	0	0	0.11	0.11	0.07	0.14	42.
	23716		0	0	0.06	0.06	0.25	0.36	68.

* SECTIONS WITH LESS THAN 500 FT.

far, most of the information collected by the CTR has consisted primarily of this pavement type.

Construction and Maintenance. The sources of construction and maintenance information are the SDHPT Construction Division (D-6), the Safety and Maintenance Operations Division (D-18), and each of the Districts. The types of information included are

(1) geometry,

(2) construction records (procedures, materials, costs, etc.),

(3) as-built properties, and

(4) maintenance records (preventive or corrective, procedure, materials, costs, etc.).

In Table 3.2 costs are considered apart from construction and maintenance records (a) to consider every type of cost, agency, and user, under one heading and (b) to stress the importance of this type of information.

Costs. The type of costs which are to be kept in a PMS are

(1) agency costs (administrative, labor, materials, equipment)

 (a) construction,
 (b) periodical maintenance, and
 (c) overlays;

(2) user costs

 (a) operational (operation, maintenance and deprciation of vehicles; time, accident, and discomfort) and
 (b) extra operational during maintenance and overlaying operations.

Agency costs can be collected relatively easily compared to user costs, which fall completely into the research domain. The lack of accurate cost models is considered one of the major deficiencies in existing PMS

(Ref 3). Costs play a major role at the network level for the proper planning of improvements and at the project level for the selection of alternative strategies through economic analysis. The CTR data base lacks information on any type of costs.

Materials Characteristics. The sources of information regarding materials characteristics are the SDHPT Materials and Tests Division (D-9), the Construction Division (D-6), the Highway Design-Research Division (D-8R), and each of the state Districts.

The minimum information which should be available in a data base, if accurate models are to be developed, includes

(1) layer thickness,

(2) concrete flexural strength and modulus of elasticity, and

(3) subbase strength and resilient modulus, and stress sensitivity.

Machado et al (Ref 37) gathered some information for the CTR by sending a questionnaire to the District Engineers. The questionnaire, according to Ref 37, was tailored to provide only information that could not be found in construction plans and specifications. Much of this information is qualitative; for instance, the concrete is classified by aggregate type (siliceous, limestone, mixture, and other) rather than by physical properties. Information on field material characteristics for a few projects has been collected by Kennedy et al (Ref 54).

Material characteristics can also be estimated for projects in which Dynaflect deflections are available in the data base. The properties are estimated by fitting the deflection basin to the one obtained by theoretical analysis (Ref 39).

Traffic. Traffic information in the CTR files was obtained from the Transportation Planning Division (D-10) of the SDHPT. The information is estimated from data collected using an in-motion weighing system.

Different amounts of distress have been found in opposing lanes of a roadway (Ref 76). One possible reason is the difference in load distribution between lanes, i.e., the directional distribution of load. Further research needs to be carried out to define the conditions leading to this difference in distress.

Planning activities make use of traffic figures in the decision process, not only because large amounts of traffic will accelerate the deterioration of the pavement but also because of the benefits to a larger number of users. It may be argued that the selection of a certain maintenance technique or material is influenced by the traffic. Therefore, it was decided to include traffic (equivalent 18-kip single axle loads) in Table 3.2 as information indirectly required for short-term scheduling. Accurate traffic information is of vital importance for research: to develop and evaluate models, to evaluate construction and maintenance under different traffic conditions, etc.

In order to establish the priority of projects needing overlay, the 1980 traffic for each of the projects was required. Based on the 1978 traffic survey and on the predicted traffic from the date of construction for 20 years provided by the SDHPT, the cumulative traffic for 1980 was computed by means of the following formula (Ref 40):

$$EAL_n = \frac{365 \ EAL_o}{Ln \ (1+i)} \left[(1 + i)^n - 1 \right] \qquad (3.1)$$

where

EAL_n = equivalent 18-kip single axle load at any year n ,

EAL_o = initial daily EAL on the day traffic is opened on the road, and

i = rate of traffic increase expressed at percent per year.

Then, by means of some algrebraic transformations on Eq 3.1, we can obtain the rate of traffic increase as follows:

$$\frac{EAL_A}{EAL_B} = \frac{\left[(1 + i)^A - 1\right]}{\left[(1 + i)^B - 1\right]} \qquad (3.2)$$

where

EAL_A = traffic from date of construction to traffic survey (1978) and

EAL_B = traffic from date of construction to 20 years.

Figure 3.3 is a plot of a typical project showing the procedure to obtain the cumulative 18-kip single axle applications based on the data given by the SDHPT.

Environmental Conditions. The types of environmental conditions which should be contained in a data base include

(a) moisture,

(b) temperature and solar conditions,

(c) freeze-thaw cycles, and

(d) site geological conditions.

For a more extensive discussion of environmental variables, Ref 3 may be consulted.

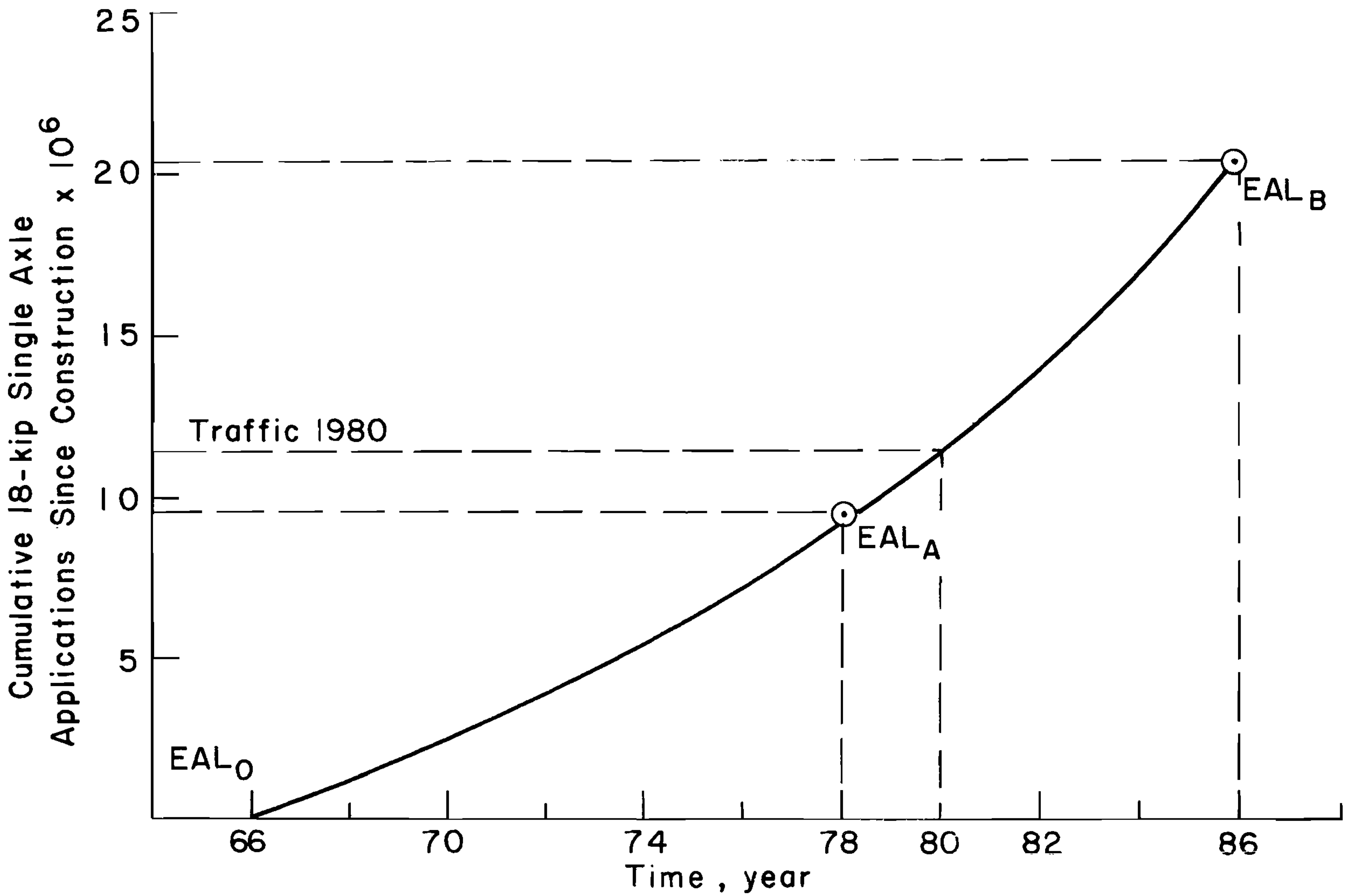

Fig 3.3. Example projection of equivalent 18-kip single axle applications using data provided by SDHPT.

Machado et al (Ref 37) collected this type of information and it is available in the CTR data base. The information is very general to be used in the derivation of accurate prediction models. Figure 3.4 is an example of the type of information contained in Ref 37; additional maps are provided for solar radiation, freeze-thaw cycles, and temperature constants.

Deflections, Riding Quality, and Skid Resistance. Although the discussion has been centered on condition surveys so far, it is important to mention again that the pavement evaluation involves several aspects: (a) riding quality, (b) load carrying capacity, (c) distress, (d) safety, and (e) aesthetics. At present, there is no precise formula to consider all these aspects in an integrated manner (Ref 3).

The quantity and quality of this information is similar to the requirements for condition surveys, shown in Table 3.1, for the different applications in a PMS.

Pavement engineers suspect that there is some correlation among riding comfort, distress, and load carrying capacity or behavior. Nevertheless, conclusive information has not yet been presented.

SAMPLING WITHIN PROJECTS

Several condition survey sampling procedures were investigated using existing CRC pavement condition survey data. Cursory observation of some of the pavements led to the idea that distress occurs in clusters and is not evenly spread throughout the length of the pavement. If this is the case, then random sampling procedures could result in extremely erroneous estimations of the actual extent of distress. Simulation of a random sampling procedure was carried out by sampling the data that was collected during the 1978 CRCP statewide condition survey. Predictions based on the samples taken

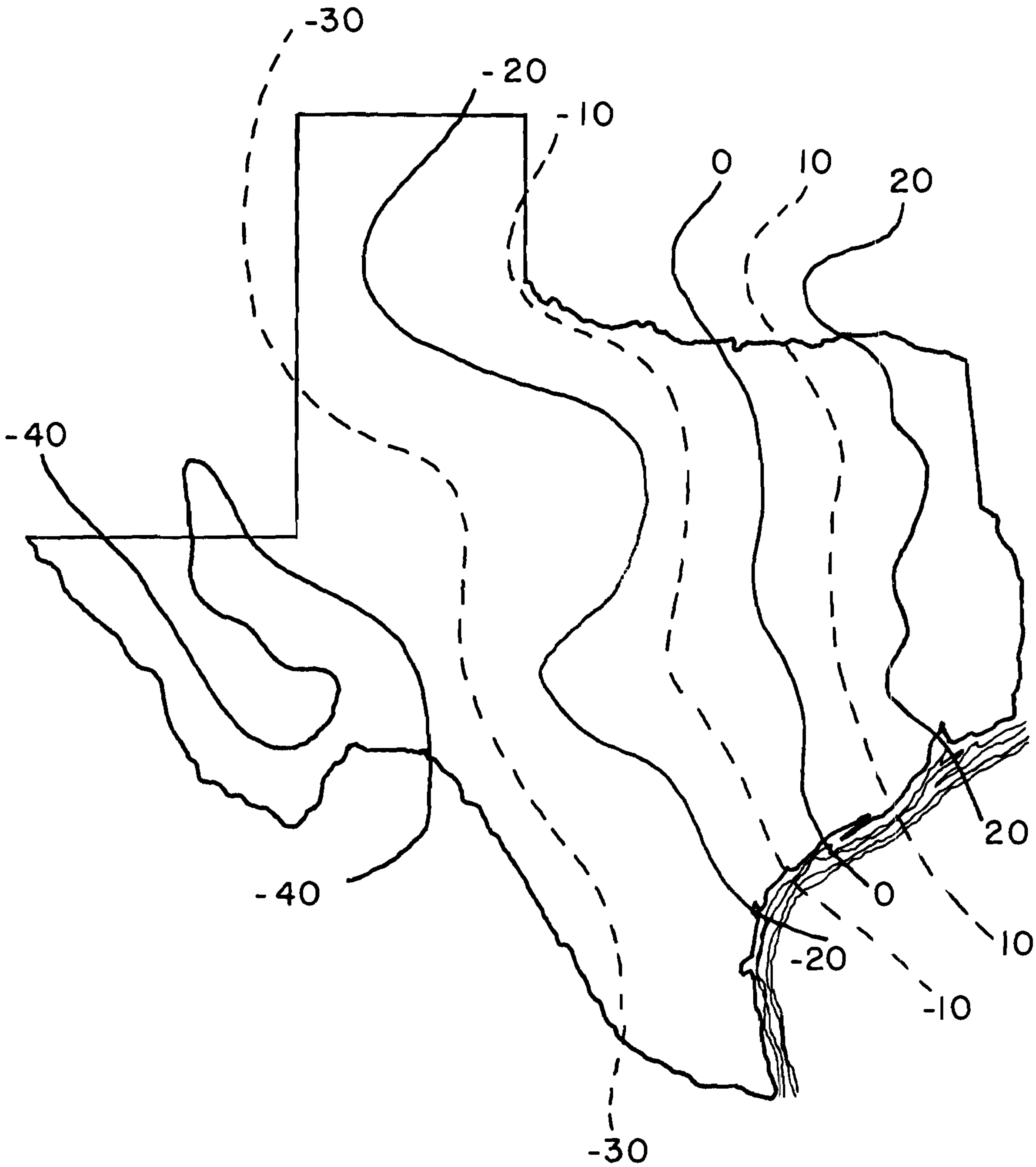

Fig 3.4. Contours of Thornwaite moisture index for Texas.

were compared with the actual distress observed when the entire pavement was surveyed. The results of the analysis revealed the extent of the probable errors in prediction associated with the different levels of sampling.

Sampling Punchouts and Patches

Taute and Noble (Ref 29) analyzed various samples of failures (punchouts and patches) drawn from all 237 CRCP sections surveyed in 1978. The distribution of errors associated with samples of varying size was plotted on a frequency diagram. Figure 3.5 indicates the probability of being within ± 25 percent of the correct answer for four different sample sizes, i.e., 20, 40, 60, and 80 percent. By inspecting this diagram, they found that 80 percent of the roadway needs to be surveyed for an error smaller than 20 percent with a confidence of 75 percent. In other words, sampling of punchouts and patches is not feasible. However, they pointed out that rigid and flexible pavements may exhibit different behavior regarding the occurrence of failures, and, thus, one may hesitate to apply these results summarily to flexible pavements. It should, however, be noted that the sections into which the 1978 CRCP condition survey and this analysis were separated were the individual pavement construction jobs. The subgrade support along the length of such a job may vary considerably. If the condition survey sections were split up further into much smaller lengths, based on a cursory examination of the pavement, the error might be reduced considerably.

Sampling Spalling

Using existing CRC pavement condition survey data from two districts, the possibility of sampling spalled cracks was investigated. Two sampling schemes were considered: (1) sampling from each mile in a project and (2) sampling a continuous length at the end of a project.

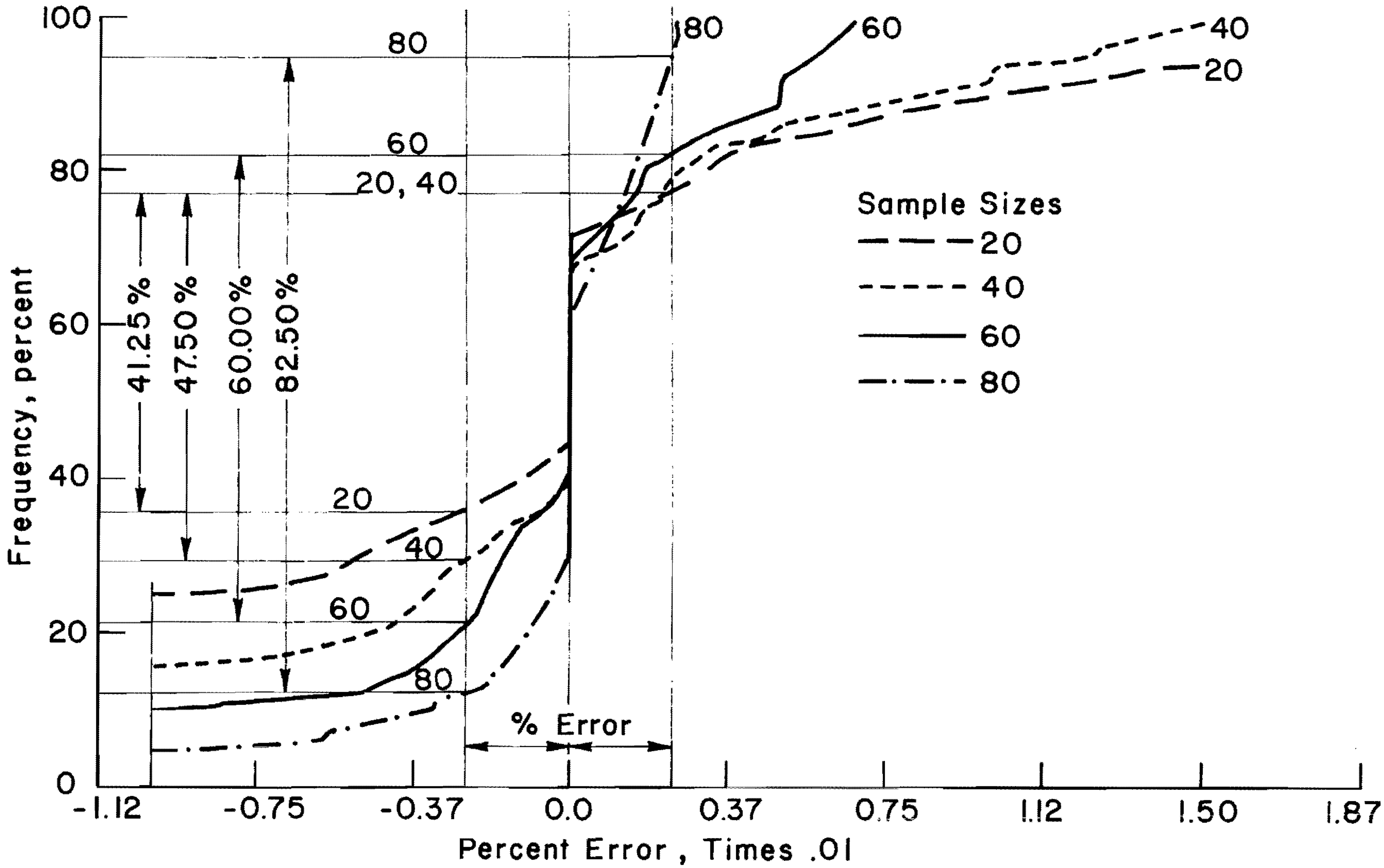

Fig 3.5. Percent error distribution for various sample sizes of failures (punchout and patches) from Texas CRCP sections surveyed in 1978 (Ref 28).

The percent error as a function of the percent of the project length sampled was obtained as follows:

$$PE_i = \left(\frac{SP - SP_i}{SP} \right) 100 \qquad (3.3)$$

where

PE_i = percent error of the sample,

SP = true number of spalled cracks in a project, and

SP_i = number of spalled cracks estimated from the sample.

The first scheme of sampling studied was a systematic sampling; for instance, for a 20 percent sample size, the first two-tenths of each mile were included in the sample. The second scheme consisted of taking a single sample at the beginning of each project; for instance, for a 20 percent sample size in a 5-mile project, the first mile was sampled.

For each of the schemes, the percent error was considered normally distributed and, using a 95 percent confidence level, the percent error versus the percent sampling was calculated. Figure 3.6 shows the results of the analysis; two curves are shown in the figure, one for each sampling scheme. It is apparent that the first sampling scheme provides better results than the second one.

The analysis was originally performed using information from one district. In order to corroborate the results, the analysis was repeated for another district. Figure 3.7 shows the results of sampling in two districts following the first sampling scheme. It appears that the results are about the same; therefore, the results from the first district sampled are valid.

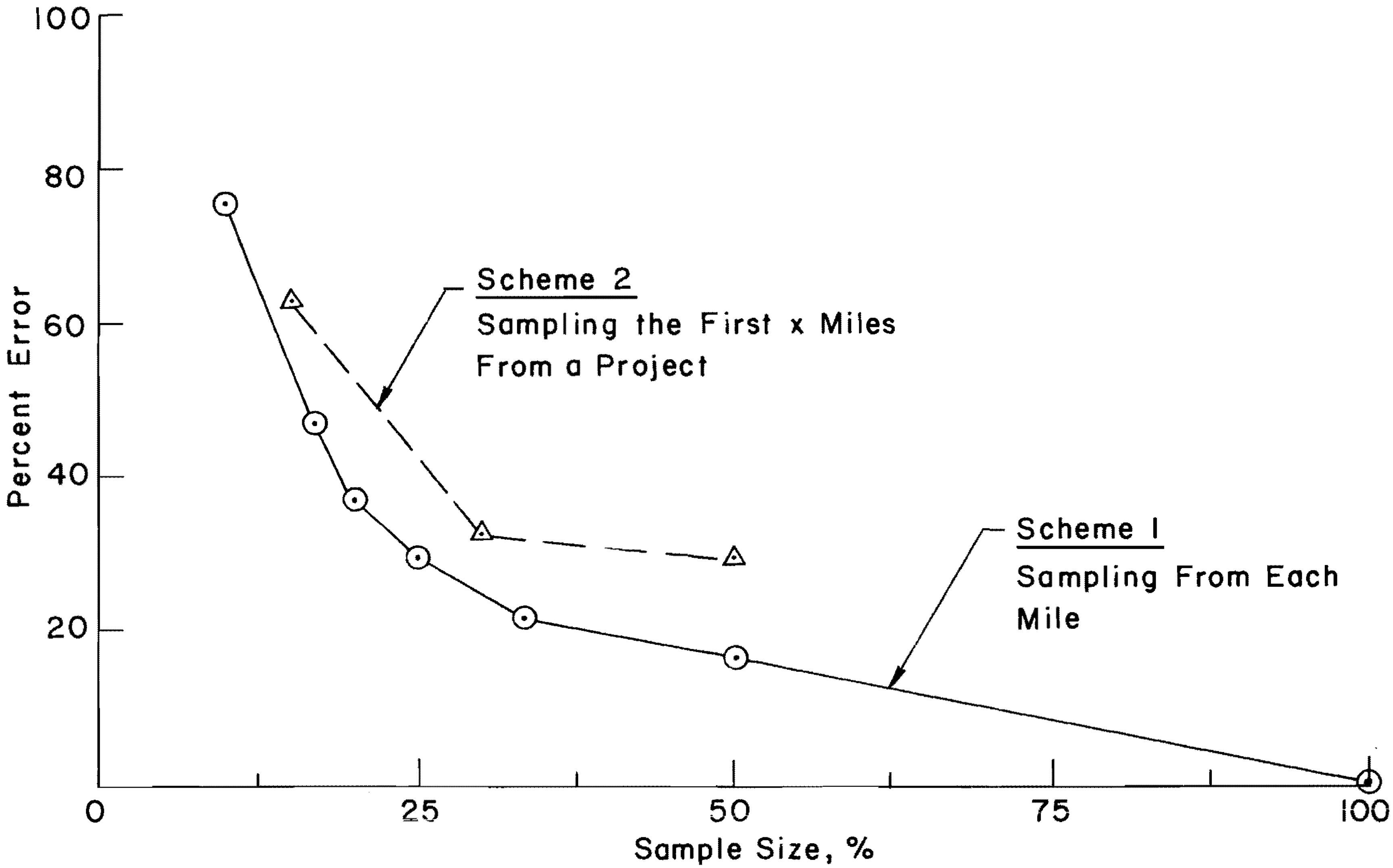

Fig 3.6. Percent error calculated for various sample sizes (95 percent confidence level) of spalling using data from Texas CRCP sections in one of the Districts (District 10) surveyed in 1978.

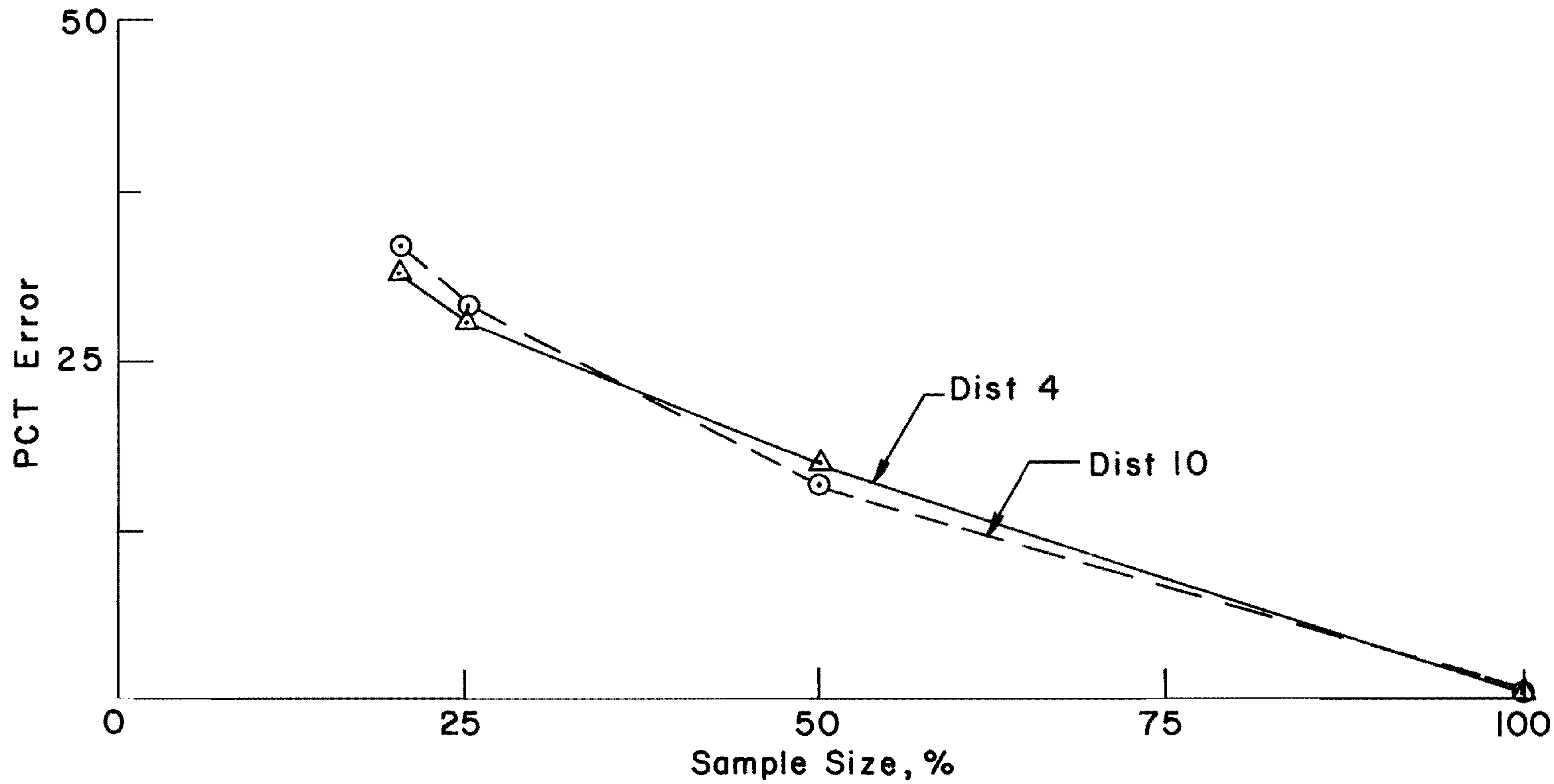

Fig 3.7. Effect of sample size in the percent error calculated for CRCP sections in two Texas Districts (Districts 4 and 10), sampling from each mile (Scheme 1).

A replication study was conducted in the 1978 CRCP condition survey to evaluate the precision of the measurements (Ref 41). Two different teams surveyed the same sections in various districts and the results were compared to assess the precision of measurements. A large difference was observed when spalling was measured. Table 3.7 shows the different results from each team when measuring spalling.

The results illustrate the need to constantly be aware of proper definitions and calibration if different teams are used. For example, for District 19, where a large difference is noted the team were working independently and at different times during the first phases of the project. For the two cases in District 24, i.e, a and b, the same problems existed for the first projects surveyed a large error existed, but later projects where better control existed the error was much smaller. The errors are also smaller in the other Districts where better calibration control was exercised. Thus, these results indicate the need for constant calibration by the teams.

Another alternative to sampling which was tried in the field by SDHPT and CTR personnel was to conduct the survey at a higher speed than the normally recommended 5 mph. Reasonable accuracy, less than 15 percent error, was obtained at 10 mph when the number of spalled cracks was less than 30 percent of the existing cracks. This result could be used in conjunction with the required degree of accuracy to speed up the condition survey procedure.

Recommendations for Sampling Within Projects

(1) In aggrement with Ref 29, the number of failures per mile can not be sampled but needs to be counted for the whole section.

(2) Pumping, although a major cause of failures, can be neglected when the purpose of the condition survey is to collect information to prioritize pavement sections for rehabilitation. The reason for

TABLE 3.7. RESULTS OF REPLICATE SECTIONS FROM THE 1978 TEXAS CRCP CONDITION SURVEY INDICATING THE NUMBER OF MINOR SPALLS PER MILE PER SECTION AND THE ERROR BETWEEN TEAMS

District	Team		Spalling Error (%)	Effect on Discriminant Score (%)
	1	2		
3	61.3	35.3	1.55	2.33
4	36.6	70.1	1.02	1.53
10	77.7	75.5	0.14	0.21
13	31.1	30.9	0.01	0.02
19	70.8	18.2	1.84	2.76
24a	86.2	133.7	2.25	3.38
24b	54.6	46.8	0.55	0.83
25	90.6	70.0	0.57	0.86

$\bar{E}$ = 0.99%

σE = 0.82%

this is that pumping is not an important factor in the prioritization equation developed in Chapter 4.

(3) Spalling, both minor and severe, may be sampled, depending on the amount of spalling in the pavement and the accuracy required.

(4) If the condition survey sections were split up further into smaller lengths, using a cursory examination of the pavement or deflections, the sampling error might be reduced considerably.

DATA REDUCTION

In this section, the programs which have been used to summarize and report the condition survey data are presented and discussed: the program CONSRV for CRC pavements, CONOVL for overlaid sections, and CONSMS for experimental sections. Additional information on each program can be found in the CTR documentation.

Data Reduction for CRCP: Program CONSRV

The condition survey program CONSRV is used to process and summarize condition survey data collected in various highway districts in Texas. CONSRV produces the following reports:

(1) project identification information, including the CTR number, length, construction data, and location of each project within a district;

(2) a failure summary, including the total and unoverlayed length, total and per-mile number of failures, and per-mile counts of spalling, patches, and punchouts for each project in each year surveyed;

(3) a riding quality summary, including serviceability indices for each project in each year surveyed; and

(4) detailed project sumary sheets which itemize all the survey data recorded in the latest survey for each project, broken down into one-mile segments and including mile posts, mile points, total and overlayed project lengths, serviceability indices, means and standard deviations of crack spacing, minor and severe spalling, minor and severe pumping, the number of minor and severe spalled

cracks, the number of minor and severe punchouts greater than and less than 20 feet, and the number of AC and PCC repair patches.

In addition, CONSRV produces a project-by-project year-by-year summary file suitable for analysis by other programs.

Figure 3.8 is a flowchart of the different reports and files produced by CONSRV. The program produces all these summaries from the condition survey files, each of which contains data for one district; these condition survey files are stored as permanent files in our data base.

In Ref 42, a description is given of CONSRV. In general terms the description is still valid; some changes have been made to the program to work with 1980 information: the failure summary prints out information for all the condition surveys, i.e., 1974, 1976, and 1980; and in the project summary sheets pumping is reported as a yes-no condition.

The program has been modified each time a condition survey is made and major work is needed to make it a general program. Currently work is under way to process the urban condition surveys, i.e., 1976 and 1981, using CONSRV.

Data Reduction for JCP and JRCP

At this time, no program is available in the CTR to process jointed pavements information. CONSRV may provide a basic model for developing such a program for JRCP and JCP.

Data Reduction for Overlays: CONOVL

CONOVL reports the condition survey information for AC overlays. The printout shows the results of all the condition surveys performed on a section so that the deterioration process is obvious from a simple inspection of the data. Figure 3.9 is a sample printout from program CONOVL.

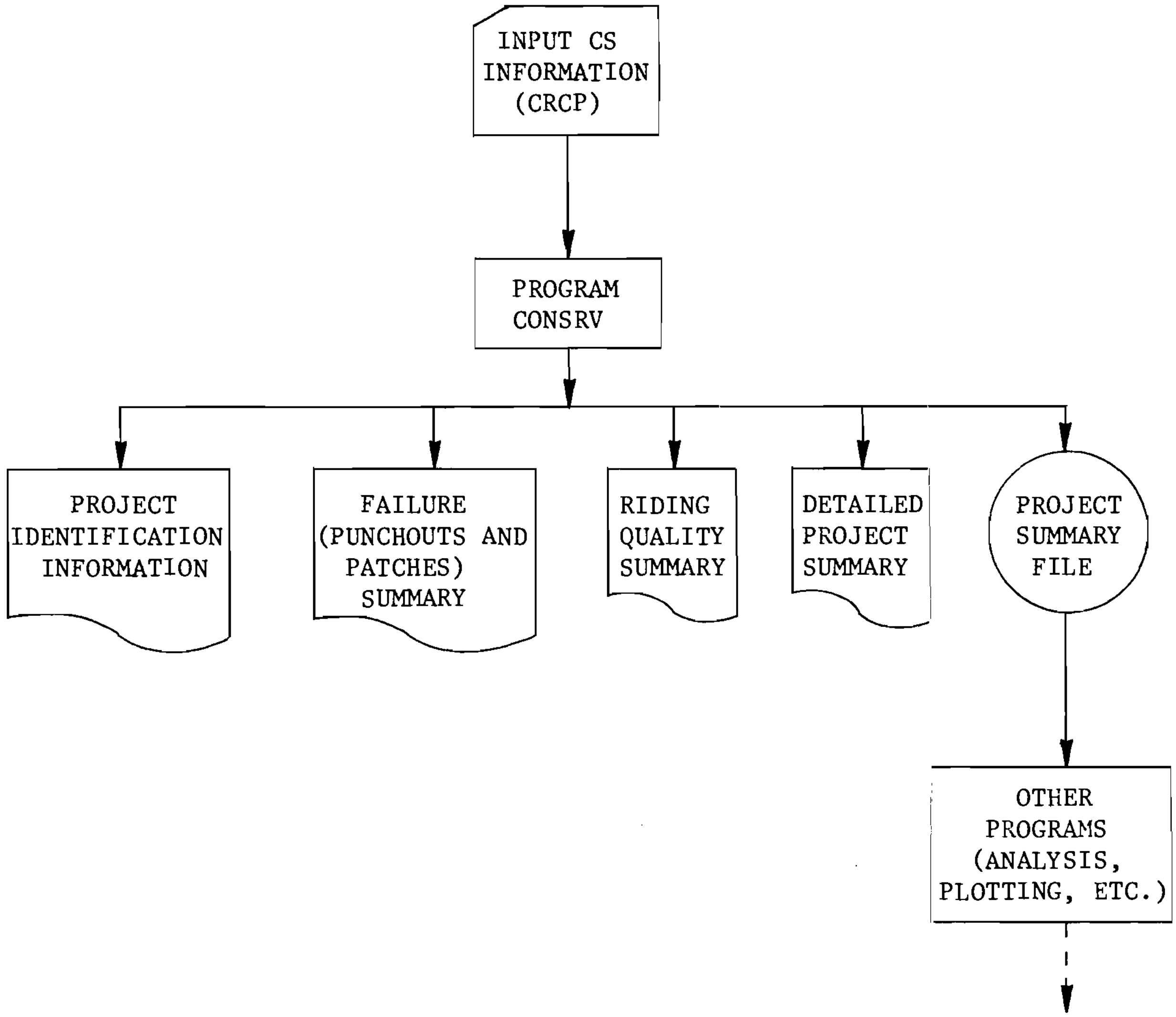

Fig 3.8. Reports and files produced by program CONSRV used to process and summarize CRCP condition survey information.

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                    ACP OVERLAY CONDITION SURVEY

**********************************************************************

FR: 741+ 0       LENGTH: 3625 FT         THICKNESS:      IN.
TO: 777+25       PERCENT STEEL:          PLACEMENT TEMPERATURE:     F.

    SURVEYS -                    MAY 81    MAR 82

    REFL.CRKS/NO.PER MI:         0/ 0.0    1/ 1.5
    PATCHES  /NO.PER MI:         0/ 0.0    0/ 0.0
    FAILURES /NO.PER MI:         0/ 0.0    0/ 0.0
    LOSS OF BOND FAILURES:           0         0
    MEAN RUT DEPTH (IN):

    COMMENTS:
**********************************************************************

FR: 742+60       LENGTH: 9665 FT         THICKNESS:      IN.
TO: 839+25       PERCENT STEEL:          PLACEMENT TEMPERATURE:     F.

    SURVEYS -                    MAY 81    MAR 82

    REFL.CRKS/NO.PER MI:         0/ 0.0    0/ 0.0
    PATCHES  /NO.PER MI:         0/ 0.0    0/ 0.0
    FAILURES /NO.PER MI:         0/ 0.0    0/ 0.0
    LOSS OF BOND FAILURES:           0         0
    MEAN RUT DEPTH (IN):                    .223

    COMMENTS:
**********************************************************************

FR: 839+25       LENGTH: 2690 FT         THICKNESS:      IN.
TO: 866+15       PERCENT STEEL:          PLACEMENT TEMPERATURE:     F.

    SURVEYS -                    MAY 81    MAR 82

    REFL.CRKS/NO.PER MI:         0/ 0.0    0/ 0.0
    PATCHES  /NO.PER MI:         0/ 0.0    0/ 0.0
    FAILURES /NO.PER MI:         0/ 0.0    0/ 0.0
    LOSS OF BOND FAILURES:           0         0
    MEAN RUT DEPTH (IN):                    .260

    COMMENTS:
**********************************************************************

FR: 866+15       LENGTH: 1610 FT         THICKNESS:      IN.
TO: 882+25       PERCENT STEEL:          PLACEMENT TEMPERATURE:     F.

    SURVEYS -                    MAY 81    MAR 82

    REFL.CRKS/NO.PER MI:         0/ 0.0    0/ 0.0
    PATCHES  /NO.PER MI:         0/ 0.0    0/ 0.0
    FAILURES /NO.PER MI:         0/ 0.0    0/ 0.0
    LOSS OF BOND FAILURES:           0         0
    MEAN RUT DEPTH (IN):

    COMMENTS:
**********************************************************************
```

Fig 3.9. Sample output from program CONOVL used to report condition surveys on AC overlays on rigid pavements.

Slight modifications need to be made to the output; it prints only star symbols when the quantities exceed the printing format, which is a common case.

<u>Data Reduction for Special Projects: Program CONSMS</u>

CONSMS reports the condition survey of small CRCP sections. The output is similar in form to that for AC overlays, but the distress manifestations are different. Figure 3.10 is a sample output of CONSMS.

SUMMARY

The collection and preparation of condition survey data for analysis has been presented. An attempt has been made to explain the data processing procedure, about which the following statements can be made:

(1) The condition survey procedure, in terms of quality and quantity, depends on the intended applications. That is, when deciding which, and how much information should be collected, it is necessary to have in mind the applications for which the data will be used.

(2) The limitations and additional information required in our data base can be assessed by comparing it to the standard information required for future applications. That is, at the present time analysis at the network level, verification of existing design methods, and some specific special studies are possible, but improvement of design methods or accurate predictions are not possible with the information available.

(3) Sampling within sections was attempted but the results are discouraging. If the existing projects could be broken into smaller sections by cursory examination or using deflections so as to reduce heterogenity within the sections, then the variability could be reduced.

(4) The computer programs used to report the information have been described. Program CONSRV needs to be modified to deal with future condition surveys. A more sophisticated data system would be of great help for the increasing amount of information being collected.

(5) In Appendix A, the developement of the condition survey procedures used by the CTR is presented. Updating of the procedures can be made when relevant variables are identified for specific applications.

```
                       SMALL SECTIONS CONDITION SURVEY
                       -------------------------------
SECT. 1 BOWIE CO. EXPERIMENTAL SECTIONS WITH A WATERPROOF JOINT SEAL
AND A 2 INCH TYPE D HMAC OVERLAY WITHOUT PUMPING


**********************************************************************
DIST:     19 CFTR NO:  1911  HIGHWAY: IH-30          COUNTY: BOWIE
SECT:      7 CONTROL:   610   JOB NO:    10    REPORT DATE:  03 SEP 81
**********************************************************************

  SEGMENTS -

**********************************************************************

  FR:1996+ 0      LENGTH: 1000 FT
  TO:1986+ 0      COMMENTS:BEFORE OVERLAY

      SURVEYS -                        JULY81

      CRACKS    /NO.PER MI:       350/1848.0
      MIN SPALL/NO.PER MI:         65/ 343.2
      SEV SPALL/NO.PER MI:        174/ 918.7
      MPO. <20 /NO.PER MI:          2/  10.6
      MPO. >20 /NO.PER MI:          0/   0.0
      SPO. <20 /NO.PER MI:          0/   0.0
      SPO. >20 /NO.PER MI:          0/   0.0
      AC. PATCH/NO.PER MI:          1/   5.3
      PCC PATCH/NO.PER MI:          0/   0.0
      MINOR PUMPING  FEET:               0
      SEVERE PUMPING FEET:               0

      FAILURES /NO.PER MI:          1/   5.3
**********************************************************************
```

Fig 3.10. Sample output from program CONSMS used to report condition surveys on small (experimental) sections.

CHAPTER 4. DISTRESS INDEX AND DECISION CRITERIA INDEX

This chapter presents some of the approximate methods found in the literature to derive distress indices and decision criteria indices. Before discussing the methods, the concepts of distress are defined. The approximate methods presented in the literature review are

(1) subjective parameters,

(2) regression analysis,

(3) factor analysis, and

(4) discriminant analysis.

After the various methods were reviewed, discriminant analysis was selected for the development of the indices used in this study, because it appears to be the most appropriate technique for the data available and because of its encouraging results.

DEFINITION OF THE INDICES

The following paragraphs define distress and decision criteria indices as commonly understood in the field of pavements. The definitions are given in a simplified form in this Chapter; Hudson and McCullough present a more detailed description in Ref 47.

Distress Index

Distress is the visible consequence of carrying to a limit the response of the pavement to load, environment, and other inputs. Distress index is the combination of distress manifestations to ascertain with a single number the amount of pavement pavement deterioration (Ref 47).

A simple form of an equation used to combine the various distress manifestations into a distress index (DI) is

$$DI = A_o + \sum_{i}^{n} \frac{m_i}{M_i} \tag{4.1}$$

where

m_i = amount of distress manifestation i ,

M_i = terminal condition of a pavement section if distress type i is an isolated occurrence,

A_o = constant, and

n = number of distress types.

Another way of presenting the same equation is to substitute the M_i 's with $1/A_i$ to give

$$DI = A_o + \sum_{i}^{n} A_i m_i \tag{4.2}$$

where the A_i is a are constant. This last equation is the one used for the rest of the discussion.

Decision Criteria Index

A decision criteria index is the combination of distress manifestations which is considered to indicate the failure condition of a pavement section associated with age, traffic, and pavement structure (Ref 47). That is, the decision criteria index when compared to the distress index will indicate if a pavement section has reached its terminal condition.

Theoretically, the decision criteria should include riding quality, safety, and economics, but in this report only the implications of distress are considered.

LITERATURE REVIEW

The existing equations which are used as distress and decision criteria indices involve subjective preferences. The only way to avoid subjective decisions is to have accurate cost and prediction models. In this case, the indices are developed only to avoid the data requirements and computer costs involved in using an optimization procedure to find the optimum time to rehabilitate a pavement section. This approach is discussed in more detail in Chapter 6.

The equations covered in this chapter involve subjective preferences and decisions. The equations covered under the heading "Subjective Parameters" are those in which the parameters, i.e., the relative weights of the variables in Eq 4.2, are assigned using only experience and engineering judgement. The other three types of approximate equations covered in this chapter involve some form of correlational procedure: regression, factor, or discriminant analysis.

Subjective Parameters

These are by far the most common types of index equation available. Almost every highway agency has its own and, of course, each equation reflects local conditions and experience. Lytton et al (Ref 48) give a summary of such types of equation. Several of the techniques which can be followed to develop an index are presented in Ref 49; among them are the ones presented below.

Pedigo and Hudson (Ref 6) present a methodology to formulate a subjective index; the procedure involves the following steps:

(1) selection of variables to be included in the index,

(2) categorization of the selected variables,

(3) assignment of numerical values for each category, and

(4) establishment of weighting factors to adjust the calculated values.

Utility theory is an extensively recognized technique for developing index type equations. The application of utility theory to measure pavement performance has been reported by Arizona and Texas (Refs 50 and 51). Basically, the procedure involves the assessment of utility functions which express a decision maker's preference over different levels of selected variables. These functions are developed primarily by soliciting expert opinion through interviews.

Fernando (Ref 49) discusses the use of Rational Factorial Rating to develop index type equations. The procedure consists of selecting the variables to be included in the index and presenting decision makers with combinations of such variables at different levels so that they rate each of the combinations. The combinations are carefully selected from experimental design so that a regression analysis or analysis of variance of the results can be performed. This approach substitutes the selection of representative pavement sections in the field for numbers on paper. It is a feasible approach if economical resources are scarce or as an initial analysis to select the variables in a more complex study.

Regression Analysis (Refs 60 and 61)

To develop a distress index equation through regression analysis, it is necessary to select pavement sections covering the distress manifestations, severity levels, and combinations thereof for which the equation is intended. Each member of a rating panel is required to rate each pavement section using a predetermined scale. The regression analysis is performed using the scores given by the rating panel as a dependent variable and the various distress measures as independent variables. The relative weighting coefficients for each type of distress are obtained from the analysis. Shahin et al (Ref 55) document the development and application of one such type of equation used in airport pavements. This approach was originally used by Carey and Irick (Ref 34) to develop the serviceability performance concept.

A decision criteria index can be derived using regression analysis by asking the rating panel to accept or reject each pavement section and then using this decision as a dependent variable.

Factor Analysis

Factor analysis is a generic name for several techniques which can be used to reduce the dimensionality of a set of variables in terms of a much smaller number of latent variables. The new variables are simply linear combinations of the original variables.

Oehler and Holbrook (Ref 56) document the use of this technique to develop an "objective" rating score for pavement structural performance. Their key assumption is that, if the distress variables linearly measure general structural performance in varying degrees, they will be intercorrelated accordingly.

The outcome of the factor analysis is an equation or set of equations which account for the variation among subjects on the observed variables; the other statistical techniques presented in this chapter answer a specific question: "Is the pavement structurally acceptable?". The problem with factor analysis is the interpretation of the resulting indices: the intercorrelations obtained might be indicating the relative effects of the different distress mechanisms or any other common caracteristic of the distress manifestations instead of measuring structural performance.

It is felt that the research question should dictate the appropriate statistical analysis rather than fitting the outcome of a certain technique to our research problem.

Discriminant Analysis (Refs 57, 58, and 59)

Discriminant analysis is a statistical technique used to classify data into groups; its objective is to construct a boundary, that is, a discriminant equation, such that the elements of each group can be separated. Once the equation is defined, any new element can be assigned to one of the predetermined groups.

The authors of this report participated in a study in which this technique was applied to develop an equation to discriminate CRC pavements with an acceptable level of distress from pavements requiring overlay

(Ref 11). Distress data, including before overlay condition, of several pavements in Texas were used to determine the reasons leading to overlay; that is, having data from two groups, overlaid and non-overlaid pavements, an equation was developed to differentiate between the groups.

The outcome of the discriminant analysis is a decision criteria index and its relative magnitude can be used as a distress index. Further details on the application of this technique are presented in the following sections.

Evaluation of the Methods

Data for jointed concrete pavements from Carey and Irick (Ref 34) and for CRC pavements from Gutierrez de V. and McCullough (Ref 11) were used to further investigate and compare the various methods previously discussed.

Because of the lack of information regarding the dependent variable (distress rating score from a panel), the regression analysis of the data was not performed. Therefore, the comparison was reduced to factor versus discriminant analysis. Equations were derived using each of these techniques from the appropriate subroutine of computer program SPSS (Ref 59). To simplify the comparison among variables within each of the equations, the weighting coefficients were made independent of the measuring units by normalizing the variables.

Careful examination and interpretation of the results is required in factor analysis: the factor scores are latent variables which are the best intercorrelation among the original variables; nevertheless, there is no support for the assumption that the latent variables are a measure of the deterioration of the pavement. Furthermore, a single equation is not defined; instead a set of equations is defined, which will increase in number as the number of independent variables is increased. For instance, examination of the equations derived for CRCP showed that failures and pumping are highly correlated and the two can be combined to form another variable or factor score. This can be explained by the fact that pumping is an indicator of future punchouts. That is, some of the punchouts are formed because of inadequate support of the pavement slab produced by pumping of material from underneath. A second equation obtained for CRCP revealed correlation between minor and severe spalls, with opposite signs. This is not surprising since the spalled cracks in a pavement are classified in one or the other category: if the percent of severe spalls increases, the percent of minor spalls is reduced.

The results from the discriminant analysis were encouraging: 92 percent of the cases for jointed pavements and 88 percent of those for CRCP were correctly classified; therefore, this type of approach was adopted to develop a decision criteria index and a distress index. The relative weighting coefficients obtained by factor analysis do not compare well with the ones obtained using discriminant analysis.

DISCRIMINANT ANALYSIS OF DATA

In the following paragraphs, a detailed description of the discriminant analysis of the data is presented. The data used in the analysis are described, the equations developed are presented, and, finally, the shortcomings of the analysis approach are discussed.

Data Base

Distress condition surveys of CRCP in Texas were performed in, among others, 1974 and 1978. Several distress manifestations were recorded, namely, punchouts and patches per mile, percent of minor spalling, percent of severe spalling, and percent of pumping. Some of the pavements surveyed during 1974 were overlaid prior to the survey in 1978. These data are used to determine the reasons leading to the decision to overlay using data on several variables from two groups (overlaid and non-overlaid pavements) to describe their differences.

The jointed pavement data used in the analysis are the data used by Carey and Irick (Ref 34) to develop the serviceability-performance concept. The justification for using this information is based on findings by Hutchinson (Ref 62) and Weaver (Ref 63). Hutchinson found that subjective estimation procedures, typified by Road Test panel ratings, were inappropriate for the task because they tended to measure pavement distortion and deterioration rather than riding quality, which is the essence of serviceability. Weaver reinforces this point in his results for developing a serviceability index for New York. He found that inclusion of "experts" in the rating panels or inappropriate definition of objectives biased the results of serviceability studies. Therefore, it has been assumed that the acceptability or unacceptability of pavement sections in the Road Test was influenced by the pavement condition.

Analysis

Using the statistical package SPSS, the following discriminant equations were obtained. The discriminant score can be interpreted as follows: if it is positive for a given pavement section, then the section is in good condition; if the score is negative (smaller than zero) the section is considered to be failed. The larger the magnitude of the discriminant score, the better the condition of the pavement.

Equation for CRC pavements (Ref 11). The equation obtained for continuous pavements was of the form

$$Z_c = A_o - 1.13\ Z_{ff} - 0.49\ Z_{ms} - 0.12\ Z_{ss} + 0.04\ Z_{pp} \tag{4.3}$$

where

Z_c = discriminant score for CRC pavements,

A_o = constant,

Z_{ff} = normalized value of failures per mile,

Z_{ms} = normalized value of percent minor spalling,

Z_{ss} = normalized value of percent severe spalling, and

Z_{pp} = normalized value of percent pumping.

As an example, the normalized value for failures per mile is calculated as

$$Z_{ff} = \frac{FF - \overline{FF}}{SD_{ff}} \tag{4.4}$$

where

FF = number of failures (punchouts and patches) per mile for the project in question,

$\overline{FF}$ = mean number of failures per mile for all sections in the discriminant analysis, and

SD_{ff} = standard deviation of the number of failures per mile for all the sections in the analysis.

Similar definitions apply for the rest of the variables.

It was decided that inclusion of the pumping term in the equation would be misleading because of its counter intuitive sign. Thus, another equation was developed without considering percent of pumping. A possible explanation for the positive sign is the high correlation between failures and pumping. In addition, the percentage of pumping observed in the sample data was of small magnitude in both good and poor conditioned pavements and, therefore, the influence of the pumping term in the equation is negligible.

The equation neglecting pumping can be further simplified by introducing the appropriate values of the means and standard deviations of the distress manifestations, given in Table 4.1, to obtain

$$Z_c = 2.113 - 0.138FF - 0.032MS - 0.020SS \quad (4.5)$$

or dividing by 2.113 so that the equation is of the form of Eq 4.2:

$$Z_c = 1.0 - 0.065FF - 0.015MS - 0.009SS \quad (4.6)$$

where

FF = failures per mile,

MS = percent minor spalling, and

SS = percent severe spalling.

TABLE 4.1. STATISTICAL PARAMETERS OF THE CRCP DATA USED FOR THE DISCRIMINANT ANALYSIS

	Means			Standard Deviations		
Condition	Overlaid	Non-Overlaid	Total	Overlaid	Non-Overlaid	Total
Failure	15.56	2.01	3.99	14.08	4.20	8.14
Minor Spalling	32.12	19.52	21.36	22.38	12.76	15.16
Severe Spalling	4.96	2.74	3.06	5.61	6.11	6.08
Pumping	5.79	3.43	3.77	6.54	5.73	5.90

In Eq 4.3 the most important variable is failures per mile, followed by minor spalling and severe spalling. The equation classified correctly 88 percent out of 224 cases. The cases used to test the prediction capability of the discriminant equation were the same as the ones used to develop the equation.

Equation for Jointed Pavements. The equation obtained for jointed pavements was the following, after algebraic manipulation so that it resembles Eq 4.2,

$$Z_j = 1.0 - 0.028C - 0.004S - 0.007P - 0.019F \qquad (4.7)$$

where

Z_j = discriminant score for jointed pavements;

C = cracking, ft per 1000 sq. ft.;

S = spalling, ft per 1000 sq. ft.;

P = patching, sq. ft. per 1000 sq. ft.; and

F = faulting in wheelpath, inches per 1000 ft.

In the normalized equation, heavier weight is assigned to cracking, while low weights are given to spalling and patching. That is, cracking has a large influence in the decision to accept or reject a jointed pavement. Equation 4.7 classifies correctly 92 percent of the 49 cases.

It was mentioned that the acceptability or unacceptability of the pavement sections used in the derivation of the discriminant equation for jointed pavements was originally formulated serviceability, a concept completely different from distress. However, the coefficients derived in

Eq 4.7 are supported by an independent analysis suggested by Zaniewski (Ref 64). He recommended transforming the equation developed for CRCP by substituting the distress terms with equivalent distress manifestations in jointed pavements (the magnitude of the new variables was scaled so the range was equal to one of the original variables). The coefficients obtained by this method were about the same as the ones derived by Discriminant Analysis (Ref 65). The approach suggested by Zaniewski appears to be viable when data are not available. Nevertheless, the approach requires good engineering judgement.

Commentaries on the Discriminant Analysis Approach

At this stage, it is important to mention some assumptions inherent in the discriminant analysis that might invalidate the results if not satisfied:

(1) That the discriminant functions obtained are linear. This might not be correct. This situation arises from the fact that the mathematics involved in the discriminant analysis are based on the assumption that distributions of the groups are equivalent (variance and covariances should be the same in both groups).

(2) That the variables are considered normally distributed.

Non-parametric and non-linear discriminant analysis techniques could be used if assumptions (1) and (2) or are not found to be valid. Regardless of the restrictions mentioned above, the prediction results obtained with the discriminant equations are encouraging.

In addition to the previously mentioned assumptions, the following points should be considered:

(3) The data points used are not comprehensive. That is, for distress values outside the range of our data, the equations derived are not applicable.

(4) The subjective decisions for overlaying the sections were assumed to be correct and not affected by availability of funds.

(5) Not all the factors have been included. The criterion followed for deciding to overlay some of the sections used in the CRCP analysis is not clear. The coefficient derived could be different if all the factors involved in the decision process were included.

SUMMARY

Several approximate methods aimed at developing a distress index have been presented and discussed; i.e. subjective parameters, regression analysis, factor analysis, and discriminant analysis. The following conclusions have been drawn from the study of these methods:

(1) The equations with subjective parameters rely heavily on engineering judgement and experience and, therefore, are useful when sufficient information is not available.

(2) Factor analysis is difficult to interpret and there is no support to the assumption used in this approach that the resulting equations measure structural performance or deterioration of a pavement section.

(3) Regression analysis and discriminant analysis are viable techniques for developing distress and decision criteria indices, the selection of one or the other being dependent on the dependent variable selected.

An alternative procedure for developing distress indices is presented in Chapter 6. Such a procedure makes use of the distress models presented in the next chapter plus cost equations which are a function of the distress condition of the pavement section.

CHAPTER 5. DISTRESS PREDICTION EQUATIONS

This section describes the derivation of distress prediction equations for concrete pavements. Field data were used to obtain models for CRCP and AC overlaid rigid pavements, while, for jointed pavements, models have been adopted from the literature. The models derived assume that at some point in time information on the distress of a pavement was collected, and such information is used to forecast the future condition of the pavement.

The models developed predict failures (punchouts and patches), minor spalling, and severe spalling in the case of CRCP pavements; cracking, spalling, and faulting for jointed pavements; and reflected distress for AC overlaid rigid pavements.

APPROACHES TO DISTRESS PREDICTION

Although it is not generally accepted, pavement models can be categorized as mechanistic and empirical. The former are theoretical models which make use of established mechanical principles and variables to estimate a pavement response. Data are used to corroborate the applicability of the model. The empirical models usually involve statistical analysis to fit an equation to field data; that is, the data are used to generate the model. Sometimes, this approach is used because the form of the model is not easily conceived, the relevant variables are unknown beforehand, or the indirect variables are included in the analysis. An important difference between the two types of models is that mechanistic models are bounded by the hypothesis used in its derivation, while empirical models are bounded by the maximum ranges of the data used in the analysis.

Due to the complexity of considering all the factors involved, such as the pavement structure, traffic, and environmental conditions, plus construction and maintenance variables, the existing prediction equations rely more on empirical results and engineering judgement than on theoretical concepts. However, theories exist that attempt to explain the formation of distress by means of distress mechanisms which make use of concepts familiar to engineers, such as stress and strain (Refs 66, 67, and 68).

A review of the methodologies reported in the literature indicates which are the techniques more commonly being used to predict distress quantities, as discussed in the following paragraphs.

Markov Process

The Markov approach uses the concept that a pavement gradually deteriorates in a series of transitions of pavement conditions, from the initially good condition to the less desirable conditions. This process takes into account only the present situation and predicts future distress on the basis of this present situation. The approach can use both objective and subjective information (Refs 50, 68, and 69).

Regression Analyses

Multiple regression analysis techniques are most commonly used for the development of distress prediction equations. The approach is used to quantify pavement distress as a function of those variables which have a significant influence in the deterioration of a pavement.

Method of Analysis

Regression analysis was used for the derivation of the distress prediction equations used in this study. Several procedures in current use were available to perform the necessary calculations, including all possible regressions, backward elimination, forward selection, and stepwise regression (Ref 60). Because of its advantages over the other procedures, a stepwise regression was used in the analyses. The regression subroutine from SPSS (Ref 59) was chosen to perform the stepwise regression.

The requirements for adopting a prediction model were adequate R and standard error, inclusion of significant variables, and acceptable plot of residuals. These requirements are presented for each of the equations adopted. Guidelines for reliable models are presented in Refs 61 and 71.

EQUATIONS FOR CRC PAVEMENTS

In the next paragraphs, the development of distress prediction equations for CRC pavement is presented. The data base used is documented, the equations derived for failures, minor spalling, and severe spalling are presented; and, finally, the results are discussed.

Data Base

The data base utilized in this study is an extension of the material presented by Machado et al (Ref 37) in 1974 and also more recent data which have been collected on the same Texas rural highway section during 1978 and 1980 (Refs 11 and 72), as described in Chapter 3. The same pavement sections were surveyed in 1974 and 1978; however, some of the sections were overlaid after the 1974 survey and were not included in the 1978 data set. In the 1980 condition survey, only the east portion of the state was monitored.

Five types of data were considered in the development of the distress prediction models:

(1) environmental factors,

(2) materials,

(3) traffic,

(4) age, and

(5) pavement distress.

The selection of factors was made on the basis of data availability. A detailed description of these factor can be found in Chapter 3.

The models developed for CRCP have as inference space Texas CRC pavements 8-inches thick and between 2 and 17 years old. Extreme caution should be exercised when attempting to extrapolate these models outside this inference space because unrealistic predictions may result.

Description of the Model for Failures

Several investigators, including Faiz and Yoder (Ref 73) and McCullough and Treybig (Ref 74), point out the following as the major causes of distress in CRCP

(1) loss of support,

(2) inadequate design,

(3) excessive traffic, and

(4) construction problems.

Inadequate design and construction problems can not be predicted unless an after construction monitoring of the pavement is made. Therefore, attempts to develop prediction equations from initial conditions have not been successful. Machado et al (Ref 37) and Potter (Ref 75) developed failure prediction equations using the 1974 data. These equations were updated by Noble and McCullough in 1978 as more information became available (Ref 76). The last equation was checked using the 1980 condition survey, and it was found that the equation tended to overpredict. A likely reason for this appears to be the various changes in measuring units for the various condition surveys. In 1974 failures were measured as an area, while in 1978 and 1980 the actual number of failures per mile was counted. Therefore, the previous equations were neglected and a new analysis performed.

Strauss et al (Ref 77) developed distress prediction equations for CRCP using theoretical formulations and field observations. However, their equations are given in units different from the ones required by the distress index and contain too many variables for a network level analysis.

The distress prediction model obtained for failures is summarized in the following paragraphs. The model assumes that condition survey information is taken at some time in the life of a selected CRC pavement and this information is used with the equation given below for the prediction of failures at some later time during the pavement's life. The equation is

$$\text{Log}\ (FF_2 + 1) = \frac{X_2}{X_1}\ \text{Log}\ (FF_1 + 1) \qquad (5.1)$$

where

FF_2 = predicted number of failures per mile,

FF_1 = failures per mile at time of condition survey,

X_2 = pavement age at time chosen for distress prediction, years, and

X_1 = pavement age at time of condition survey, years

The relevant summary statistic for the regression analysis from which the equation was determined is standard error = 0.267 (using logarithmic transformation of the dependent variable) for 147 cases. The R statistic is not significant since the regression was forced through the origin. Figure 5.1 is a plot of the predicted versus the actual number of failures per mile.

Description of the Model for Minor Spalling

Early attempts were made by Machado et al (Ref 37) and Potter (Ref 75) to develop an equation to predict spalling using Texas CRCP information from the 1974 condition survey. In both cases, the resulting equations were not useful for prediction purposes.

If data on the spalled condition of a pavement section are known at some point in time, the prediction procedure is greatly simplified. An inspection of the data and the fact that the highest possible amount of spalling is 100 percent suggested an exponentially asymptotic model of the form

$$MS = A_o + A_1 \cdot \exp (B \cdot X_1)$$

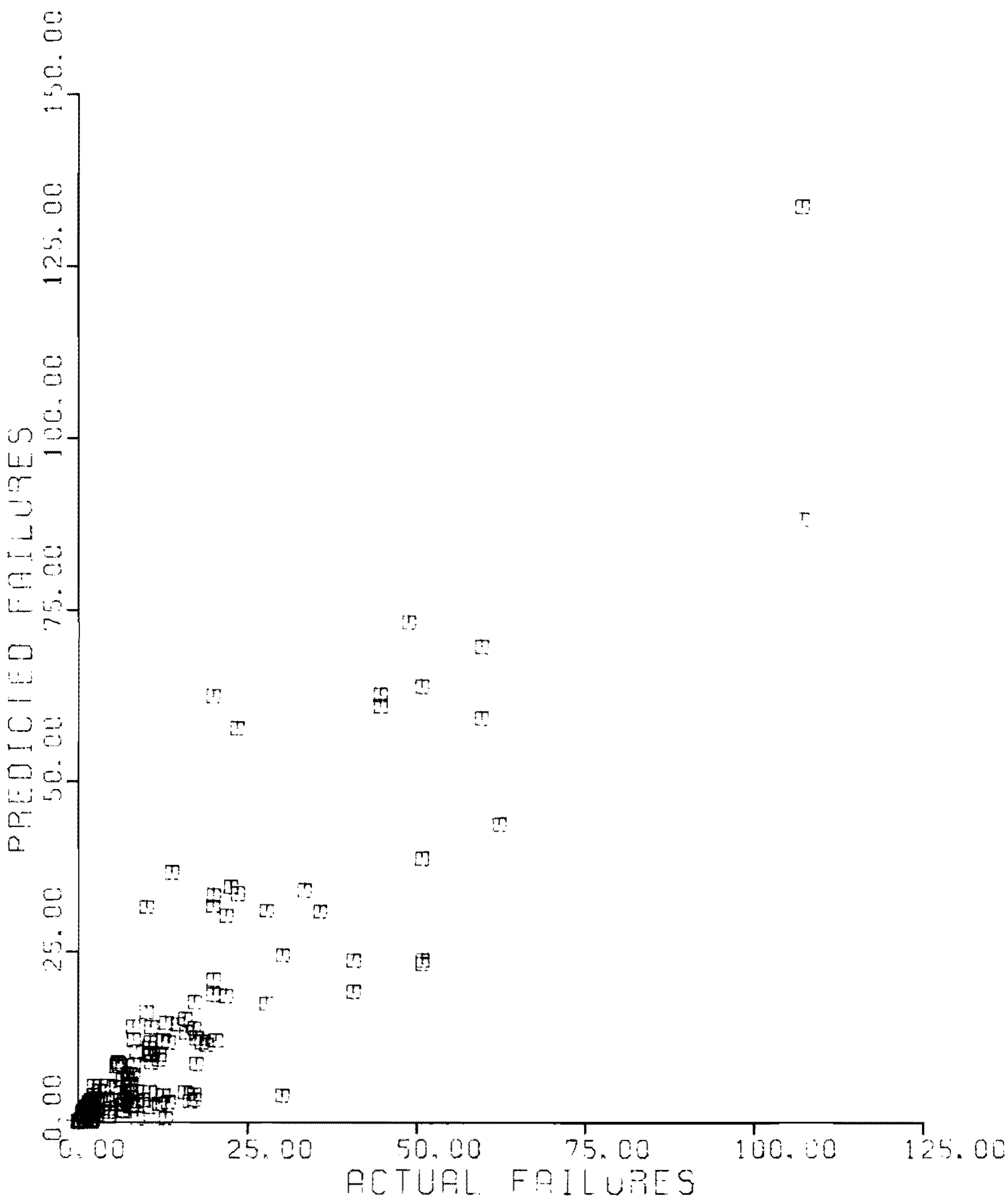


Fig 5.1. Comparison of actual versus preducted failures per mile for CRCP sections in Texas.

where

MS = percent minor spalling,

X_i = age at time i, and

A_o, A_1, and B = constants.

B can be estimated, if past information is available, as

$$B = \text{Ln}\ (1.0 - MS_1/100.0)/X_1 \qquad (5.2)$$

and so the equation becomes

$$MS_2 = A_o + A_1 \exp\ (B \cdot X_2) \qquad (5.3)$$

where

MS_2 = predicted percentage of minor spalling at future age;

MS_1 = percentage minor spalling at time of condition survey;

X_2 = pavement age at time of prediction, years;

X_1 = pavement age at time of condition survey, years;

A_o = 92.357; and

A_1 = -87.764.

A_o and A_1 are the coefficients obtained from the regression analysis. Relevant statistics for the regression are R^2 of 0.846 and standard error of 6.606, with 139 cases used in the analysis. Figure 5.2 is a plot of the predicted versus the actual percentage of minor spalling.

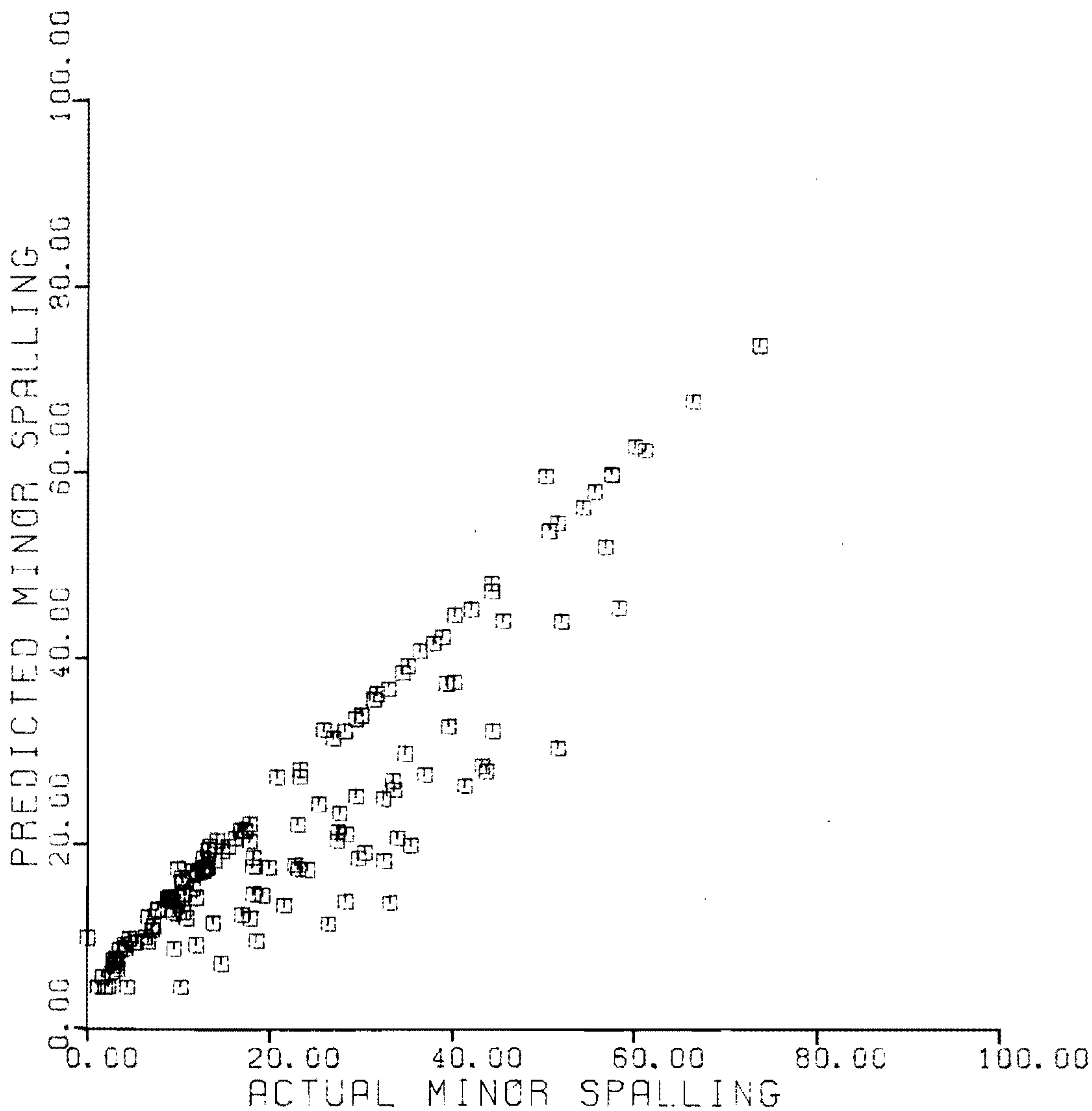


Fig 5.2. Comparison of actual versus predicted minor spalling for CRCP sections in Texas.

One problem with the equation is that it considers percent spalling rather than the actual number of spalled cracks in a mile, which seems more appropriate for picturing the distress of a road section. Percent spalling is used because the distress index equation, developed in Chapter 4, was derived partly using 1974 data, which was estimated as a percentage.

Description of the Severe Spalling Model

The reasoning behind the severe spalling model is the same as the reasoning used in developing the minor spalling model. Therefore, the following equation can be used to predict severe spalling:

$$SS_2 = A_o + A_1 \exp (B \cdot X_2) \tag{5.4}$$

where

SS_2 = predicted percentage of severe spalling;

X_2 = pavement age at time of prediction, years;

B = $\mathrm{Ln}(1.0 - SS_1 /100.0)/X_1$;

SS_1 = percentage severe spalling at time of condition survey;

X_1 = pavement age at time of condition survey, years;

A_o = 93.804; and

A_1 = -92.857.

Relevant statistics for the regression are R^2 of 0.860 and standard error of 2.575, with 139 cases. Figure 5.3 is a plot of the predicted versus the actual percentage of severe spalling.

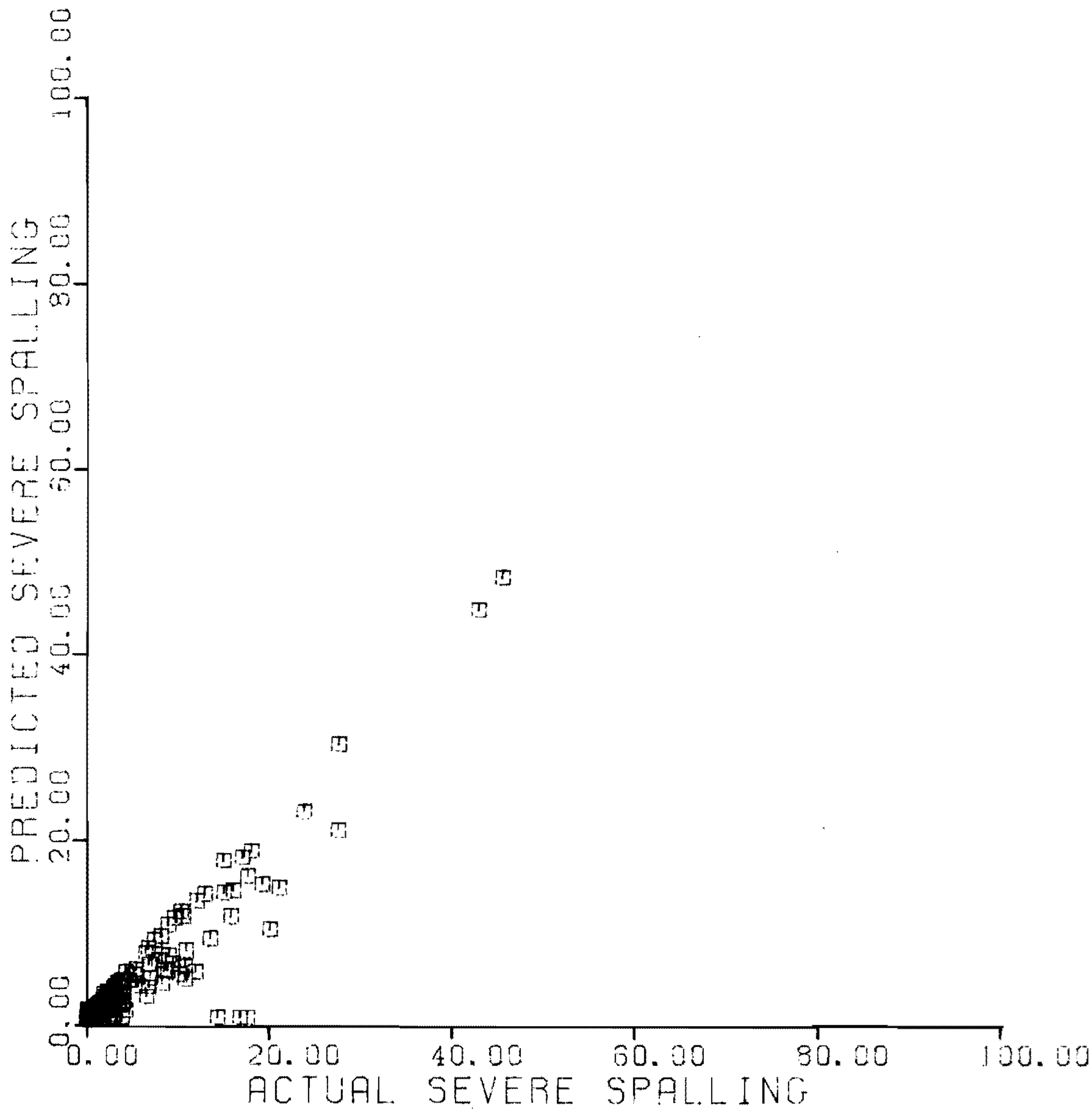


Fig 5.3. Comparison of actual versus predicted severe spalling for CRCP sections in Texas.

Discussion of Equations

The information used for the development of the CRCP equations did not come from an experimental design but from data collected primarily for the purpose of evaluating the Texas CRCP network. Further improvement of the models should consider experimental design techniques. Useful guidelines for such design have been developed by Pedigo and Hudson (Ref 38).

All the equations presented consider past conditions as an independent variable. This factor helps to "characterize" the pavement sections, i.e., accounts for material properties, environmental conditons, and construction variables, as well as previous age and traffic conditions. However, new pavements or modification of these variables in existing pavements can not be handled by the equations to forcast future conditions.

Since the highly deteriorated pavements are usually overlaid, the prediction equations are biased because only "good" pavements were used in their development. In addition, the application of the equations is bounded by their inference space.

EQUATIONS FOR JOINTED PAVEMENTS (JCP AND JRCP)

In order to include jointed rigid pavements in the rehabilitation scheduling scheme under development, and since field information has not been gathered by the CTR for this type of pavement, it is necessary to review the work done on the subject by other agencies. The distress index equation derived from Carey and Irick's data involved the following distress manifestations: cracking, spalling, faulting, and patching. Therefore, distress prediction equations for such distress manifestations are required.

Patching can be confounded with cracking since it is usually performed to cover excessively cracked areas. The results from the factor analysis mentioned in Chapter 4 support this simplification, since it appeared that cracking and patching can be substituted for another single variable. Similar substitutions have been used before; for instance, in the AASHO Road Test (Ref 23) "patched area" was assigned the cracking equivalent of one foot of crack for each square foot of patch to form the variable C', total projected length of all cracks.

In the next paragraphs, the selection of equations is presented for the various distress types in jointed pavements. The selection is made by comparing the advantages and disadvantages of the equations found in the literature.

Prediction of Cracking

Cracking occurs when the tensile stresses in the concrete slab exceed the strength of the concrete. The tensile stresses result from traffic, loss of foundation support, and temperature and moisture changes.

Fatigue cracking, that produced by repeated loading from traffic, has been used successfully in the development of design equations for jointed pavements (Refs 78 and 79). However, these design approaches use a limiting amount of cracking rather than predicting the actual quantity.

An attempt was made in the AASHO Road Test to develop equations to predict cracking (Ref 23). The factorial experiment considered the following factors: traffic applications, axle load and configuration, slab thickness, subbase thickness, and reinforcing; other factors, such as material characteristics, construction procedure, environmental conditions, and joint spacing, were fixed. Each test section was inspected weekly for defects, such as cracking. Plots of cracking versus axle load applications suggested the following model:

$$\text{Log} \frac{C^1}{W^2} = \text{Log } A_o + A_1 \text{ Log } L_1 - A_2 \text{ Log } D_2 \qquad (5.5)$$

where

C^1 = cracking index, defined as the total projected length of all cracks, in feet per 1000 sq ft of pavement area;

W = cumulative axle load applications;

L_1 = axle load, kips;

D_2 = slab thickness, inches; and

A_o, A_1 and A_2 = constants determined from the analysis.

Although several equations were developed for various combinations of axle configuration and reinforcing, only the general form of the equation is of interest to the following development.

For a specific pavement section, the values of L and D are constants; therefore, it is possible to estimate the future value of cracking if one point in the cracking history of the pavement is known; that is,

$$\frac{C_1^1}{W_1^2} = \frac{C_2^1}{W_2^2} \qquad (5.6a)$$

and

$$C_2^1 = C_1^1 \left(\frac{W_2}{W_1} \right)^2 \tag{5.6b}$$

where

C_2^1 = predicted cracking index for W_2 ;

W_2 = axle load application at a future date;

C_1^1 = cracking index at W_1 , measured in the field; and

W_1 = axle load applications at the time of the field evaluation.

Another study conducted to develop distress prediction equations, by Darter et al (Ref 36), derived a crack deterioration model of the following form:

$$TC = X * ESAL \left[-1.5 + \frac{1.113}{D_2 * ASTEEL} + \frac{4.584}{L} + \frac{1.129}{STAB + 1} \right] \tag{5.7}$$

where

TC = deteriorated transverse cracks, no./mile;

X = age of the pavement, years;

ESAL = equivalent 18-kip single axle loads, millions;

ASTEEL = area of longitudinal steel, in.^{2} /ft;

L = joint spacing, ft;

STAB = 1, if stabilized subbase is used, or 0, if granular subbase; and

D_2 = slab thickness, inches.

The statistics reported for the equation are R^2 of 0.52 and standard deviation of 39 cracks/mile, with 622 observations. The inference space includes age (0-22 years), equivalent axle loads (0-18 million), slab thickness (8-12.5 in.), joint spacing (40-100 ft), reinforcement content (0.09-0.17 in./ft), and subbase type (granular and stabilized).

For a specific pavement section, the values of D_2, ASTEEL, L_1, and STAB are constants; therefore, it is possible to estimate the future number of deteriorated cracks using the equation

$$TC_2 = TC_1 * \left[\frac{X_2 * ESAL_2}{X_1 * ESAL_1} \right] \tag{5.8}$$

where the sub index 1 refers to measured values, and the sub index 2 refers to a future point in time.

The difference between Eqs 5.6b and 5.8 is readily apparent. The AASHO equation is a function of squared axle load applications while that of Darter et al is a function of the product of age and axle load applications. However, the equations are similar if the rate of axle load applications in the Road Test is considered. The comparison between equations is possible regardless of the different units of C' and TC.

For this study Eq 5.8 is adopted. If prediction of cracking for new pavements is required, Eq 5.7 has more appeal because of the variables in it.

Prediction of Spalling

Spalling can be present at both cracks and joints. Several factors have been identified as causatives of spalling, including infiltration of incompressibles, weak concrete, poorly designed or constructed load transfer devices, and excessive deflection.

Spalling was not studied at the AASHO Road Test because this defect was included in the classification of cracking stages. Darter et al (Ref 36) developed a prediction model for joint deterioration which includes joint spalling; however, the model can not be easily reduced into a simple form because of the intrinsic algebraic form and the large number of dependent variables in the equation. Therefore, a spalling prediction model for cracks and joints of the form of the one derived for CRC pavements was adopted:

$$S_2 = 100.0 * \left[1.0 - \exp (B * X_2) \right] \tag{5.9}$$

where

S_2 = percent spalling at a future date;

X_2 = age at which prediction is required, years;

B = $[\mathrm{Ln}\,(1.0 - S_1/100.0)]/X_1$;

S_1 = percent spalling at X_1 ; and

X_1 = age of pavement section at the time of measuring S_1 , years.

The form of the model has been determined using engineering judgement, and validation of the model becomes mandatory as soon as field information becomes available.

Prediction of Faulting

Faulting occurs at joints and cracks with time and traffic as the joints or cracks lose their load transfer efficiency through pumping and deterioration of the aggregate interlock or of the concrete surrounding the dowel bars.

Faulting was not studied at the AASHO Road Test. Faulting at cracks sometimes occurred in the later stages of pavement deterioration, but faulting at joints was notably absent throughout the test.

Gulden (Ref 35) carried out a pavement faulting study on Georgia Interstate Highways. The pavement sections studied were 9 or 10 inches thick, the subbase was in most cases bituminous or cement stabilized, and joint spacing on most of the projects was 30 ft, with expansion joints only at bridge structures. Equations were developed for both bituminous and cement stabilized subbase. The equations are of the form

$$FI = A_o * (TA)^{0.45} \qquad (5.10)$$

where

FI = faulting index, the average expected accumulative amount of faulting for five consecutive joints, expressed in units of 1/32 of an inch;

TA = accumulative annual average number of daily one-way tractor-semitrailer combinations; and

A_o = constant.

An R^2 of 0.87 using 28 data points was reported for the bituminous subbase model and an R^2 of 0.88 with 9 points was reported for the cement stabilized subbase. Only the term A_o is significatively different in the two equations. The equations can be manipulated to obtain

$$FI_2 = FI_1 \left(\frac{TA_2}{TA_1} \right)^{0.45} \tag{5.11}$$

where the subindex 1 refers to measured values and the subindex 2 refers to a future condition.

Darter et al (Ref 36) developed a faulting prediction model of the form

$$Ln\ (F + 1) = (-0.091 + 0.0001 * BSTRESS) * Ln\ (ESAL + 1) \tag{5.12}$$

where

F = transverse joint faulting of adjacent slabs, inches;

ESAL = cumulative applied 18-kip equivalent single axle loads in the given lane, millions; and

BSTRESS = maximum bearing stress of the dowel bars as determined by Friberg's method for an 18-kip single axle load.

The statistics reported for the model show R^2 not meaningful, since the equation was forced through the origin, standard error of 0.09 in., and coefficient of variation of 60 percent, for 284 cases. Through algebraic manipulation, the following equation was obtained:

$$(F_2 + 1) = (F_1 + 1) * \left[\frac{ESAL_2 + 1}{ESAL_1 + 1} \right]^{B_o} \quad (5.13)$$

where

$= -0.091 + 0.0001*BSTRESS$

and the subindexes 1 and 2 are interpreted as before.

In order to compare the equations, calculations of future values of faulting were performed using various levels of BSTRESS, axle load applications, and initial faulting. Table 5.1 presents the results of such analysis. The comparison is possible regardless of the different units in the two equations. It appears that, as the ratio of traffic approaches unity, the equations produce similar results. The largest difference between equations is obtained at low values of BSTRESS and high traffic ratios. The traffic ratios which will be more commonly used in the scheduling scheme under development are close to unity.

Equation 5.11 was adopted for this study because it has a simpler format and involves less input data than Eq 5.13. If faulting for a new JRC pavement is required, then the equation of Darter et al (Eq 5.12), seems more appropriate because the BSTRESS term can be extended to different cases of slab thickness or foundation support. Notice that the equation selected is applicable to both JCP and JRCP.

TABLE 5.1. COMPARISON OF RESULTS FROM TWO FAULTING PREDICTION EQUATIONS FOR JOINTED PAVEMENTS

BSTRESS	Traffic, $ESAL_1$	Traffic, $ESAL_2$	Faulting, F_1	Faulting, F_2	
				Gulden	Darter et al
1000	1.0	2.0	0.2	0.273	0.204
			0.6	0.820	0.606
	1.0	6.0	0.2	0.448	0.214
			0.6	1.344	0.618
3000	1.0	2.0	0.2	0.273	0.306
			0.6	0.820	0.741
	1.0	6.0	0.2	0.448	0.559
			0.6	1.344	1.079
	5.0	6.0	0.2	0.217	0.239
			0.6	0.651	0.652

EQUATIONS FOR AC OVERLAID RIGID PAVEMENTS

In the next paragraphs, the development of distress prediction equations for AC overlaid rigid pavements is presented. The data base used is documented, the equations derived for old and new overlays are presented, and, finally, the results are discussed.

Data Base

Several experimental sections of AC overlay on CRCP were constructed on IH-45, Walker County, in 1974. The total length is 11.4 miles. Since IH-45 is the primary connection between Houston and Dallas, the percentage of truck traffic is high. The estimated cumulative 18-kip ESAL was 5.25×10^6 in both directions between the date of placement of the overlay and the latest condition survey, in 1980.

The typical pavement section consists of 6.0 inches of lime stabilized subbase, 6.0 inches of crushed stone base, 8.0 inches of CRCP, and variable thicknesses of overlay, i.e., 2.5, 4.0, 5.0, and 6.0 inches.

In order to monitor the distress condition of the AC overlay, condition surveys were carried out before and at 20, 28, 55, and 71 months after the overlay was placed. Twenty-four sections were surveyed. The distress manifestations recorded are number of reflected cracks, patches, reflected failures, loss of bond, and mean rut depth. A sample of the condition survey report printout was given in Fig 3.8.

Analysis Approach

A distress index was used to group the different reflected distress manifestations into a single figure. Loss of bond was not included in the index since it did not occur in any of the sections analyzed. Rut depth was considered separately.

The distress index used in the anlaysis was similar to the discriminant scores presented in Chapter 4. The discriminant score for CRC pavements, Eq 4.6, was modified so it could be applied to AC overlays on rigid pavements. It was decided to include patches and failures per mile in the failures per mile term of the equation, and reflected cracks in the spalling term. Furthermore, since the analysis is conducted in terms of percentage of distress from the before overlay condition, the A_o coefficient was subtracted from the equation. The resulting equation is

$$Z^1 = Z - A_o = -A_1 (RF + P) - A_2 (RC) \tag{5.14}$$

where

Z = distress index for AC overlaid rigid pavements,

Z_1 = modified Z,

A_o = 1.0,

A_1 = 0.065,

A_2 = 0.015,

RF = number of reflected failures per mile,

P = number of patches per mile, and

RC = percent of reflected cracks.

Table 3.6 presents a summary of the percentages of distress and rut depth in relation to the before overlay condition for the various ages of the overlay. Column 1 contains the overlay thicknesses, column 2 presents the section lengths, column 3 contains the discriminant scores for the before overlay condition, columns 4 through 7 are the percentages of reflected distress, columns 8 and 9 are the measured rut depth in inches, and column 10 gives the percentage of failures repaired before the overlay was placed.

From Table 3.6 it is apparent that

(1) distress increases with age,

(2) distress decreases with overlay thickness,

(3) rut depth increases with age, and

(4) rut depth increases with overlay thickness.

Figures 5.4 and 5.5 are plots of the data presented in Table 3.6. Average values of distress for each thickness were used in these figures. Tyner et al (Ref 80) obtained similar results in AC overlays on jointed pavements; their observations at 48 months yielded the following values: 100 percent reflected cracks for 2.0-inch overlays, 75 percent for 4.0-inch, and 24 percent for 6.0-inch.

Description of Distress Prediction Models

Linear regression analysis was used to analyze the data and to develop equations to predict distress in new and existing overlays. In the following paragraphs, both equations are presented and discussed.

Prediction of Distress in New Overlays. The equation for new overlays was developed using percent distress as the dependent variable and age and

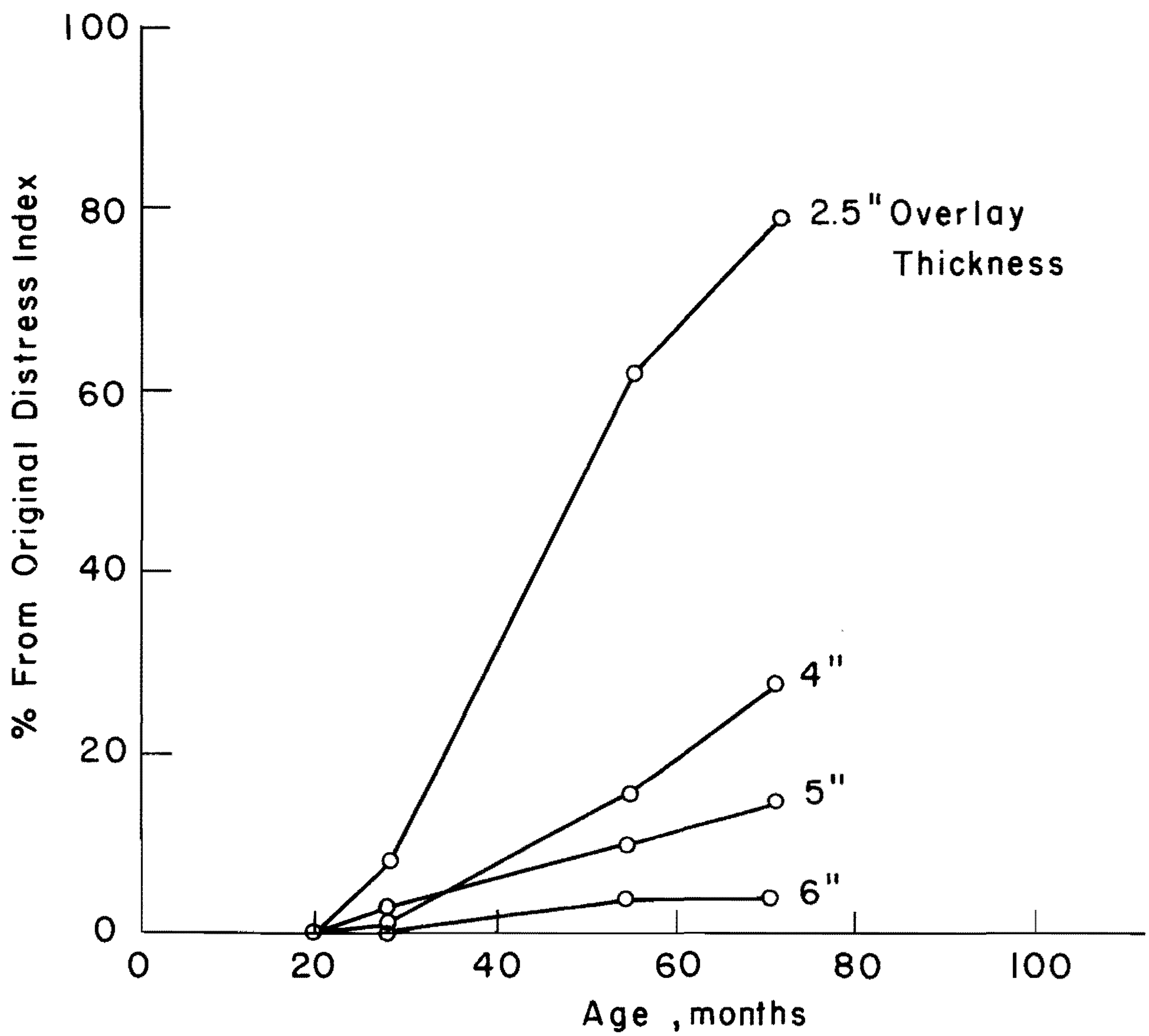


Fig 5.4. Plot of average percent distress time history for different overlay thicknesses as monitored in Walker County, Texas.

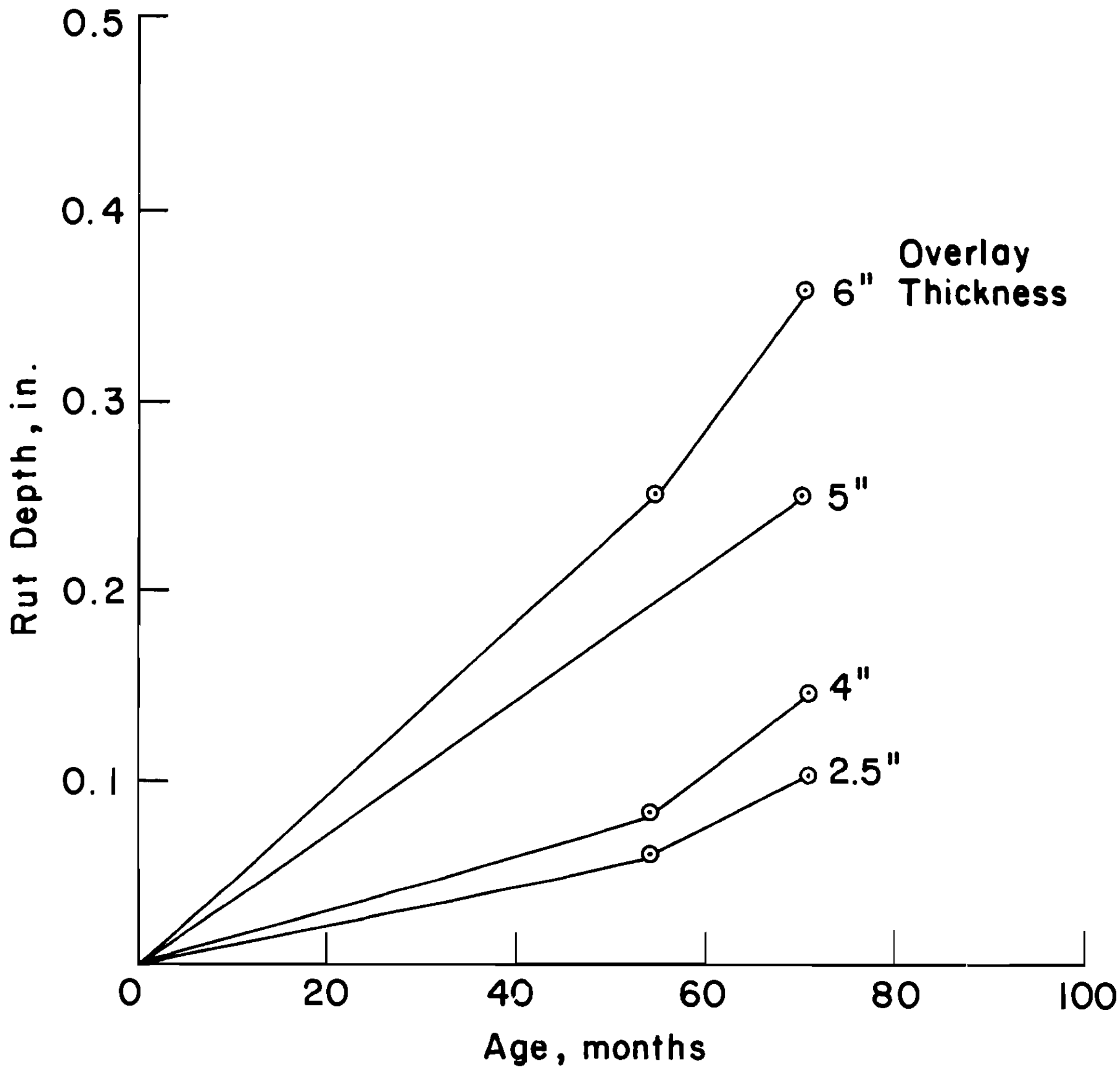


Fig 5.5. Plot of average mean rut depth time history for different overlay thicknesses as monitored in Walker County, Texas.

thickness as the independent variables. The equation, obtained with 21 observations at four different ages, was

$$Y = \frac{Z^1}{Z_o^1} = 3.012 * \frac{(X - 1.667)}{D_o^{2.8}} \tag{5.15}$$

where

Y = predicted distress percentage;

X = age of overlay when prediction is required, years; and

D_o = thickness of overlay, in.

The equation R^2 is 0.682 with a mean standard error of 0.289 and a poor plot of residuals. Figure 5.6 presents a comparison of actual versus predicted reflected distress as obtained from Eq 5.15. By analyzing the residual plots, it was found that other independent variables are required in the equation to account for the quality of the supporting soil and the quality of the pavement structure beneath the overlay.

Figure 5.7 indicates the increase in variance of the predicted distress with age for the 2.5-inch overlay; furthermore, the variance is different for the various thicknesses. It is felt that the inclusion of variables to account for the soil and the pavement structure will overcome this problem.

The equation was retained because it accurately predicts avErage values. In future analyses, the sections need to be separated using lengths with similar Dynaflect deflections, representing sections with similar soil and pavement structure quality.

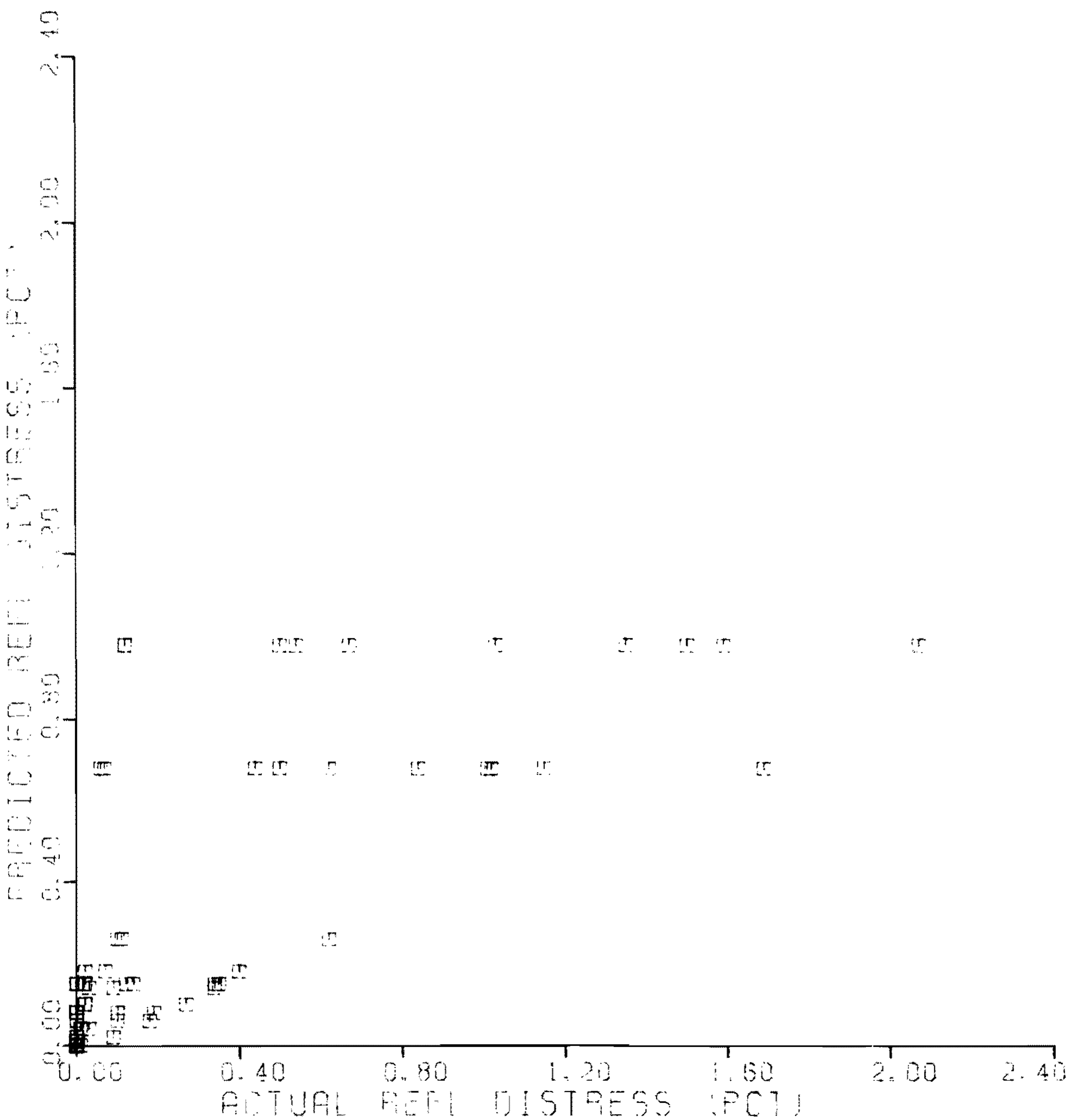


Fig 5.6. Comparison of actual versus predicted reflected distress for new overlaid rigid pavements in Walker County, Texas.

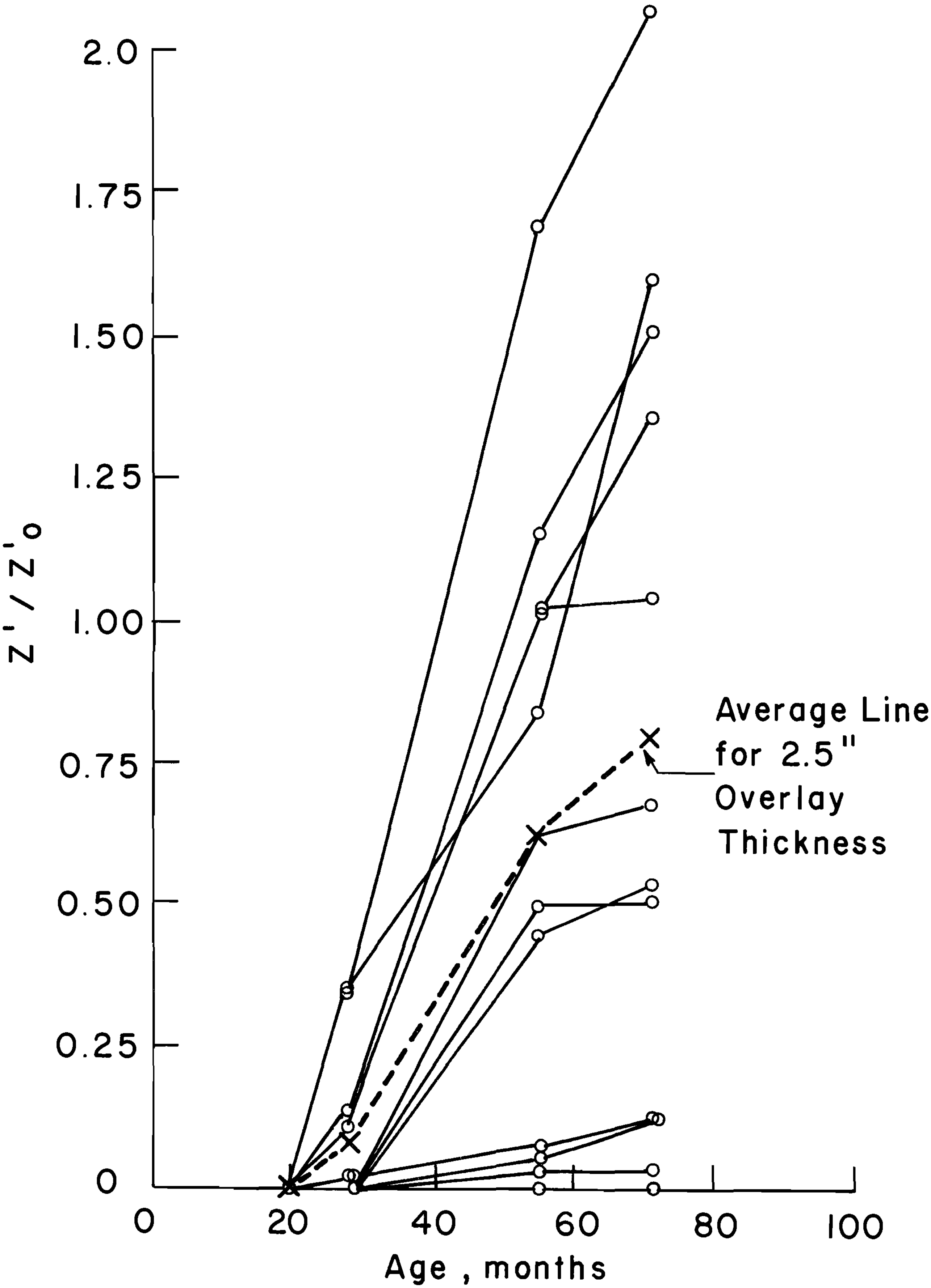


Fig 5.7. Plot of percent distress versus time for the 2.5-inch overlay on CRCP monitored in Walker County, Texas and used to develop distress prediction equations.

<u>Prediction of Distress in Existing Overlays.</u> The equation for existing overlays was developed using percent distress as the dependent variable and thickness, previous age, previous percent distress, and age at time of prediction as the independent variables. The equation obtained with 21 observations at six different age increments was

$$Y_2 = Y_1 \left[\frac{X_2 - 1.67}{X_1 - 1.67} \right] \qquad (5.16)$$

where

$Y_2 = \frac{Z_2^1}{Z_o}$, predicted distress percentage at age X_2 ;

$Y_1 = \frac{Z_1^1}{Z_o}$, previous distress percentage at age X_1 ;

X_2 = age of overlay when prediction is required, years; and

X_1 = previous age of overlay, years.

The equation R^2 is 0.968, with a standard error of 0.066 and good plots of residuals (Fig 5.8). The inclusion of previous distress at a given age accounts for the quality of the soil and the pavement structure. This equation has better prediction capabilities than Eq 5.15 but it requires the knowledge of previous distress history of the overlay.

<u>Discussion of Equations</u>

In regard to the analysis approach, the following commentaries can be made:

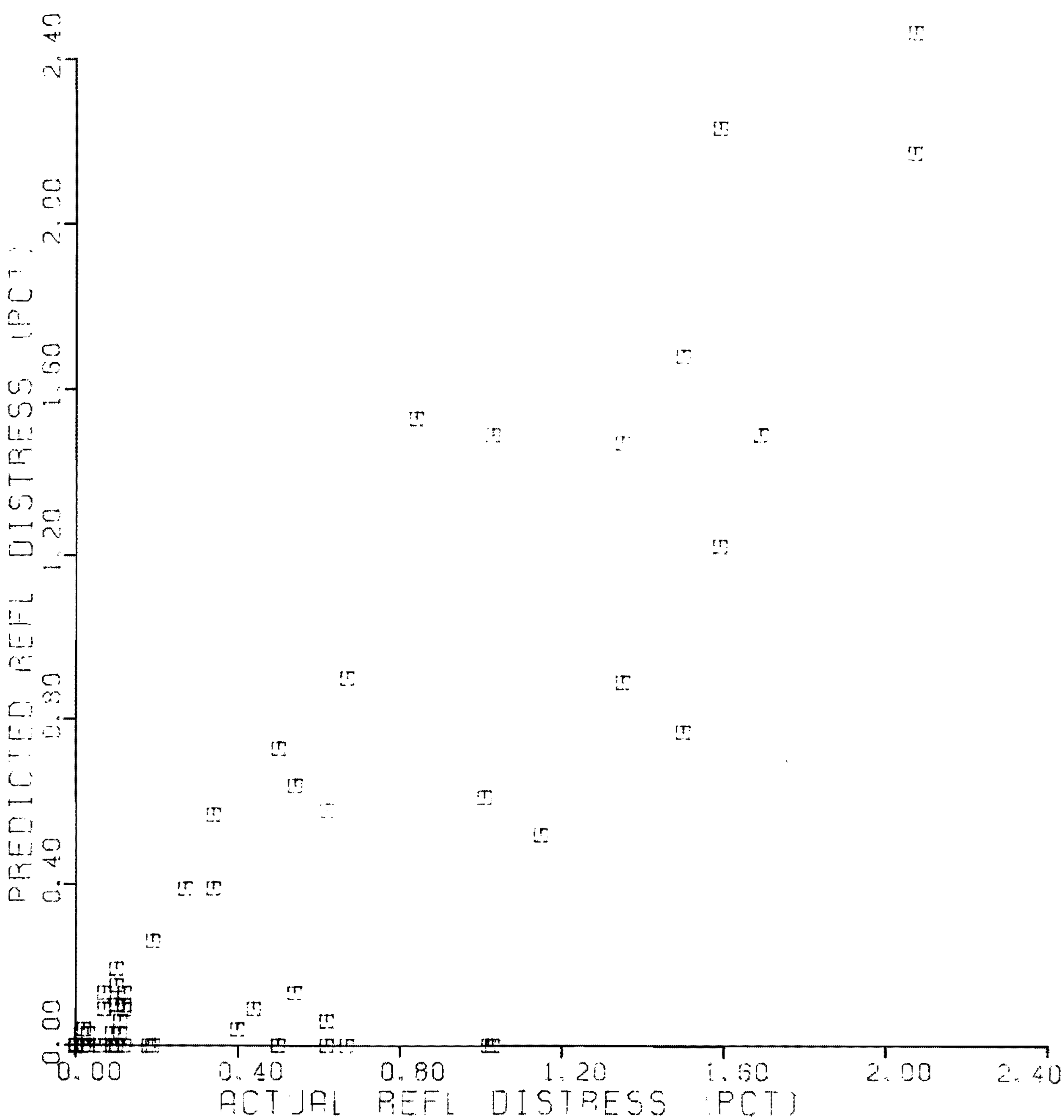


Fig 5.8. Comparison of actual versus predicted reflection distress for AC overlays on rigid pavements.

(1) The analysis approach, i.e., pulling together all the distress manifestations into a single index, appears to be helpful in simplifying the analysis.

(2) Nevertheless, a discriminant score (or distress index) which includes loss of bond and rut depth needs to be developed for AC overlays.

In relation to the regression equations derived, the following comments can be made:

(3) The prediction equations correctly model the change of distress with age and overlay thickness.

(4) Nevertheless, their prediction capabilities are restricted to AC overlays with conditions of pavement structure, traffic, and environmental conditions similar to those of overlays in Walker County.

(5) Therefore, it is recommended that future analyses include other overlay projects with different traffic and environmental conditions.

Finally, in relation to the results obtained from the analysis, the following comments can be made:

(6) Initial distress of the overlays occurred after 20 months. Therefore, it seems that the first survey can be postponed for about 2 years.

(7) The analysis supports the conclusion derived in a previous study of the Walker County overlay project (Ref 81), specifically, that there is a maximum thickness beyond which the rate of failures in the AC overlay decreases to a minimum amount, from the standpoint of maintenance.

(8) Thick overlays need to be checked against rut depth.

(9) For future analysis, sections with similar overlay thicknesses need to be separated using Dynaflect deflections to reduce the variance of the observations.

SUMMARY

This chapter describes the development of distress prediction models for rigid pavements and AC overlaid rigid pavements. Regression analysis was used to obtain equations for each type of distress considered in the distress indices developed previously. The application of both the distress indices and the distress prediction equations is shown in the next chapter.

CHAPTER 6. APPLICATIONS OF THE DISTRESS MODELS

A system is not a computer program per se; however, the large number of calculations involved make it essential to develop a program to move past the conceptual stage into a working system.

The purposes of this chapter are to

(1) demonstrate the application of the distress models developed in Chapters 4 and 5 in a PMS at the network and project levels.

(2) document the development of a computer program to prioritize a set of rigid pavement sections for maintenance and rehabilitation within a certain time frame.

(3) generate a list of candidate projects for rehabilitation using Texas CRCP condition survey information. It is intended that this type of list help the Texas State Department of Highways and Public Transportation in planning future allocation of money for rehabilitation.

(4) present a project level program for the evaluation of design and maintenance of specific projects.

(5) indicate how the distress index equations can be improved by means of computer simulation using a project level design and maintenance evaluation program.

NETWORK LEVEL APPLICATION: REHABILITATION PRIORITIZATION AND SCHEDULING

The first part of this chapter is concerned with the applications of the distress models at the network level. This includes development of a rehabilitation prioritization and scheduling program and the use of such a program in preparing a list of candidate rehabilitation projects for the Texas network.

The section begins with an explanation of the scheduling procedure before describing the computer program. The capabilities of the program are described and some sample runs are made to illustrate such capabilities. Appendix D presents a list of recommended projects for rehabilitation in the next five years, using field information as an input.

Rationale of the Prioritization and Scheduling Scheme

Figure 6.1 depicts the distress history of three hypothetical projects (A, B, and C) that will be used to explain, using a heuristic approach, the procedure used in the prioritization scheme presented in this section. Each of the plots on the graph corresponds to one of the projects; the Y-axis is the distress index and the X-axis is time in years. A broken line in the figure indicates an acceptable maximum level for the distress index. That is, when any project reaches that level, it is considered to have reached terminal condition and needs to be rehabilitated.

Assume that a condition survey of the network is performed in 1982 and the resulting information indicates that rehabilitation of the projects needs to be programmed. The problem seems fairly easy, i.e., determine the date on which each of the pavement sections reaches the terminal condition and prepare a list showing that. An output list is shown in Fig 6.1.

There are several problems which complicate the procedure:

(1) Which pavement responses should be considered in ascertaining the condition of the pavement?

(2) What levels of the responses or combinations thereof are to be considered terminal condition?

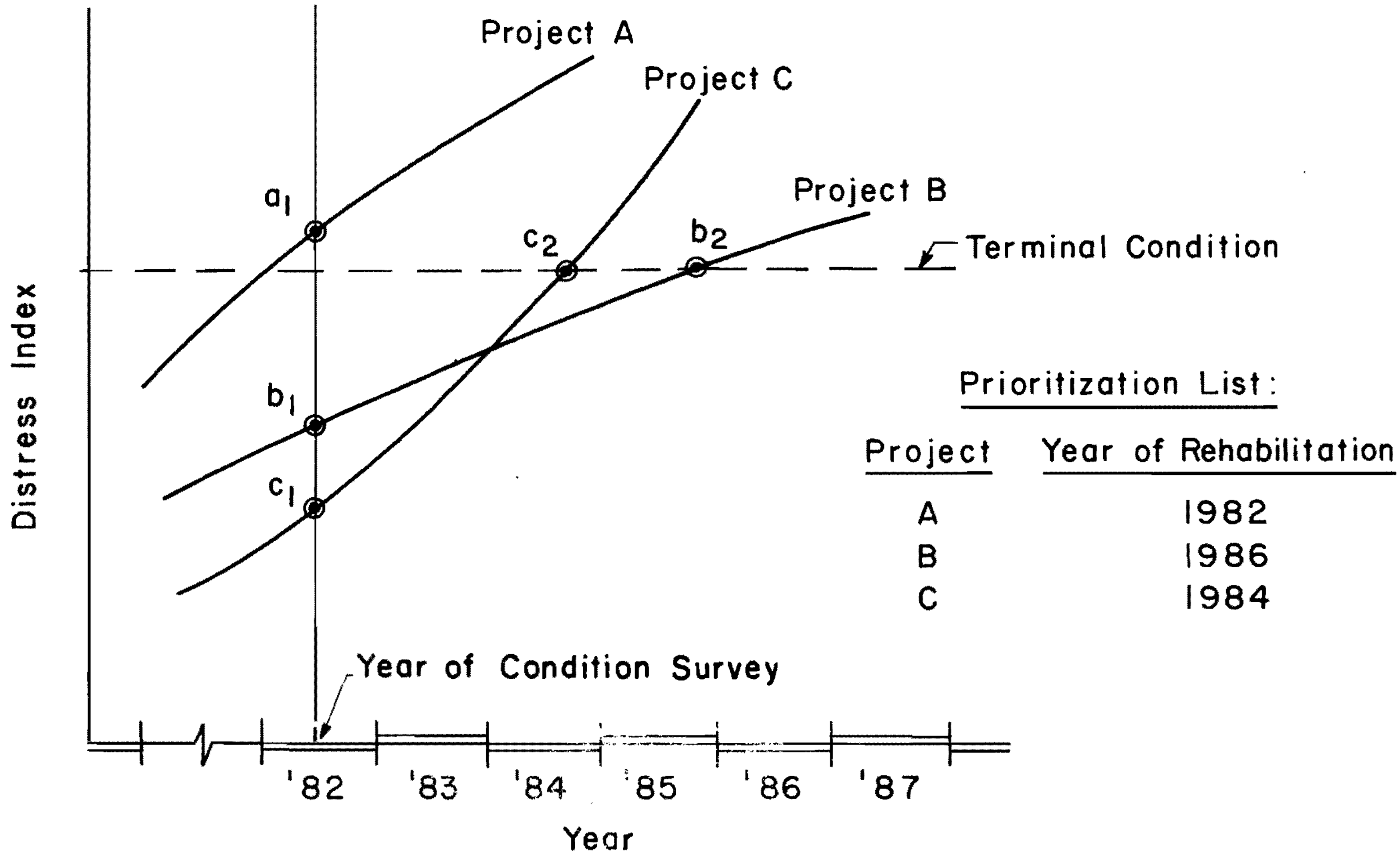


Fig 6.1. Distress history of several hypothetic projects showing the concept of prioritization.

(3) How accurate are the response prediction equations?

(4) Are there any budget constraints?

The first three questions were addressed in past chapters. This section is concerned with presenting the developmentof a program which produces an ordered set of pavement sections requiring rehabilitation with and without budget constraints.

Description of Program PRP01

A program named PRP01 was developed to schedule rehabilitation of rigid pavements (JCP, JRCP, and CRCP) within a certain design period. The input data are condition survey information on a set of rigid pavements for the same year. The solution is obtained using distress models: distress indices and distress prediction equations. All of the distress models were integrated as subroutines in the program in order to facilitate future modifications.

The program output has several alternatives:

(1) A prioritized list of pavement sections according to their distress condition at the time of the condition survey.

(2) A multi-period rehabilitation schedule of the pavement sections without considering budget constraints. The selection of candidates for each year is made on the basis of the magnitude of the distress index.

(3) A multi-period rehabilitation schedule of the pavement sections accounting for budget restrictions. The selection for each year depends on the magnitude of the distress index and the budget availability.

Figure 6.2 is a simplified flowchart of the computer program. Information on the distress condition of each project is required as an input. The program starts by calculating the distress index for each

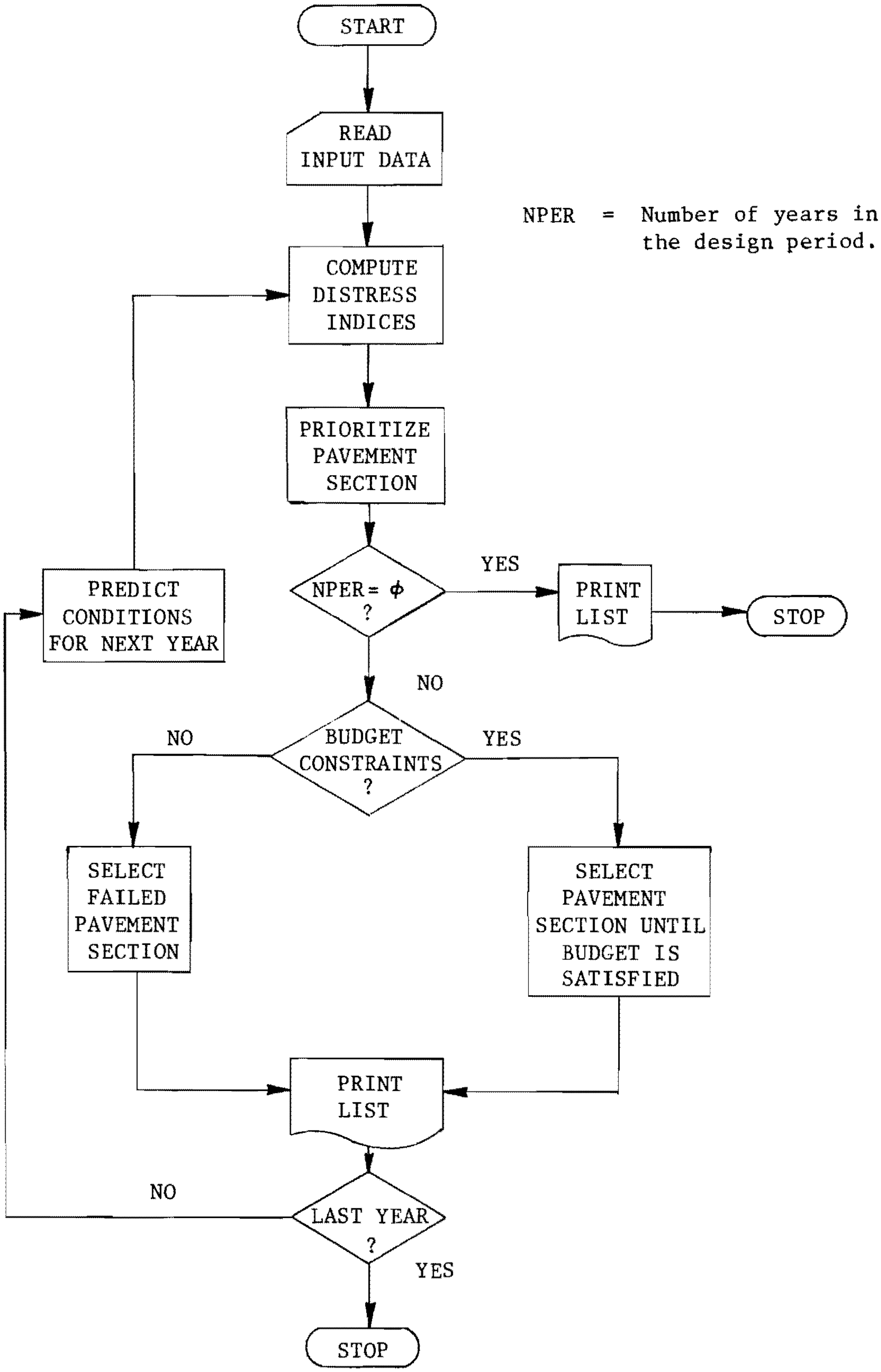


Fig 6.2. Simplified flowchart of the computer program (PRPØ1) developed in this report to prioritize and schedule rehabilitation.

section. The sections are prioritized according to the magnitude of their distress indices. At this stage, a check is made of the design period. If the design period is set equal to zero, the program prints the priority list and stops, but, if the design period is larger than zero, the program continues. Next, a check is made for budget restrictions and two different criteria are followed, depending on the existance of budget constraints. If no budget constraints are imposed by the user, the rule for selecting the rehabilitation candidates is very simple: all the pavements which have reached terminal condition are included in the list for that year. If budget constraints are present, the selection of candidates is made on the basis of budget availability. The already prioritized sections are considered one by one, and the rehabilitation cost of each is calculated and accumulated until the budged is satisfied. A list of candidate projects is printed for each year of the design period. The program checks to see if the design period has been covered, in which case it exits; otherwise, conditions are predicted for the next year and the program returns to the step in which the distress indices are calculated.

The possibility exists of optimizing the average condition of the sections using budget restrictions; however, it was thought this would complicate the program unnecessarily. A better objective function for optimization would consider user and maintenance costs, which, at this time, are not available in terms of distress.

In Appendices B, C, and D, relevant information on the program is given. Appendix B contains the FORTRAN listing of the program, Appendix C an input guide, and Appendix D sample input and outputs.

Distress Models in the Program. Table 6.1 presents in summary form the equation numbers used in the report for the distress models in program PRP01.

A couple of modifications were made to the distress index equation formulated for jointed pavements. First, the cracking and patching terms were pulled together since, usually, patching is the repair of cracking. Second, the spalling term had different units than the prediction equation and it was modified to appear as a percentage instead of feet per 1000 square feet. The reasoning behind the units change is the following: percent spalling is the ratio of the number of spalled cracks and joints to the total number of discontinuities; if an area of 83 x 12 sq ft (1000 sq ft) is considered,

$$PS = (\text{spalled discontinuties/total no. of discontinuties}) \times 100$$

$$= \frac{S/12}{83L} \cdot (100.0)$$

$$= S \cdot L/10.0$$

where

S = spalling in ft per 1000 sq ft, and

L = spacing between consecutive discontinuities.

If the spacing, L, is not available, an assumption is needed for estimating this value. Usual joint spacings are from 15 to 50 ft, the smallest value being used for JCP (no reinforcement), and, if intermediate cracking occurs, L = 7.5.

TABLE 6.1. EQUATION NUMBERS USED IN THIS REPORT FOR THE DISTRESS MODELS IN COMPUTER PROGRAM PRPØ1.

Pavement Type	Distress Manifestations	Prediction Equations	Distress Index Eqs.
CRCP	Punchouts and patches	(5.1)	(4.6)
	Spalling	(5.3)	
	Scaling	(5.4)	
	Pumping	NC*	
JRCP and JCP	Cracking	(5.8)	(6.1)
	Spalling	(5.9)	
	Patching	(5.8)	
	Faulting	(5.11)	
AC Overlay on Rigid Pavement	Reflected	(5.15)	(5.14)
	Punchouts and patches	(5.15)	
	Loss of bond	NC	
	Rutting	NC	

*NC: Not considered

An additional modification was to transform the terms in the equation into per mile figures instead of the original units. Substituting the modifications into the distress index equation, the following is obtained:

$$Z_j = 1.0 - 0.005\ C_m - 0.006\ PS - 0.003\ F \tag{6.1}$$

where

$$C_m = C + 0.25\ P \tag{6.2}$$

and all the rest of the terms are as previously defined.

Several distress manifestations were not considered in the distress index equations. Pumping was not considered in the case of CRCP because its inclusion resulted in an illogical equation, as described before. In the case of overlaid rigid pavements, loss of bond did not appear in the sections considered for the development of the distress index equation. Rutting, although not included in the distress index of overlaid pavements, is a very important factor and needs to be considered when an overlay is designed.

A key assumption made in the program is that all of the distress indices are equivalent. This assumption in based on the fact that the best possible value for all the indices is unity and the terminal condition is zero. However, no formal proof of the assumption is given.

Sample Runs Using the Prioritization and Scheduling Program PRP01

Figures 6.3, 6.4, and 6.5 are partial outputs of sample runs made with the prioritization and scheduling program PRP01. These sample outputs are used to explain the contents of the lists produced by the program for the various available options. In addition, the program automatically prints the input information, except that printing detailed information from the condition survey is left as an alternative to the user.

Figure 6.3 is the type of output generated when the option selected is the prioritization of projects using the condition survey information directly. This option does not involve any type of distress prediction. The program calculates the distress index for each of the sections and sorts them all according to the relative magnitude of the indices, with the worst condition first. The output contains 4 columns. The first one is the section identifications; the second is the distress indices (note that the numbers increase progressively, as the condition of the sections does); the third column is the cumulative equivalent single axle loads, which were input by the user; and the last column is the ranking of each section as obtained from the distress indices, with the poorest pavement listed first.

Figures 6.4 and 6.5 are the type of output obtained for both the second and third options of the program, i.e., multi-period rehabilitation scheduling without and with budget constraints, respectively. Any of these options prints a list of projects requiring overlay for each year of the design period similar to Fig 6.4, plus a summary of the design period similar to Fig 6.5. In Fig 6.4, which represents the year-by-year output, each of the lists indicates the number of years after the condition survey for which it is generated. The output contains 6 columns: the first one is the

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PRIORITIZED SECTIONS AT TIME OF CS

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	RANK
1908EB	-4.476	5.480	1
1908WB	-2.215	5.480	2
1007WB	-2.124	5.830	3
1906EB	-2.041	5.310	4
1014EB	-1.694	5.160	5
1406WB	-1.688	5.900	6
904 SB	-1.652	7.220	7
1001EB	-1.490	5.700	8
1007EB	-1.304	5.830	9
1004WB	-1.194	5.680	10
1303WB	-1.073	2.020	11
2009WB	-1.062	3.160	12
1902EB	-1.057	5.770	13
1906WB	-1.007	5.310	14
1001WB	-.941	5.700	15
2009EB	-.909	3.160	16
1303EB	-.864	2.020	17
1014WB	-.850	5.160	18
1008EB	-.760	4.440	19
1010EB	-.739	5.130	20
1305SB	-.683	1.490	21
1306WB	-.653	1.820	22
1004EB	-.513	5.680	23
907 NB	-.475	5.830	24
1902WB	-.465	5.770	25
1010WB	-.445	5.130	26
1313WB	-.391	1.910	27
1011WB	-.334	4.630	28
108 SB	-.290	3.250	29
1003EB	-.276	5.950	30
1307WB	-.245	1.510	31
1909EB	-.242	6.420	32
1904WB	-.238	6.160	33
1002EB	-.208	5.860	34
1904EB	-.199	6.160	35
1706SB	-.198	5.490	36

Fig 6.3. Sample output from the program PRPØ1 using the prioritization option.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1984 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 1

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1008EB	-6.037	5.918	9.80	4686232.	1
1008WB	-3.055	5.918	10.00	3629770.	2
1006EB	-2.784	5.629	7.00	2450482.	3
1007WB	-2.617	6.180	5.00	1714050.	4
904 SB	-2.322	7.653	1.60	591402.	5
1014EB	-2.218	5.676	8.20	2051398.	6
1006WB	-2.123	6.296	5.20	1656546.	7
1001EB	-1.749	6.099	4.00	1195507.	8
1007EB	-1.617	6.180	4.80	1399609.	9
	-.094		55.80	19978996.	

Fig 6.4. Sample output page from the computer program PRPØ1 using the scheduling option.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

SUMMARY TABLE

YEAR	AVG. DI	LENGTH (MILES)	BUDGET (DLLS)
1	-.094	55.80	19978996.
2	.032	64.80	18852102.
3	.134	65.10	17574961.
4	.204	75.00	19301323.
5	.347	75.30	17445063.
6	.452	93.40	19739679.
7	.550	99.00	19022178.
8	.699	108.40	19017960.
9	.833	118.70	18582421.
10	.996	0	0
	.415	756.50	169514682.

Fig 6.5. Sample output summary from the computer program PRPØ1 using the scheduling option.

section identifications; the second one is the sorted distress indices calculated from the distress predicted for that year; the third one is the cumulative equivalent single axle loads estimated for that year; the fourth column contains the section length; the fifth column contains the estimated cost of each overlay; and the sixth column shows the ranking given to each section as a function of the distress indices. At the bottom of the printout the total length and the total cost to overlay the candidate sections for that year are printed.

For the second option, i.e., scheduling of pavement sections without budget constraints, the distress indices for years other than the first one are very close to zero and they are not very different; therefore, further ranking of the sections can be made in terms of cumulative ESAL.

Figure 6.5, which presents the summary of the year-by-year analysis contains, for each year, the following information: the average distress index calculated for the network, the total length of projects recommended for rehabilitation, and the yearly budget. An overall summary is printed at the lower part of the table.

Appendix D contains a list of CRC pavements suggested for rehabilitation in the five years after the 1980 condition survey. Forecasts for longer periods would reduce the accuracy of the predictions.

PROJECT LEVEL: DISTRESS AND MAINTENANCE EVALUATION SCHEME

In order to complete the discussion on the use of distress models in PMS, this section presents the application of such models at the project level. The project level schemes can be used to accomplish several different tasks:

(1) Pavement design - The current design schemes are based on the prediction of serviceability-history or by fatigue prediction approaches. Since design is accomplished by deriving cost effective alternatives, the cost models should include maintenance and user's costs related to pavement distress.

(2) Definition of optimal maintenance strategies - If the effect of maintenance on the future occurrence of distress is ascertained, comparisons among different maintenance strategies can be performed to derive the more cost effective ones (Refs 69, 88, and 89).

(3) Improvement of distress index equations - An alternative procedure for the development or improvement of a distress index equation can be performed by computer simulation, using a project level program, to determine the optimal rehabilitation timing from cost standpoint.

The development of a design and maintenance evaluation program is presented in the next pages for illustrative purposes. At the present time, it is considered difficult to implement distress models in a working program for rigid pavements to successfully accomplish tasks similar to the ones mentioned previously.

In the case of pavement design, distress models are commonly used in the design procedure to evaluate maintenance costs but they are not a factor in defining the pavement structure. This is easily understood if one considers the poor prediction capabilities of the available models. The most effective overlay thickness can be derived with the program presented if cost optimization is derived from the use of the distress index instead of the optimal timing approach.

For the derivation of optimal maintenance strategies, adequate information is not extensively available. Reference 90 presents the evaluation of several maintenance methods for CRCP. Similar information is currently being collected by the CTR to ascertain the effectiveness of maintenance methods, such as void grouting, underdrains, special patching techniques, and fabric underseals.

The improvement of distress index equations requires for its implementation the derivation of user's costs related to the degree of distress of the pavement. Guidelines are presented in this section for improving the distress indices through computer simulation.

In the next paragraphs, a rationale is presented for the derivation of a design and maintenance scheme at the project level. Guidelines are presented to transform the scheme into a working program. Finally, an application of such a program is suggested to develop a distress index.

Rationale of a Design and Maintenance Evaluation Scheme

The distress history of a given pavement is shown in Fig 6.6. For each age, there is a corresponding distress level in the pavement; at each stage, a decision is needed as to whether to overlay the pavement or to accept a higher level of distress. If the decision is to overlay, the pavement will have zero distress immediately after the overlay is placed and a new rate of distress occurrence will begin. When a higher level of distress is accepted, the distress rate will keep on increasing until, eventually, the rate becomes excessive from a cost standpoint. There are a number of different rehabilitation strategies which can be followed and, obviously, one of them is the most economical.

By performing an economic analysis for a specific pavement, the failure condition, i.e., the distress level at the optimum time to overlay, can be defined for that pavement. Of course, the failure condition will be different for different pavement structures, traffic, and environmental

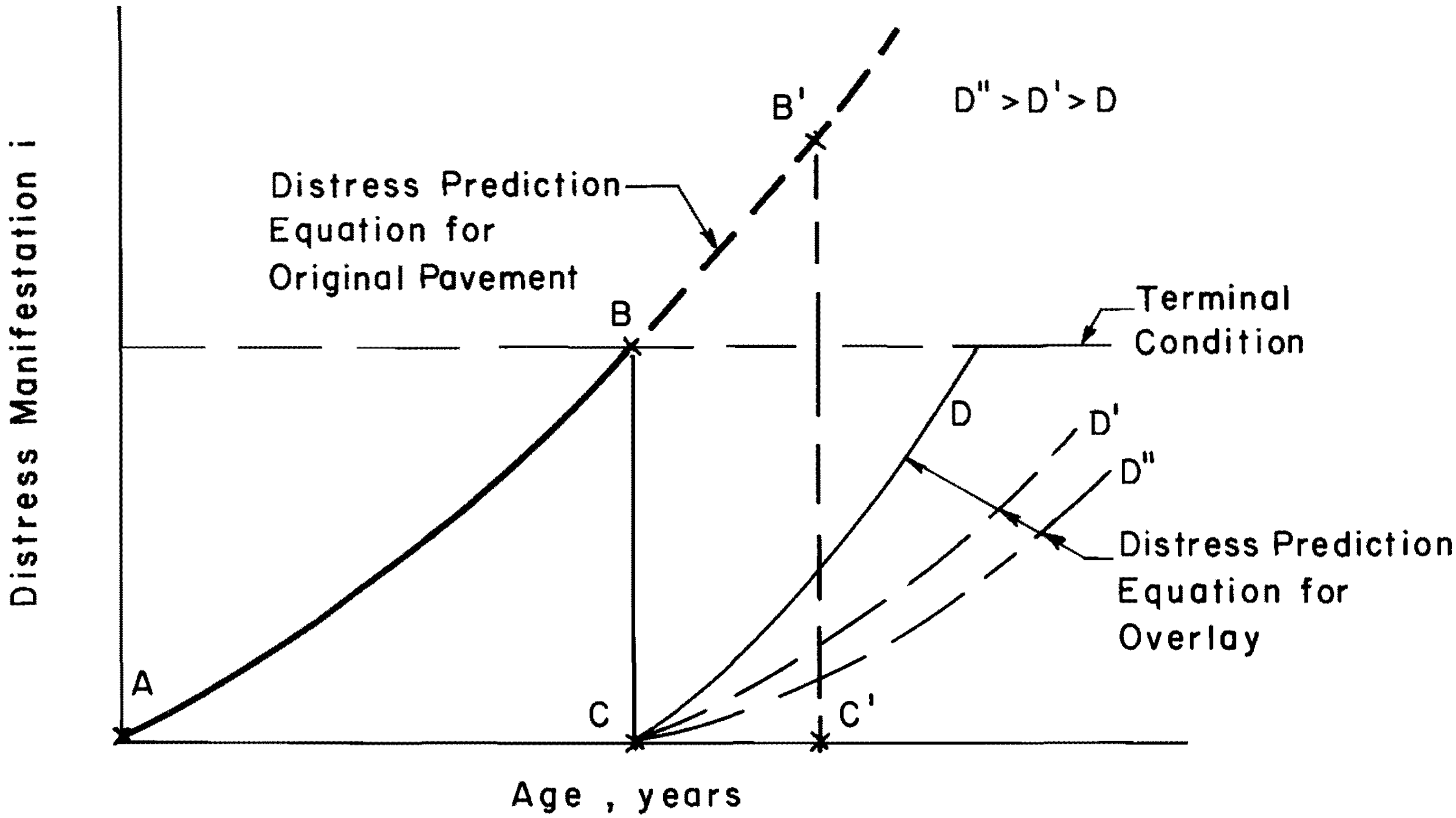


Fig 6.6. Hypothetical distress history of a pavement section.

conditions. Furthermore, this method can be used to define the traffic or years left to an existing pavement before overlaying is required. If overlaying is needed for causes other than distress, i.e., safety or riding quality, this "remaining life" prediction will be useful in designing thinner overlays.

In order to develop such an analysis, distress prediction equations and accurate cost functions are needed. Also, the effect of periodic maintenance should be accounted for. Because the current models are not accurate and because of the computer and manpower costs, this type of analysis does not appear more beneficial than the use of approximate methods at the network level. However, this approach can be used to develop approximate equations.

Daniel et al (Ref 82) developed a methodology to determine the optimum time to overlay a pavement structure based on the total cost encountered over the entire design life. The models developed in that reference failed to minimize the cost function and, therefore, do not optimize the number of years to overlay within the range of years to overlay selected for the experiment.

Although the approach presented in this section is similar to the one recommended in Ref 82, there are several differences, the most important being the distress models and the emphasis placed on distress for the selection of a pavement overlay thickness.

Description of the Program DMEO1

Program DMEO1 was developed for illustrative purposes only, and extensive improvements are required if significant results are to be obtained from it. The program reads as input information the condition of a pavement at a given time and iterates to determine the timing of overlays, calculating the user and agency costs incurred in each case. If there is an optimum time to overlay, it is optimal from the standpoint of economics, i.e., it is the timing with the minimum overall cost.

Figure 6.7 is a sample output of the program for a specific timing. The first column is the pavement age; the second is the traffic volume; the third one contains the present value interest factor for each year since the costs are discounted to the first year for comparative purposes among the different alternatives. The fourth contains the amount of distress calculated for each specific year, and the fifth shows the incremental distress from one year to the other. Columns 6 and 7 are the agency and user's costs estimated for the maintenance, or excess cost, required by the distressed state of the road; the last column gives the overall cost for each year. In the lower part of the page, the totals discounted to the first year are given.

Similar output pages are produced for other overlay timings. The timing which produces the minimum overall cost is the optimum time to overlay. The FORTRAN listing of the program is not documented since the purpose of developing it was to illustrate concepts rather than produce a working program.

Models Used by DMEO1. The distress models used by the program are the ones presented in Chapter 5. With current condition survey information as a starting point, the program uses models for the particular pavement type to predict future distress. When the section is theoretically overlaid, models for overlay pavements are used for distress prediction.

USER*S AND AGENCY COST RELATED TO PAVT DISTRESS

AGE (months)	TRAFFIC VOLUME	PVIF(I)	DISTRESS	DISTRESS INCREMENT	AGENCY MAINT COST	USER*S MAINT COST	TOTAL MAINT COST
12,00	.18250E+07	.94	.07	.07	62,90	21,12	84,02
24,00	.20506E+07	.89	.27	.20	178,01	67,17	245,18
36,00	.21736E+07	.84	.60	.33	279,90	111,94	391,84
48,00	.23040E+07	.79	1,07	.47	369,67	156,72	526,39
60,00	.24423E+07	.75	1,67	.60	448,39	201,50	649,89
72,00	.25888E+07	.70	2,40	.73	517,01	246,27	763,29
84,00	.27441E+07	.67	3,27	.87	576,43	291,05	867,48
96,00	.29088E+07	.63	4,27	1,00	627,46	335,83	963,29
108,00	.30833E+07	.59	5,40	1,13	670,87	380,60	1051,48
120,00	.32683E+07	.56	6,67	1,27	707,36	425,38	1132,74
132,00	.34644E+07	.53	8,07	1,40	737,56	470,16	1207,72
144,00	.36723E+07	.50	9,60	1,53	762,08	514,93	1277,02
156,00	.38926E+07	.47	11,27	1,67	781,46	559,71	1341,17
168,00	.41261E+07	.44	13,07	1,80	796,21	604,49	1400,69
180,00	.43737E+07	.42	15,00	1,93	806,78	649,27	1456,04
192,00	.46361E+07	.39	0	0	0	0	0
204,00	.49143E+07	.37	0	0	0	0	0
216,00	.52092E+07	.35	0	0	0	0	0
228,00	.55217E+07	.33	.53	.53	175,69	178,50	354,19
240,00	.58530E+07	.31	1,21	.68	213,10	229,50	442,60
252,00	.62042E+07	.29	2,05	.84	245,71	280,50	526,21
264,00	.65765E+07	.28	3,04	.99	273,95	331,50	605,45
276,00	.69710E+07	.26	4,18	1,14	298,20	382,50	680,70
288,00	.73893E+07	.25	5,47	1,29	318,83	433,50	752,33
300,00	.78327E+07	.23	6,91	1,44	336,17	484,50	820,67
312,00	.83026E+07	.22	8,50	1,59	350,53	535,50	886,02
324,00	.88008E+07	.21	10,25	1,75	362,18	586,50	948,68
336,00	.93288E+07	.20	12,15	1,90	371,39	637,50	1008,89
348,00	.98886E+07	.18	14,20	2,05	378,40	688,49	1066,89
360,00	.10482E+08	.17	16,40	2,20	383,42	739,49	1122,92
					12029,67	10544,10	22573,77

Fig 6.7. Sample output of a project level program which makes use of distress quantities to evaluate alternatives.

Descriptions of the models, which can be used to calculate the cost components, can be found elsewhere (Refs 82 and 83) with the exception of the user's operational cost. Several sources, such as Winfrey, Claffey, McFarland, and Zaniewski et al (Refs 84, 85, 86, and 87) present user's operational cost data for various highway types and design characteristics. However, McFarland was the first to considers the effects of varying pavement serviceability on user's cost. None of the above mentioned references consider the effects of distress on user's operational costs. This is the primary flaw of the scheme proposed.

Alternative Procedure to Derive a Distress Index

The purpose of this section is to sketch an alternate procedure for developing a distress index and/or an output function for the prioritization and scheduling procedure at the network level. The alternative procedure involves the following steps:

(1) Prepare or select a project level computer program with the capacity to generate the optimum time to overlay and the costs of maintenance and rehabilitation for a specific section.

(2) Set an experimental design to derive, through regression techniques, approximate models to calculate

   (a) the optimum time to overlay and

   (b) costs of maintenance and rehabilitation for different overlay timings.

(3) With these equations, introduce an improved distress index into the prioritization scheme, as a function of

$$(X_i - X_o)$$

where

X_i = time of overlaying,

X_o = optimum time to overlay,

or, introduce cost equations to optimize the scheduling procedure by minimizing costs.

SUMMARY

This chapter presents the application of distress models at both the network and project levels. At the network level, a program was developed to prioritize or/and schedule rigid pavements for rehabilitation. The program was run using Texas CRCP field data, and the outputs are shown in Appendix D; similar runs are intended to help the State Department of Highways and Public Transportation with future rehabilitation decisions. At the project level, a design and maintenance evaluation program was presented for illustrative purposes. Guidelines were suggested to apply a similar program for the derivation or improvement of the distress index equations.

CHAPTER 7. APPLICATIONS OF THE REHABILITATION SCHEDULING PROGRAM PRP01

The most obvious application of the computer program PRP01 is to generate lists of candidate pavements for rehabilitation similar to the ones presented in Appendix D. However, the use of the program can be extended to analyze the impact of several different budgeting policies on the condition of the pavement network. The purpose of this chapter is to present the effects of different budget policies using information from the 1980 East Texas CRCP condition survey. The data used for the analysis came from 139 sections, representing 7 districts, with a total length of 756.5 miles and an age range of 9 to 18 years. These specific questions will be dealt with:

(1) What is the effect of various yearly budgets on the distress condition of the pavement network?

(2) What is the effect of considering the time value of money in the analysis?

(3) What is the additional cost incurred if a pavement section is overlaid at a later date than the one recommended using the distress index?

ANALYSIS APPROACH

As described in Chapter 6, program PRP01 can generate lists of candidate pavements for rehabilitation with and without budget restrictions. The analysis approach followed makes use of this capability: several computer runs were performed for a 10-year analysis period using several budget levels, i.e., 5, 10, 15, 20, and 30 million dollars per year. An additional computer run was carried out without considering budget restrictions. The output of the runs was plotted to observe the effect of the various yearly budgets on the distress condition of the pavement network. The same results were used to perform an economic analysis of the various budget levels considered.

A different approach was followed to ascertain the additional cost incurred when the overlay date is postponed. Several runs were carried out, first using only the pavement sections which required overlay the first year, assuming a zero budget for the first year, and then those which required overlay for the first and second years, and so on. From the output, the percent increase in cost of postponing an overlay is obtained for severe and slightly distressed sections and for the network as an average. The numbers used in the analysis are not definitive since the cost of overlay used was approximate. An accurate figure should include costs such as the cost of handling traffic, materials, equipment, labor, etc.

ANALYSIS OF THE RESULTS

Effect of Yearly Budget

Tables 7.1 and 7.2 present in summary form the results from the computer runs performed using several budget levels. Table 7.1 presents summary information for each budget level considered: the second column contains the total number of miles repaired for the design period considered; the third column contains the total budget used in the design period in millions of

TABLE 7.1. SUMMARY INFORMATION FOR SEVERAL DIFFERENT BUDGET LEVELS FROM THE COMPUTER PROGRAM PRPØ1 USING TEXAS CRCP INFORMATION

Budget Level (millions/year of dlls)	Length Repaired (miles)	Budget Used (millions of dlls)	Avg. Overlay Cost Per Mile (10^3 dlls/mi)	Avg. Distress Index
Variable	532.2	119.957	225.40	0.628
5	70.8	35.052	495.09	-0.670
10	261.0	91.934	352.24	-0.128
15	506.3	137.974	272.51	0.154
20	756.5	169.515	224.08	0.415
30	756.5	157.850	208.66	0.648

*10-year analysis period

TABLE 7.2. SUMMARY TABLE OF AVERAGE DISTRESS INDEX PREDICTIONS FOR VARIOUS BUDGET LEVELS FROM PROGRAM PRPØ1 USING TEXAS CRCP INFORMATION

	Budget Level					
Year	V*	5	10	15	20	30
1	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
2	0.74	-0.20	-0.16	-0.07	0.03	0.14
3	0.74	-0.32	-0.14	-0.01	0.13	0.32
4	0.73	-0.41	-0.13	0.04	0.20	0.53
5	0.71	-0.55	-0.11	0.08	0.35	0.70
6	0.69	-0.69	-0.12	0.15	0.45	0.91
7	0.68	-0.85	-0.14	0.23	0.55	1.00
8	0.67	-1.03	-0.15	0.33	0.70	1.00
9	0.69	-1.22	-0.13	0.40	0.83	1.00
10	0.72	-1.33	-0.09	0.50	1.00	1.00

*V = Variable Budget

dollars; the fourth column contains the average overlay cost per mile for each budget level, without considering the time value of money. The average overlay cost per mile was obtained by dividing the total budget by the number of miles repaired. Column five presents the average distress index for each budget level. The poor condition of the network for the low budget levels, exemplified by negative average distress index values, is obvious, as is the improved condition for higher budgets.

Table 7.2 presents summary information on the average distress index predicted each year within the design period for the network and for the various budget levels. Figure 7.1 presents the same information in graphical form. In this figure it is readily apparent that the rate of deterioration, i.e., the slope of any of the lines in the figure that occur when a low budget is used, i.e., 5 million dollars per year, can be diminished or even reversed if higher budgets are adopted. Also, it can be noticed that there is a yearly budget, i.e., 10 million dollars, for which the condition of the network is maintained at a constant level. This budget level may not be recommendable because of the low initial distress condition of the network, i.e., the average distress index in year one. The use of a variable budget involves investing an extensive amount of money the first year, about 84 million dollars for the problem in question, to bring up the condition of the network, and a yearly budget of about 4 million dollars (lower than the 10 million per year required if the network is not restored to a better condition) for the rest of the design period.

In order to help the reader visualize the meaning of the distress index, Fig 7.2 was produced. A 0.2-mile section with several different stages of distress is depicted in the figure. Notice the different stages of deterioration corresponding to various magnitudes of the distress index.

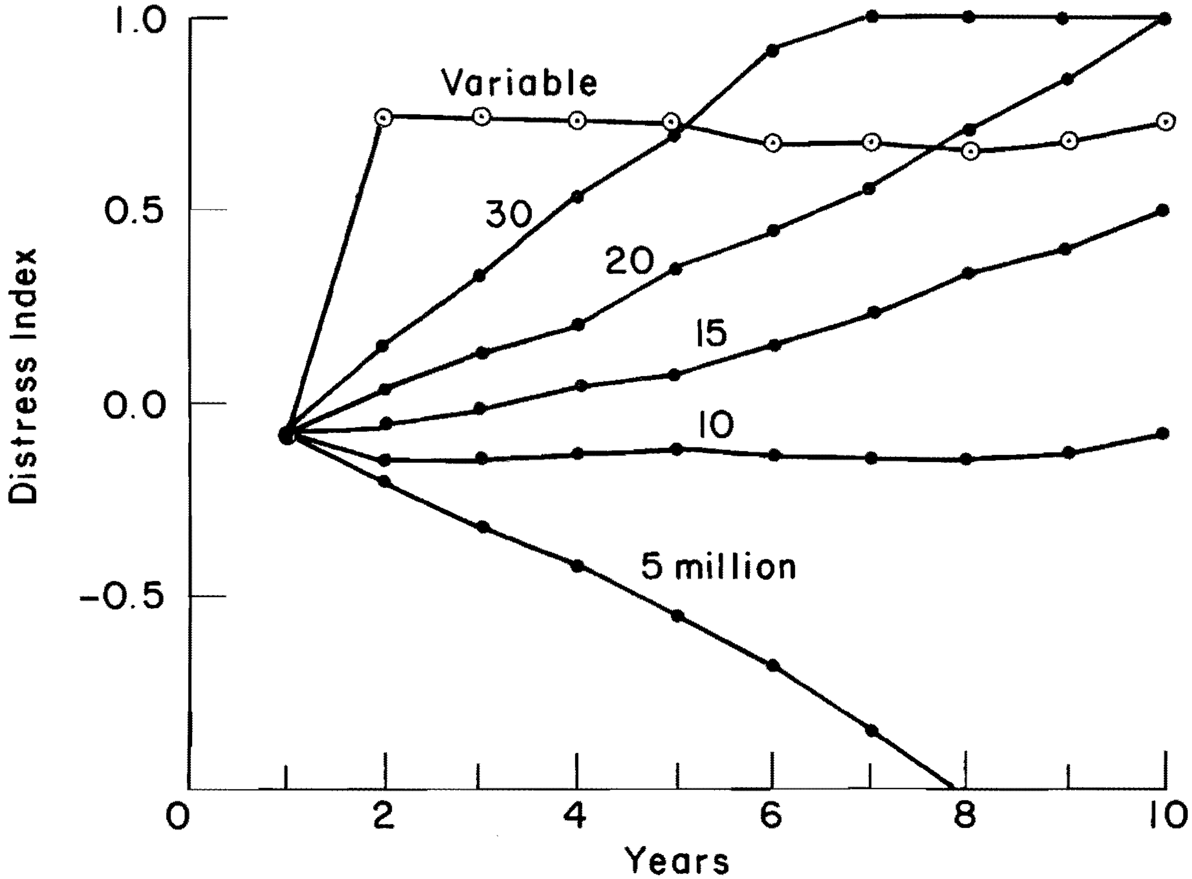


Fig 7.1. Average distress index for the network through time for various yearly budgets using Texas CRCP information.

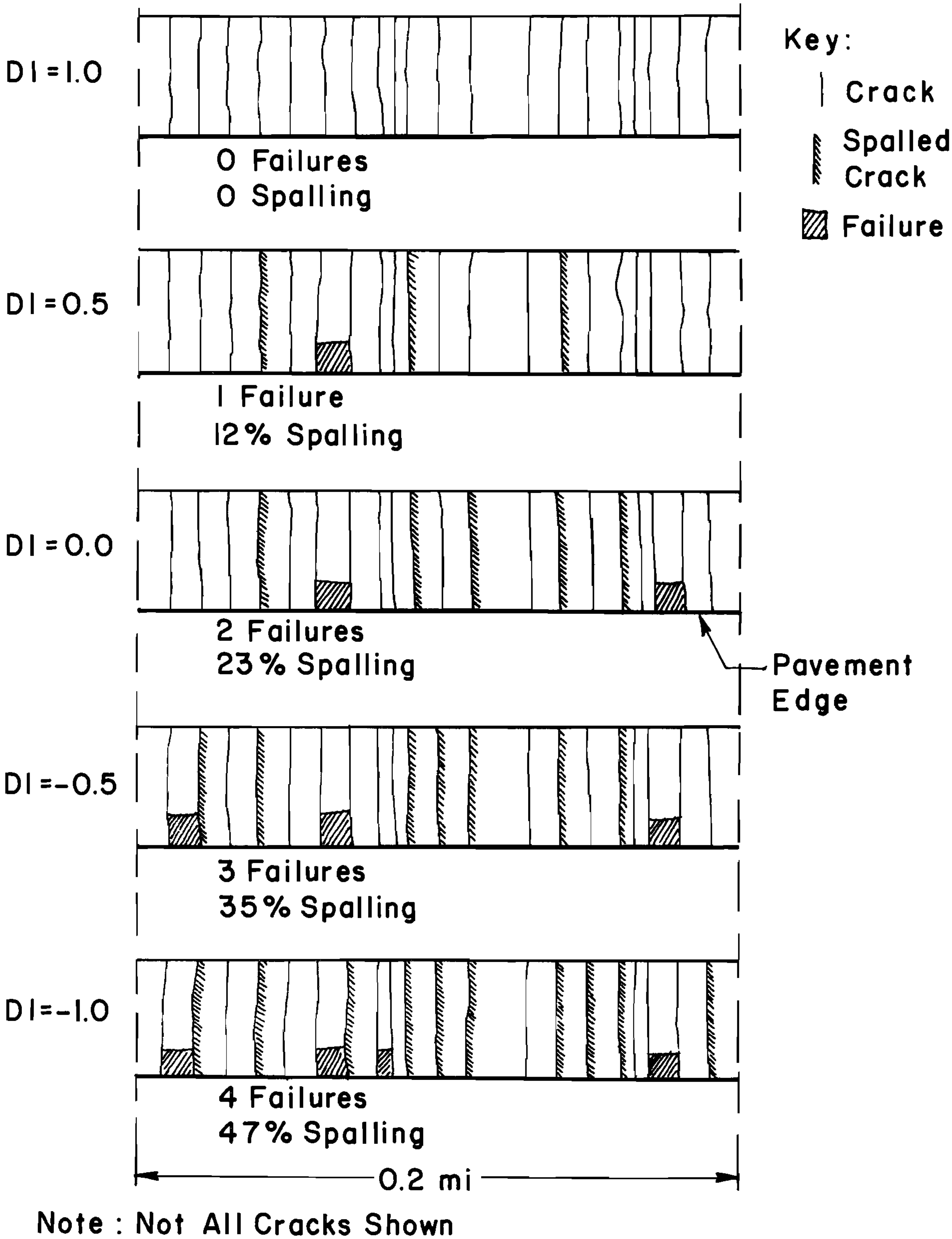


Fig 7.2. Sample distress condition of a Ø.2 mile CRC pavement section with different values of the distress index.

Then, if a low budget is used, the deterioration of the pavement follows stages similar to the ones presented in Fig 7.2.

Effect of the Time Value of Money

Table 7.3 is a summary of the computations performed as part of an economic analysis to ascertain the effect of the time value of money in choosing a budgeting policy; a 10 year analysis period was used. This table contains the average cost per mile of overlay to the agency for various budget levels and interest rates. Caution is recommended when the results of this analysis are used since user costs are not considered. The results presented in Table 7.3 are plotted in Fig 7.3.

From the plot, it can be observed that a minimum average cost per mile exists for the problem under analysis. This outcome is not surprising if one considers that as the budget increases above the minimum, the number of sections repaired in the short range increases. On the other hand, budget levels below the minimum tend to exclude sections requiring overlay. An important observation to be made is that the yearly budget which produces the minimum cost per mile of overlay is not necessarily the budget producing the "ideal" average distress index (Table 7.1).

Cost of Postponing an Overlay

Table 7.4 presents the results of the analysis carried out to investigate the additional cost incurred when postponing the recommended date of overlay. The time lags considered were from one to five years. Table 7.4 indicates the increased cost per mile of overlay for three different cases: first, for the network as an average, i.e., when all the sections which

TABLE 7.3. AVERAGE COST PER MILE OF OVERLAY FOR VARIOUS BUDGET LEVELS AND INTEREST RATES USING TEXAS CRCP INFORMATION

Budget Level (10^6 dlls/year)	Interest Rate (Percent)		
	0	5	10
Variable	225.40	211.13	201.26
5	495.09	405.90	342.88
10	352.24	284.90	237.23
15	272.51	219.79	182.56
20	224.08	185.94	157.94
30	208.66	187.75	170.69

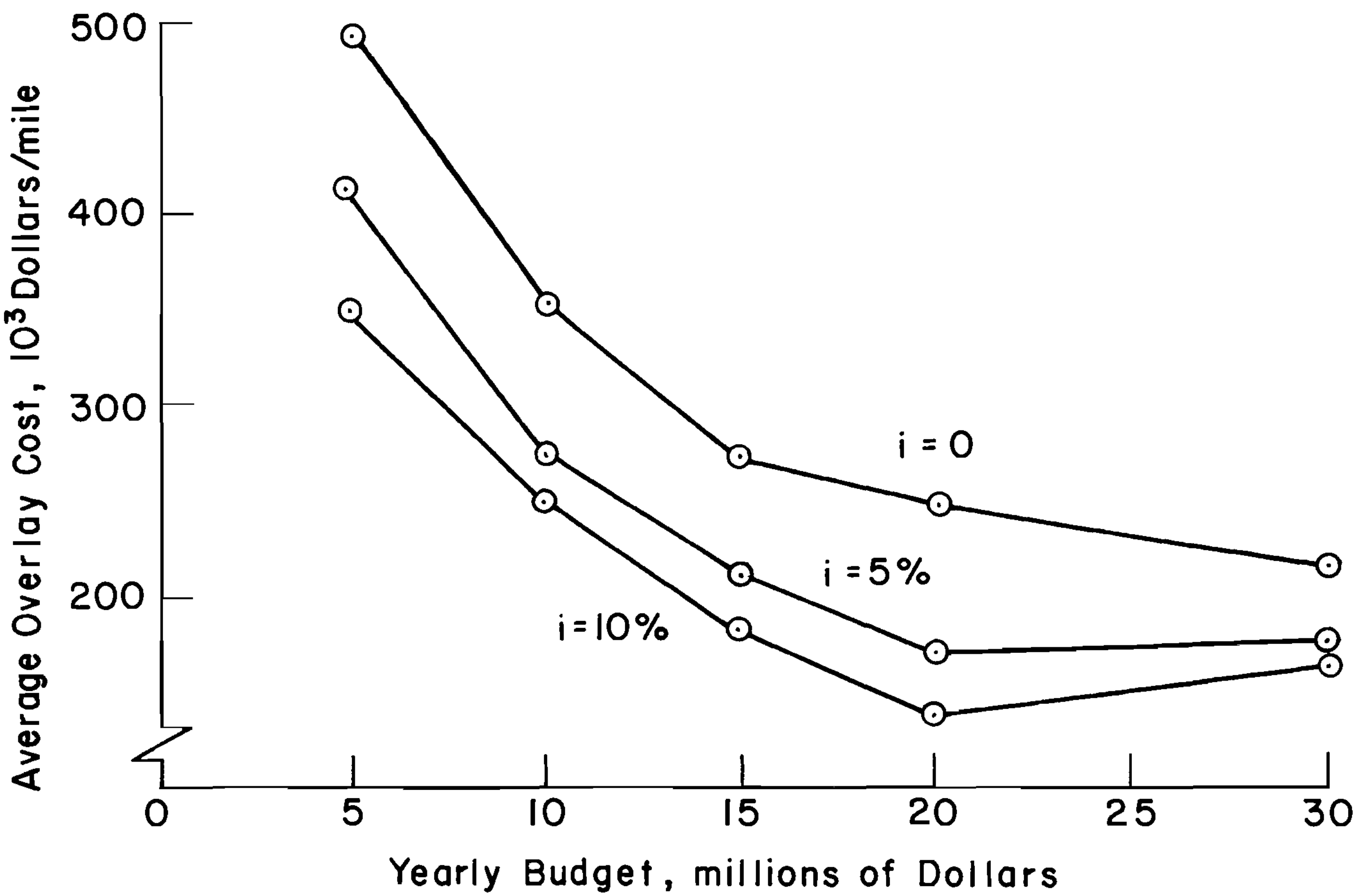


Fig 7.3. Average overlay cost per mile versus different yearly budgets for various interest rates using Texas CRCP information.

TABLE 7.4. ADDITIONAL COST INCURRED WHEN POSTPONING THE OVERLAY OF A PAVEMENT SECTION DEVELOPED FROM TEXAS CRCP INFORMATION

	Network Average		Severely Deteriorated Section		Slightly Deteriorated Section	
Year of Overlay	Cost Per Mile (10^3 dlls/mi)	Percent Increase	Cost Per Mile (10^3 dlls/mi)	Percent Increase	Cost Per Mile (10^3 dlls/mi)	Percent Increase
1	247.87	--	478.16	--	180.37	--
2	265.30	7.03	545.20	14.02	182.22	1.03
3	284.65	14.84	624.59	30.62	184.07	2.05
4	306.22	23.54	718.06	50.17	185.93	3.08
5	330.37	33.28	828.06	73.18	187.96	4.21

should have been overlaid in year one were postponed a certain time lag and the average cost incurred was calculated; second, for a severely deteriorated section with a high rate of deterioration; and, finally, on the other side of the spectrum, for a slightly deteriorated section with a low rate of deterioration.

The results indicate that, on the average, a 7 percent increase in cost per year may be expected if the recommended date of rehabilitation is postponed. This cost increment varies, for the information used in the analysis, from one to 14 percent per year, depending on the specific conditions of the pavement section under consideration.

DISCUSSION OF RESULTS

Availability of funds and managerial preferences play an important role in the budget selection procedure; however, program PRP01, or similar computer programs, can be used as an aid in the selection of a budget policy. The use of the program for the purposes of this report has indicated that its results are supported by a-priori considerations.

From the analysis conducted in this chapter the following conclusions are drawn. Although they may seem obvious, the program corroborates and provides means for estimating them.

(1) A minimum budget is required to maintain the condition of a pavement network. This minimum is variable depending on the original condition of the network.

(2) If the network is allowed to deteriorate, the amount of money required to upgrade its condition to a certain level will increase with time. That is, more money will be needed to upgrade the network as time goes by.

(3) In addition to availability of funds and personal preferences, an economic analysis is an important factor in the selection of a budget. However, since user costs are not included in the analysis, in the computer program presented, detailed consideration should be paid to

(a) the initial distress condition of the network and

(b) the predicted distress history of the network.

SUMMARY

This chapter is devoted to demonstrating the capabilities of the rehabilitation prioritization and scheduling program presented in Chapter 6. The program can be used

(1) to generate a list of candidate pavements for rehabilitation within a design period and

(2) as a tool in the analysis of alternatives to select budget policies.

The use of the program in the selection of budget policies is explained and demonstrated in the course of the chapter. Conclusions are derived on the impact of different budget levels, the time value of money, and the postponing of the overlay date in the selection of a budget policy.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the principal conclusions and recommendations derived in this study. The first section of the chapter is dedicated to summarizing the work accomplished and to presenting the status of this effort in the context of an M & R management system. The principle conclusions and recommendations, already presented throughout the report, are grouped and organized in the second section of the chapter. This section has been further subdivided into conclusions and recommendations related to (a) the scheme in general and (b) the models therein.

SUMMARY OF WORK ACCOMPLISHED

The main contribution of this report is a working scheme to prioritize and schedule M & R in a rigid pavement network. In addition to the procedure, other major contributions have been made, such as developing a failure criteria, and stressing the use of distress quantities in PMS. The scheme makes use of a distress index as a decision criterion to determine when a pavement has reached its terminal condition. The distress index is calculated by combining into a single number the various distress manifestations occurring in a pavement section. The initial pavement condition is determined from field distress condition surveys, and the future condition is determined by means of prediction models.

The material presented in this report is part of an effort to develop an M & R management system. Figure 8.1 presents, the pavement maintenance and rehabilitation management system currently under development in CTR Research Project 249. The flowchart indicates the activities carried out in the PMS at the network and project levels. The cycle starts by collecting field information to assess the current condition of the network. The information collected is the input data for Program PRP01, which helps management select rehabilitation candidates for the next years. Once the selection has been made, the activities are carried out at the project level. Several Project 249 reports dealing with project level activities have been published.

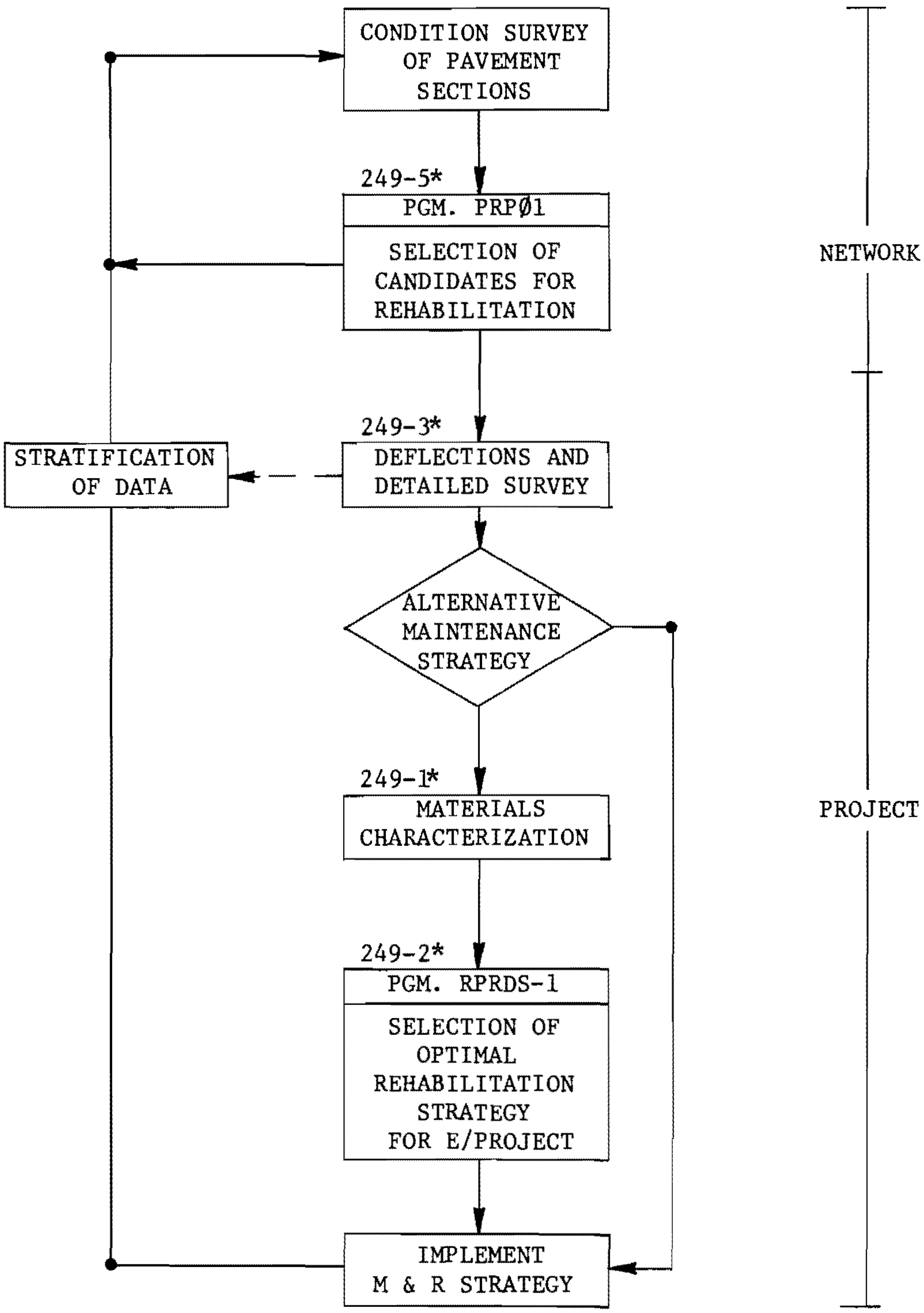
CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions and recommendations derived in this study concerning the rehabilitation prioritization and scheduling scheme for rigid pavements at the network level are summarized here:

(1) When the computer program was used to analyze the impact on the future distress history of a pavement network of several different budgeting policies, it was concluded that the program is a very useful tool for selecting an adequate budgeting policy. From the analysis conducted, the following additional conclusions were drawn:

   (a) A minimum budget is required to maintain the condition of a pavement network. This minimum is variable, depending on the original condition of the network.

   (b) If the network is allowed to deteriorate, i.e., is not maintained, the amount of money required to upgrade its condition to a certain level will increase with time.



*Report Number

Fig 8.1. Flowchart of pavement M & R management system as developed in CTR project 249.

(c) In addition to availability of funds and personal preferences, an economic analysis is an important factor in the selection of a budget. However, since user costs are not included in the analysis, detailed consideration should be paid to the initial distress condition and the predicted distress history of the network.

(2) It is recommended that the program be implemented, using current information, in order to obtain an updated rehabilitation schedule and budget. That is, performing another condition survey is recommended, for estimating future maintenance requirements.

(3) The program estimates, in terms of both dollars and distress predictions, need to be verified to corroborate and improve the scheme. As with any PMS, continuous upgrading is required to achieve improved management of funds.

In relation to the models within the rehabilitation prioritization and scheduling scheme, the following conclusions and recommendations have been derived:

(1) From experience in Texas with rigid pavements, it appears that distress is a better indicator of the condition of a pavement section than riding quality. Therefore, it is recommended that distress be used as the decision criterion in the prioritization and scheduling scheme.

(2) The distress index used to prioritize and schedule pavement sections for rehabilitation should include other variables such as traffic and environmental conditions. Future efforts should be aimed towards including these variables in order to improve the decision criterion.

(3) The following conclusions were obtained from the study of several approximate methods aimed at developing a distress index, i.e., subjective parameters, regression analysis, factor analysis, and discriminant analysis.

(a) The equations with subjective parameters rely heavily on engineering judgement and experience and, therefore, are useful when sufficient information is not available.

(b) Factor analysis is difficult to interpret and there is no support to the assumption used in this approach that the resulting equations measure structural performance or deterioration of a pavement section.

(c) Regression and discriminant analyses are viable techniques for developing distress and decision criteria indices. Because of the configuration of the information available, the latter was selected in this report to derive a distress index.

(4) An alternative procedure has been sketched for developing distress indices for the prioritization and scheduling procedures at the network level. This alternative procedure involves the use of cost equations which are functions of the distress condition of a pavement. At the present time, this type of equations is not available. Therefore, reseach should be conducted to estimate user cost equations as a function of the distress of the pavement.

(5) If the rehabilitation scheduling procedure is to include flexible pavements, similar distress indices need to be developed so as to have a common "yard stick" for evaluating both types of pavements, i.e., rigid and flexible.

(6) Field data were used to obtain models for CRCP and AC overlaid rigid pavements; for jointed pavement, the models have been adopted from the literature. When applying these models, the following points should be kept in mind:

   (a) All the equations presented consider past condition as an independent variable. This factor helps to "characterize" the pavement sections, i.e., it accounts for material properties, environmental conditions, and construction variables as well as previous age and traffic conditions. However, any change in these variables from previous conditions can not be accounted for; also, new pavements can not be handled by these equations.

   (b) In the case of parent pavements, the highly deteriorated pavements are usually overlaid; therefore, the prediction equations are biased because only "good" pavements were used in their development.

   (c) The equations presented are bound by their inference space.

   (d) The information used for the development of the equations came not from an experimental design but from data collected primarily for evaluating pavement conditions.

(7) The distress prediction equations need to account for the effect of preventive maintenance. Therefore, it is recommended that the monitoring of experimental sections to assess the impact of different maintenance techniques on the rate of deterioration of a pavement section be continued.

(8) Future improvements of distress prediction equations should contemplate experimental design techniques. Guidelines exist in the literature (Ref 38) for that purpose.

(9) Accurate traffic information is of vital importance in the prioritization and scheduling procedure. Current practice followed by the Texas SDHPT involves estimating traffic from data collected using a few in-motion weighing scales. A more extensive weighing system should be procured to obtain accurate information, as recommended in Ref 52.

(10) In order to have homogenous sections for the development of improved distress prediction equations or to be able to sample within projects, it is recommended that the existing sections be broken into smaller sections using the Dynaflect to characterize the subgrade and the pavement structure.

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APPENDIX A

CONDITION SURVEYS: EVOLUTION OF PROCEDURES AND FORMS

APPENDIX A. CONDITION SURVEYS: EVOLUTION OF PROCEDURES AND FORMS

This appendix is devoted to presenting the different types of condition surveys which have been carried out by the Center for Transportation Research to study rigid pavements in the state. Each of the pavement condition surveys is categorized in regard to its quantity and quality, and the evolution of the condition survey procedure and forms is presented.

For the purpose of the presentation, the pavements have been divided as follows:

(1) rigid pavements;

(2) overlaid rigid pavements

(a) AC overlays,

(b) rigid overlays; and

(3) special projects.

Portland cement concrete pavements, i.e., rigid pavements, are classified according to whether or not they contain joints and reinforcement, as shown in Table 1.1, Chapter 1.

The CTR is currently monitoring a number of overlaid rigid pavements. The overlays have been classified as either flexible, i.e., AC overlay; or rigid, i.e., PC overlaid. The rigid overlays can be further subdivided as the rigid pavements, and only AC, JRCP, and CRCP overlays have been studied in our research projects.

"Special projects" includes innovative maintenance construction, or design features which are being tested to assess the benefits they provide to the pavement and to check if they are cost effective. In a more detailed fashion, the special projects include new materials, new procedures, new design features, maintenance (i.e., prestressed slab repairs, grouting, drains, concrete shoulder addition, fabrics), etc. The CTR is currently monitoring several of these projects.

CONDITION SURVEYS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Condition surveys for CRC pavements have been carried out in rural and urban districts; the condition survey procedure in urban zones is different from the one used in rural zones due to the different traffic conditions. The rural districts were surveyed in 1974, 1978, and 1980; the urban districts were surveyed in 1976 and 1981. In some cases, different criteria were followed in measuring the same distress manifestation; the transformations used to put the information into common units will be mentioned.

CRCP Condition Survey Procedure

Rural Districts (Ref 6 and 9). In 1974, the road was surveyed by two persons in one vehicle, travelling on the shoulder at approximately five miles per hour. Only the outside lane was surveyed. The driver, while noting the condition of the shoulder to comment on it later, had to assess the section length that was subjected to pumping, count the punchouts, and determine the size of the repair patches.

The passenger, who sat behind the driver to get a better view of the road, quantified transverse and localized cracking and made a note of the spalling encountered.

The road was surveyed in sections of 0.2-mile, and the driver informed the passenger of his findings at the end of every section. This, with his own assessment, was entered in one column of the survey sheet. Therefore, only one survey sheet was used between the two raters.

At the end of every three miles, when a sheet of the survey form had been completed, the condition of the shoulder was discussed and commented on. Other obvious distress phenomena or interesting facts about the road were also noted under general comments.

In the 1978 condition survey, the driver noted the punchouts and pumping along the roadway while the passenger noted the minor and severely spalled cracks and patches. A 300-foot portion of each project, roughly in the middle of the section, was selected for measuring crack spacing.

In 1980, in order to expedite the condition survey procedure, only the structural failures, i.e., punchouts and patches, were counted in detail. Minor and severe spalling were counted the first mile of a project; if no difference was detected from the 1978 condition survey, then spalling was not considered for the rest of the surveys; if it was found to be different, then it was counted for the rest of the project. Pumping was not measured or estimated but its occurrence was noted as a yes-no condition.

Urban Districts (Ref 5). Before the 1976 condition survey, a study was conducted to develop a technique for surveying heavily trafficked highways.

Because of the need to be able to conduct a survey at a speed of at least 30 miles per hour (48 km/h), the possibility of utilizing photographic techniques was investigated; accuracy, speed, and reasonable cost are important criteria for a successful condition survey on urban highways.

It was found that by mounting a camera with a shutter speed of up to 1/2000 second and capable of taking 4 to 5 frames per second on a boom hanging in front of a vehicle so that the line through the camera lens is perpendicular to the road surface, a birdseye view of the distress can be obtained on film. By adjusting the vehicle speed and equipment, a survey of the condition of a CRCP pavement is possible. The difference in quality between a visual and a photographic survey is minimal.

In 1976, the condition survey was conducted using photographic techniques. Sample lengths of about 300-feet per mile were used and it was recognized that cracking, spalling, and pumping were accurately represented by the sample, but punchouts and patches were not; therefore, it was suggested that all these structural failures be counted. Although pictures provide an excellent record of pavement condition, the analysis of the photographs is a time consuming task.

In 1981, it was decided to return to the visual survey. The procedure adopted was similar to the 1978 rural condition survey.

<u>CRCP Distress Discriptions (Refs 4 and 6)</u>

<u>Transverse Cracking.</u> All CRCP show transverse cracking; the design concept of this type of pavement is to replace the joints by closely spaced narrow cracks, and cracking per se is not a distress manifestation. Only

cracks that deviate from the regular crack pattern and at spacing closer than about 2 feet can be considered as distress.

During 1974, the different lengths of road, within the section surveyed that experienced crack spacing of less than 18 inches were added up and the accumulated length of the road as a percentage of the section length, i.e., 0.2-mile, was entered in the survey sheet. The intensity of cracking was further divided into minor and severe: minor transverse cracks were defined as cracks which were newly formed, narrow, or not easy to be seen; and severe transverse cracks as big, well defined openings.

In 1978, it was decided to measure the crack spacing by taking 300-foot samples around the middle of the job. The crack spacing is the distance in feet between transverse cracks in the outer lane of the roadway.

In 1980, cracking was not measured. The percent transverse cracking below 18 inches can be estimated from the 1978 condition survey using the frequency or cumulative distribution of the crack spacing sample. Measurements of crack spacing in experimental sections appears to indicate that it does not change after the first year of the pavement. Figure A.1, developed from 1978 data, seems to corroborate this observation.

Localized Cracking. The formation of Y-cracks that link the transverse cracks, which occurs when the closely space transverse cracks start to deteriorate, is called localized cracking.

Localized cracking was measured only in 1974. The amount of localized cracking was determined using the same method as described in transverse cracking.

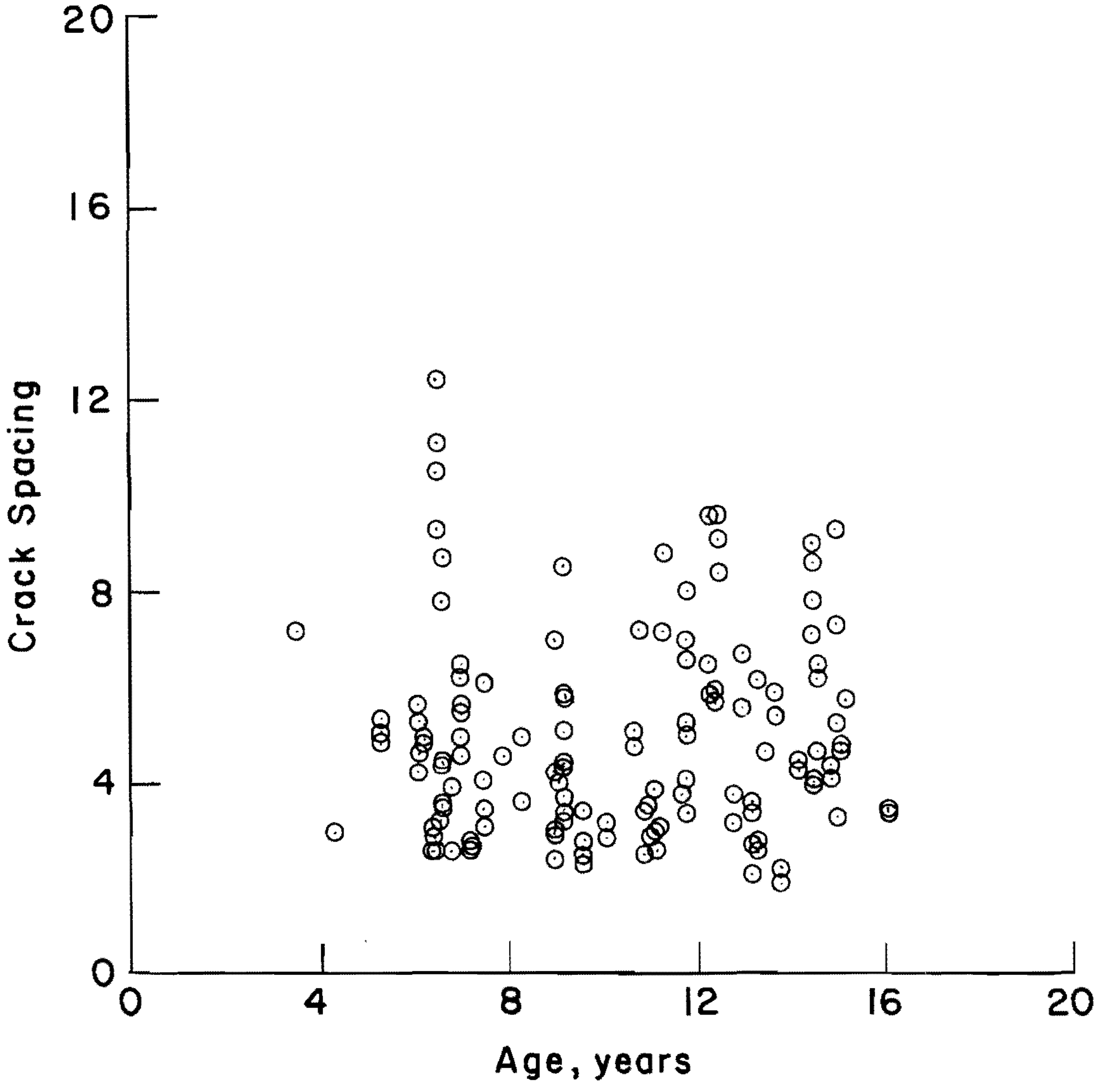


Fig A.1. Plot of measured crack spacing versus age in the 1978 Texas CRCP condition survey.

Spalling. Spalling is defined as the widening of existing cracks by secondary cracking or breaking of the crack edges. The depth of a spall is generally less than one inch but it can be very wide. Minor and severely spalled cracks are distinguished by the width of the spall. Minor spalling is defined as a condition of edge cracking in which the loss of material has resulted in a spall roughly one half inch in width. Severe spalling is defined as a condition in which the spall is wider than one-half inch.

In 1974, an estimate of the percentage of cracks that showed minor and severe spalling was recorded. The percentage was not exact since four categories were provided for estimating the quantity.

In 1978, the actual number of cracks showing either type of spalling was recorded; that is, they were keyed into a mechanical counter and every 0.2-mile were transferred to the surveying form. This counting procedure happened to be very time consuming; therefore, in 1980, samples were taken to see if there was no difference with 1978. When the sample was different from that in the previous survey, all the spalled cracks in the section were counted.

In order to compare the 1974 condition survey to the 1978 and 1980 results, the following equation can be applied:

$$PS = \frac{NSPL * CSPC}{1056.0} \tag{A.1}$$

where

PS = percent spalling in a 0.2 mile section,

NSPL = number of spalled cracks in a 0.2 mile section, and

CSPC = mean crack spacing for the project.

Pumping. Pumping is said to occur if water penetrates through cracks and openings in the pavement and then, when a load, such as a heavy vehicle passing over a crack, is applied, is pressed out again, taking fine material of the sublayers with it.

Pumping may occur at construction joints that have opened up longitudinal cracks or transverse cracks. However, for the purpose of these surveys, only pumping at the edge of the pavement was recorded. The edge in this case is the joint where the pavement and the shoulder meet.

Minor pumping occurs when water is pumped out leaving streaks of fines on the surface of the shoulder or pavement. Severe pumping is indicated by a severe loss of fines from the sublayers and it is also associated with vertical movement of the pavement where pumping occurs.

The percentage of section length that is subjected to pumping is recorded. The worst condition of pumping again defines the quality of pumping at that section, although some minor pumping may also experienced within the section. If a few distinct spots of pumping are found, say 300 feet apart, they are handled as separate sections subjected to pumping and are assessed as minor or severe separately. The minor sections are added separately from the severe sections and recorded.

The same measuring criterion was used in 1974 and 1978. In the 1980 survey, pumping was recorded as a yes-no occurrence; therefore, it can be assessed only if pumping, minor or severe, appeared in a section from 1978 to 1980.

Punchouts. When closely spaced transverse cracks are linked by longitudinal cracks to form a block, the block is called a punchout. This must not be confused with longitudinal cracking, which is not recorded on the sheet. A minor punchout is defined as a condition where, although a block has formed, no sign of movement under the traffic is apparent. The cracks surrounding the punchout are narrow and few signs of spalling are apparent. A severe punchout is recorded when the block moves under traffic. The surrounding cracks will be wide and signs of pumping around the edge of the block may be apparent.

Punchouts were divided into four categories in the 1974 survey according to their lengths, namely 1-3, 4-9, 10-19, and above 20 feet. In 1978 and 1980 minor and severe punchouts per 0.2-mile sections were recorded in two categories: those shorter than 20 feet and those longer than 20 feet.

Repair Patches. The pavement needs to be repaired in the final stages of distress. Repairs can be made with either portland cement concrete or asphalt cement concrete. The condition of the repair patch is not determined. Columns are provided to record whether the patch is made of asphaltic or portland cement concrete.

It is important to note that repair work that is done over the full depth of concrete thickness is classified as a repair patch. Patching of spalling and overlaying part of the concrete pavement is not classified as patch work. The former is defined as spalling and the latter is commented on under General Comments.

To determine the amount of patching that was involved in 1974, a scale was provided for in square feet of patch work. The scale is divided into four categories, namely 1-15, 16-120, 121-240, and greater than 241 square foot patches. The category under which every patch falls is determined, and the number of patches for every category is counted and the figure entered on the survey sheet.

In 1978 and 1980 only the number of repair patches observed was recorded. In some cases, fewer patches were observed in 1978 than in 1980, because several adjacent patches observed in 1978 were replaced in several instances by a larger single patch.

CRCP Survey Forms

Slightly different condition survey forms have been used for the different surveys. The modifications to the survey form are related to the changes in the procedure or in the criteria to measure the distress manifestations.

A copy of the survey form used in the 1974 rural survey is included as Fig A.2. At the top of the sheet, a few details are given to define the position of the section. Space is provided for the control number, section number, highway number, district number and county in which the sections are located. The exact location of the section must be described to facilitate reference to or a detailed survey of the section at a later stage.

The names of both raters must be listed as well as the date of survey.

It is imperative to tie the sections to the mileposts alongside the road. The trip recorder of the vehicle may be used to facilitate the

CRCP

PERFORMANCE SURVEY

District	Control	Section	Highway	County	Leave Blank	Date Mo. - Day - Yr.

Leave Blank	Location From	To	Raters

Mile Post	Mile Point	Transverse Cracks % M				Transverse Cracks % S				Localized Cracks % M				Localized Cracks % S				Spalling % M				Spalling % S				Pumping % M				Pumping % S				Punch Outs in feet M				Punch Outs in feet S				Repair Patches Square feet A.C.				Repair Patches Square feet P.C.C.				Ride
		1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–5	5–20	20–50	50–100	1–3	4–9	10–19	> 20	1–3	4–9	10–19	> 20	1–15	16–120	121–240	>241	1–15	16–120	121–240	>241	

5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

M - Minor S - Severe A.C. - Asphalt P.C.C. - Portland Cement

Condition of Shoulder ______________________________

General Comments ______________________________

____

Fig A.2. Form used in the 1974 rural condition survey for CRCP in Texas.

subdivision of section lengths into 0.2-mile sections. The milepost readings, however, must be entered in the space provided.

The sheet is divided into nine main columns, of which five are subdivided into two columns each, designated by "M" and "S", which stand for "minor" and "severe", to describe the severity of the different distress phenomena. Distress on the other hand is quantified by estimating length or area or by counting the spots of distress. The transverse cracks, localized punchouts, and repair patches that fall under the same category are counted and entered in the column provided. The figure that represents rating of ride is written in, as shown. This is discussed later. However, it is necessary to draw attention to the fact that the amount of distress is divided into four categories, which makes it unnecessary to determine the exact quantity. A good estimate is sufficient for the purpose of this survey.

A copy of the survey form used in 1978 is shown in Fig A.3, and Fig A.4 shows a copy of the crack spacing field sheet. The survey form shows the modifications for measuring distress manifestations. The crack spacing form was used only in the 1978 survey. It provides space to identify the county, district, highway, and direction, as well as the control number, section, job number and location. The cumulative readings from the measuring device, a rolotape, are input in the form.

In 1980, the survey form shown in Fig A.3 was used, the difference was that pumping was entered as a yes or no condition instead of percentages. Crack spacing was not measured.

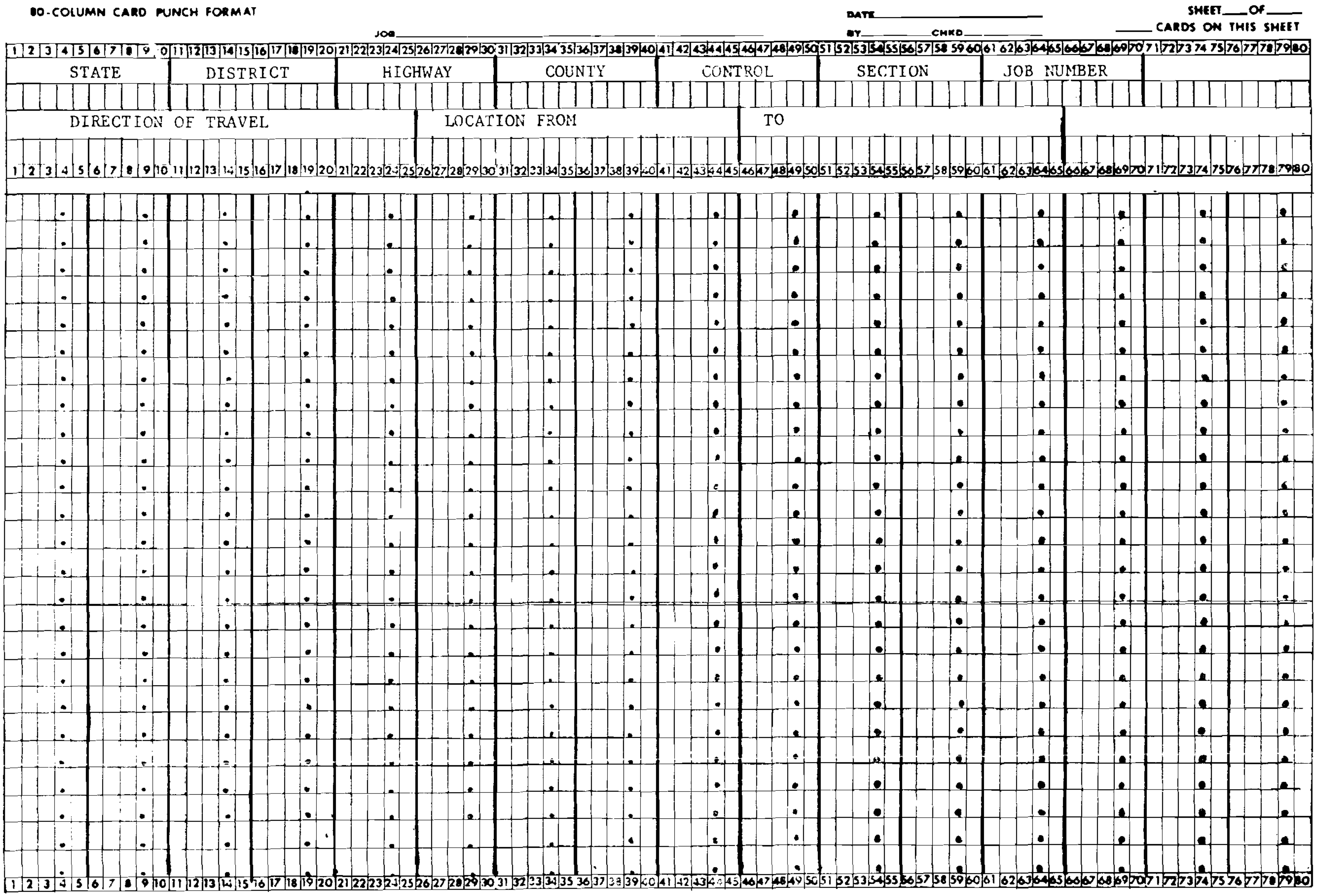
CRCP CONDITION SURVEY

DISTRICT	CONTROL	SECT.	HIGHWAY	AGE (F10.0)		DIR	COUNTY	JOB	CFHR NO.		MO DAY YEAR

	LOCATION FROM	TO	

MILE POST	MILE POINT	COMMENTS [BRIDGES OVERLAYS LANDMARKS]	SPALLING		PUMPING		PUNCH OUTS MINOR		PUNCH OUTS SEVERE		REPAIR PATCHES ASPHALT CONCRETE	REPAIR PATCHES P.C. CONCRETE	RIDING QUALITY
			MINOR NO. OF CRACKS	SEVERE NO. OF CRACKS	MINOR %	SEVERE %	<20FT	>20FT	<20FT	>20FT	NO. OF OCCURRENCES	NO. OF OCCURRENCES	

Fig A.3. Form used in the 1978 rural conditon survey for CRCP in Texas.


80-COLUMN CARD PUNCH FORMAT

JOB ____ DATE ____ BY ____ CHKD ____

SHEET ____ OF ____

____ CARDS ON THIS SHEET

STATE	DISTRICT	HIGHWAY	COUNTY	CONTROL	SECTION	JOB NUMBER

DIRECTION OF TRAVEL	LOCATION FROM	TO

Fig A.4. Crack spacing survey form for CRC pavements used in Texas in 1978.

CONDITION SURVEYS FOR PLAIN AND REINFORCED JOINTED CONCRETE PAVEMENT

This jointed pavement condition survey procedure has not been used to a large extent in the field. It is based on concepts used in the development of the CRCP condition survey procedure which has been used with success in the statewide condition survey in Texas.

In order to make the survey procedure as comprehensive as possible, a large number of different distress manifestations are observed. Reinforced and unreinforced pavements may exhibit different distress types. A transverse crack in an unreinforced pavement may cause more structural damage than a transverse crack in a reinforced pavement.

Different joint types may also exhibit different distress manifestations. For example, spalls along a wrinkled tin joint may be fairly deep before significant load transfer is lost at the joint. In the case of a dowelled joint, such a deep spall may result in further cracking and loss of load transfer.

In order to make the survey as objective as possible, most of the distress manifestations are counted and not estimated. In this manner no subjective measurement of the severity and extent of a distress manifestation will result. In the interests of speed, time consuming measurements are avoided.

Regular surveys of the distress manifestations should provide conclusive results regarding the significance of each type of distress in the gradual development of pavement failure.

Procedure for the Jointed Concrete Pavement Condition Survey

The procedure for the survey is as follows. The roadway is divided into sections which correspond to the SDHPT control sections and job numbers. The road is surveyed by two people who travel in a vehicle on the shoulder at approximately 5 miles per hour. Depending on the condition of the roadway, the driver and passenger may keep track of different distress manifestations. The driver will typically note distress manifestations which can be seen from a distance. This will enable the driver to concentrate on driving as well as surveying.

Distress Description for JCP and JRCP

Slab Associated Distress. These distress manifestations occur along the length of the slab and not in the vicinity of a joint. The first three distress manifestations relate only to jointed reinforced concrete pavement.

(a) Transverse Cracks. Transverse cracks occur at intervals along the slab. Transverse cracks in the vicinity of a joint, which may have resulted from some joint defect, do not fall into this category. Transverse cracks occur as a result of temperature drop stresses, drying shrinkage, and traffic loading.

(b) Spalled Transverse Cracks. Spalling is the widening of existing cracks by secondary cracking or breaking of the concrete at the edges. Spalling results from traffic loading and from stresses which occur because of material which enters the crack an resists thermal expansion. Both these situations result in high stresses in the upper edge of the concrete along the crack, and a spall results.

The number of spalled cracks in the outer lane is recorded. If the spall is less than an inch wide and deep and only a few of these spalls occur along the length of a crack, the crack is not counted as spalled. For a crack to be counted as spalled, a significant amount of spalling must have occurred and a drop in the riding quality of the pavement must result. If the spall has been patched, the spalled crack should be counted, not the patch.

(c) Faulted Transverse Cracks. Faulted transverse cracks occur as a result of a loss in subgrade support and traffic loading. The concrete in the immediate vicinity of the steel will break off and the final result will be the difference in the level of the slab across the crack. This will result in a significant loss of riding quality.

The number of faulted transverse cracks in the outer lane of the roadway per 0.2-mile section is recorded.

(d) Crack Slabs. Typical unreinforced slabs are 15 feet long. A crack in this type of slab results in two smaller slabs, which may begin to move under load. The number of cracked slabs in both the inside and the outside lane are counted. Corner breaks are not counted as cracked slabs, but rather as joints with cracking. If the joint side of the corner break triangle is longer than half a lane width, then the corner break is counted as a cracked slab. Longitudinal cracks may also result in cracked slabs.

(e) Shattered Slabs. These slabs are counted similarly to the cracked slabs except that the slab should be broken into three distinct pieces in order to be counted as a shattered slab.

(f) Slab Patches. The number of repair patches in both lanes of the roadway is recorded. Portland cement concrete and asphalt concrete patches are recorded separately. Neither the condition nor the size of the patch is recorded.

(g) Edge Pumping. Water passes through cracks in the pavement and penetrates the sublayers. When a load, such as a heavy vehicle passes over the crack, the water is forced out of the crack, taking fine material of the sublayers with it. This is defined as pumping. From the survey vehicle, pumping is generally evident from an accompanying stain on the shoulder of the road.

The length of the edge crack causing this staining is estimated and divided by the length of the section (approximately 1000 feet) to arrive at a percentage. Because it is difficult to estimate the length of the edge crack which is pumping, this result will be slightly subjective.

Joint-Associated Distress. This distress should be directly related to the joints in the pavement.

(a) Spalled Joints. Spalled joints occur in a manner similar to the occurrence of spalled cracks. The number of joints exhibiting spalls which are wider and deeper than one inch is recorded. The whole joint across both trafficked lanes should be examined for spalls.

(b) Faulted Joint. The number of faulted joints per 0.2-mile section are recorded. The joint should be examined across both lanes for faulting.

(c) Joints with Cracking. A large number of different crack types and patterns occur at joints. In order to simplify the recording of this distress form, all the crack types have been grouped under one heading. Figure A.3 shows a number of different crack patterns at a joint. The number of joints with cracking in every 0.2-mile section are recorded. The joint should be examined across both lanes widths for cracking.

(d) Patched Joints. When the cracking at a joint becomes severe, the joint is repaired with a patch. The number of patched joints per 0.2-mile section is recorded. The joint should be examined for patches in both trafficked lanes. Care must be taken to count a repaired spall in the spalled joint category rather than in this category.

(e) Bad Joint Sealant. Traffic and environment will cause a deterioration of the joint sealant in the pavement. Eventually some of the sealant will be stripped out of the joint and water may pass through the joint. The number of joints in which the sealant is significantly damaged is recorded. The joint should be examined across both lanes of the roadway.

(f) Pumping Joints. Once the joint sealant has failed, water may pass through the joint and pumping may occur. Telltale pumping stains will be removed by traffic in the dry season. Thus, if any accurate record of this distress manifestation is required, the condition survey should be carried out immediately after a period of rainfall. The number of joints exhibiting pumping in one 0.2-mile section is recorded. The joint should be examined across both traffic lanes for pumping.

JCP and JRCP Survey Form

A copy of the survey form is shown in Fig A.5. The form provides space to identify the county, district, highway, and direction, as well as the control, section, and job number. The exact location of the section must be fixed by relating the ends of the section to some detail which can be located on a map of the area. The date of the survey and the name of the survey team should also be entered on the sheet. The slab joint spacing is also entered on the field sheet.

JOINTED CONCRETE PAVEMENT CONDITION SURVEY

DIST.	CONTROL	SECT	JOB	HIGHWAY	DIR.	COUNTY	J. SPACING	AGE	MO DAY YEAR	TEAM	

LOCATION FROM	TO

MILE POST	MILE POINT	COMMENTS [OVERLAYS BRIDGES RAMPS LANDMARKS]	SLAB ASSOCIATED DISTRESS						JOINT ASSOCIATED DISTRESS						
			TRANSVERSE CRACKS			ASPHALT PATCHES [N°]	PCC PATCHES [N°]	EDGE PUMPING [FT]	SPALLED JOINTS [N°]	FAULTED JOINTS [N°]	CRACKING AT JOINTS [N°]	ASPHALT PATCHES [N°]	PCC PATCHES [N°]	BAD JOINT SEALANT [N°]	JOINT PUMPING [N°]
			N°	N° SPALLED	N° FAULTED										
1 2 3 4 5	6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80
1 2 3 4 5	6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80

Fig A.5. Field sheet for recording distress of jointed concrete pavements.

In the field, the only references to position are the mileposts. Further subdivision into 0.2-mile segments is facilitated by the trip recorder of the vehicle. In order to tie the various 0.2-mile sections in with SDHPT records, space is provided for the mile points of the highway. These mile points can be obtained from road logs.

Between the column provided for mile points and the column for the number of spalled transverse cracks, space is provided for comments about bridges and other structures or landmarks within the 0.2-mile section. The observed quantities of the various distress manifestations should be right-justified on the field sheets.

Although distress manifestations are observed between, for example, mileposts 128.8 and 128.6, the rows of the field sheet are not staggered as one would expect in order to note the distress between the mileposts: for ease of computation, the distress manifestations are noted in the same row as the preceding milepost. If for example, 100 minor spalled cracks were counted when traveling from milepost 128.8 to milepost 128.6, this figure would be written in the same row as milepost 128.8. When travelling in the opposite direction, from milepost 128.6 to milepost 128.8, the observations would be noted in the same row as milepost 128.6.

CONDITION SURVEY OF OVERLAID SECTIONS

Procedure

The overlays that are currently monitored by the CTR fall in the category of experimental sections. That is, the condition survey procedure is of the detailed type; nevertheless, the additional information is not detailed to the standard of the condition survey.

The distress manifestations are sketched on a sheet of opaque plastic. The same sheet is used in follow up surveys using different colors. Once in the office, the information is transferred into the survey form and input into the computer.

Distress Descriptions of Overlaid Sections

The distress manifestations surveyed are described in the following paragraphs. Only the AC overlays are considered since the distress manifestations of rigid overlays are similar to the ones in rigid pavements.

Reflection Cracking. Cracks and joints of the underlaying pavement may reflect into the upper layer. The before overlaying condition is recorded and if a crack appears in the same location after the overlay is placed it is recorded as a reflected crack.

Failures. Punchouts and patches which have reflected through and which will soon require patching are named failures.

Patches. Repaired failures found in the overlay are recorded as patches.

Bond Failures. Bond failures can be described as areas of the pavement where the asphalt overlay has separated from the underlying layer, exposing the original pavement.

Rut Depth. A form of surface distortion which is manifested as a longitudinal depression along the wheel path.

Overlaid Sections Survey Form

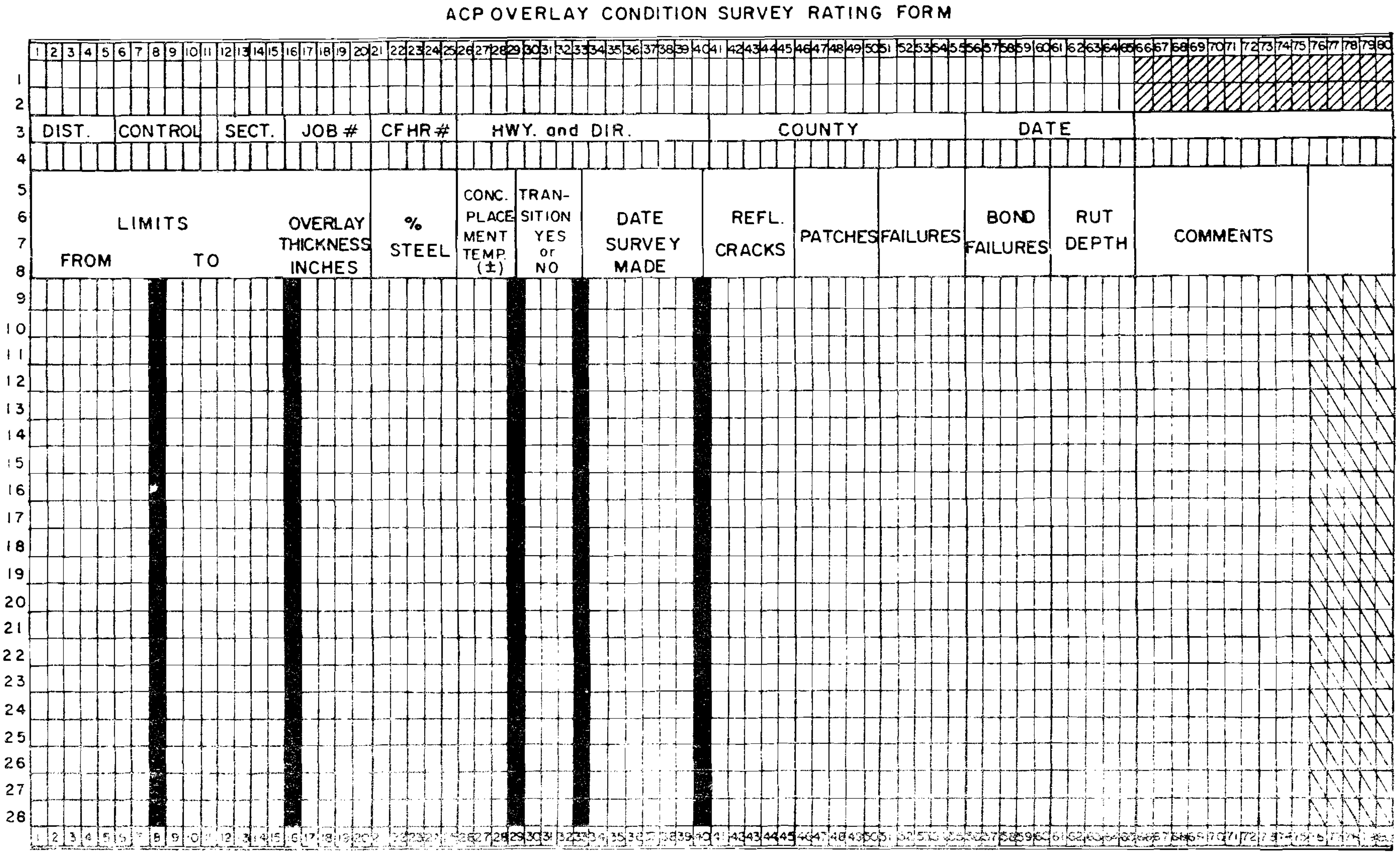
In Fig A.6 the condition survey form for the overlays is presented. Space is included in the form to enter the project identification: district, control, section, job number, CTR number, highway and direction, and county; using an 80 space format, fields are provided to record all the distress manifestations mentioned above. Note that the number of manifestations is entered in each field except for rut depth, which is measured and recorded using inches as unit.

CONDITION SURVEY OF SMALL SECTIONS (EXPERIMENTAL)

In order to standardize the condition surveying of small sections of CRC pavement, a survey procedure was developed. This procedure is used on short sections of road which need to be surveyed. The distress manifestations measured are the same as those in a more general survey but the exact location of each distress is properly recorded.

Survey Procedure and Forms for Small Sections

This survey procedure should be applied only to sections of road which are shorter than 1,000 feet. The persons making the survey walk along the side of the road while measuring the distance to the various distress manifestations with a rolotape. All the distress manifestations are sketched on a sheet of opaque plastic. The advantage of this type of survey procedure is that the initial distress need be plotted only once. All subsequent distress manifestations are merely added to those which already exist on the


ACP OVERLAY CONDITION SURVEY RATING FORM

DIST. | CONTROL | SECT. | JOB # | CFHR # | HWY. and DIR. | COUNTY | DATE

LIMITS FROM TO | OVERLAY THICKNESS INCHES | % STEEL | CONC. PLACEMENT TEMP. (±) | TRANSITION YES or NO | DATE SURVEY MADE | REFL. CRACKS | PATCHES | FAILURES | BOND FAILURES | RUT DEPTH | COMMENTS

Fig A.6. AC overlay condition survey form.

sheet. Different colors may be used for different surveys in order to show the development of distress. A copy of such an opaque sheet is shown in Fig A.7. The number of spalled cracks and the linear feet of pumping observed along the edge of the roadway are not sketched on the survey sheet. These distress manifestations can be entered onto the survey form directly at the site, or a separate note can be made for subsequent transfer to the survey form in the office.

Once all the distress manifestations have been marked on the sheet the survey in the field is complete. In the office, the number of individual distress manifestations is taken off the sheet and transferred to a survey form. The form is shown in Fig A.8. Space should be left on the survey form for subsequent surveys of a particular section. This is shown in Fig A.8.

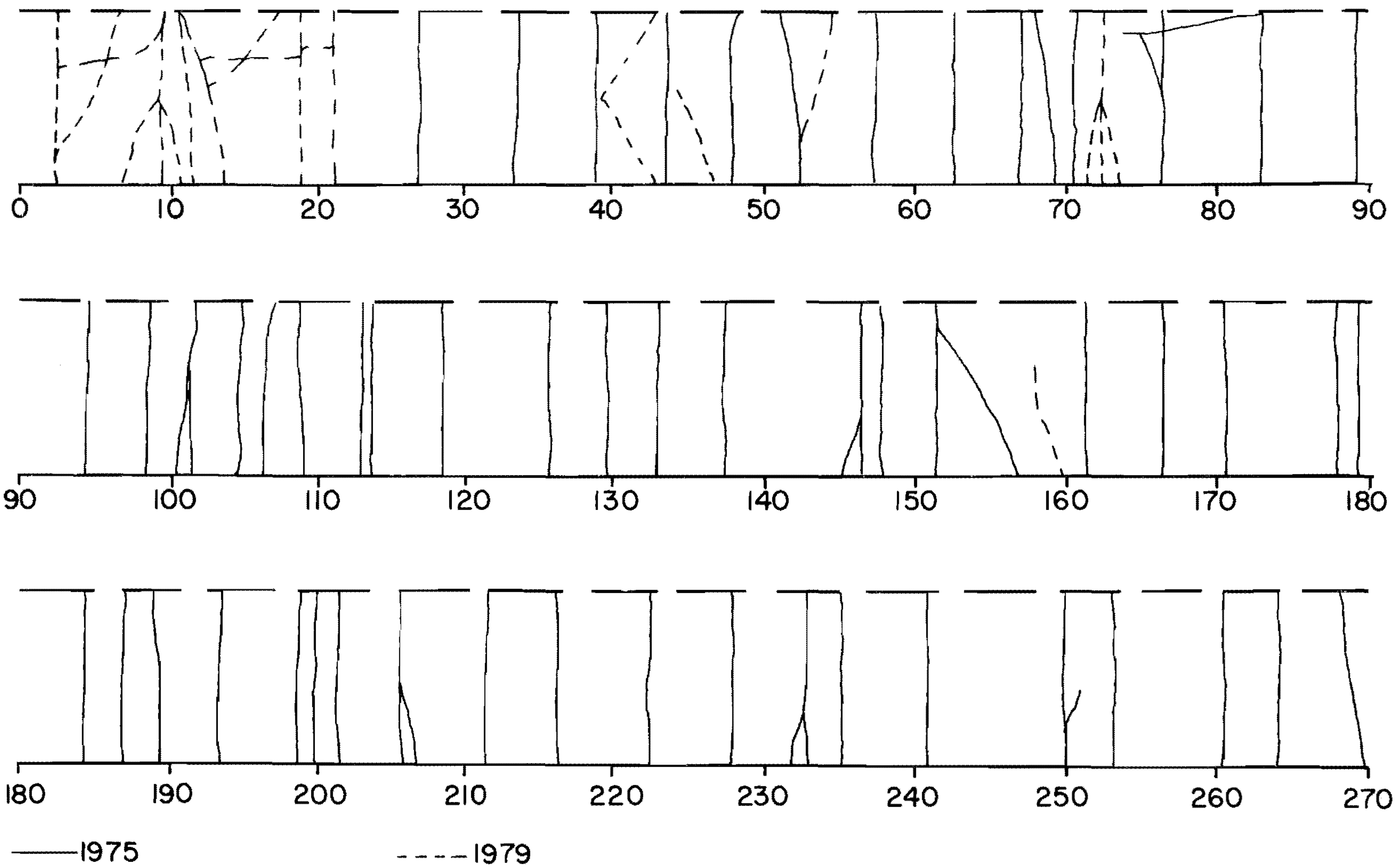


Fig A.7. Copy of field map used to record distress manifestation in small (experimental) pavement sections.

CRC PAVEMENT CONDITION SURVEY FORM FOR SMALL SECTIONS

DISTRICT	CONTROL	SECTION	JOB Nº	CFTR #	HIGHWAY AND DIRECTION	COUNTY	DATE

LOCATIONS		COMMENTS	DATE OF SURVEY	NUMBER OF CRACKS	NUMBER OF SPALLED CRKS		PUNCHOUTS				PATCHES		PUMPING	
							MINOR		SEVERE					
FROM	TO				MINOR	SEVERE	< 20'	> 20'	<20'	> 20'	A.C.	PCC	MINOR	SEVERE
1–8	9–16	17–33	34–40	41–46	47–50	51–54	55–57	58–60	61–63	64–66	67–69	70–72	73–76	77–80

Fig A.8. CRCP condition survey form for small sections.

APPENDIX B

FORTRAN LISTING OF THE REHABILITATION SCHEDULING PROGRAM PRPØ1

```
      PROGRAM PRP01(INPUT,OUTPUT,TAPE6=INPUT)
C ******************************************************************
C
C      COMPUTER PROGRAM WRITTEN BY M.GUTIERREZ DE V.
C      CENTER FOR TRANSPORTATION RESEARCH
C      UNIVERSITY OF TEXAS AT AUSTIN
C      MARCH 1982
C
C ******************************************************************
C
C
C
C      THIS PROGRAM PRIORITIZES A SET OF RIGID PAVEMENTS
C      (JCP,JRCP,AND CRCP) FOR REHABILITATION WITHIN A
C      GIVEN TIME PERIOD. THE PRIORITIZATION PROCEDURE
C      IS PERFORMED USING A DISTREX INDEX FOR EACH
C      PAVEMENT TYPE AND SEVERAL DISTRESS PREDICTION
C      EQUATIONS. BUDGET CONSTRAINTS CAN BE CONSIDERED
C      IN THE PRIORITIZATION PROCEDURE.
C
C
C
      DIMENSION    TITLE1(6),   TITLE2(6),   B(20),       DT1(500),
     1             DT2(500),    DT3(500),    AGE(500),    ESAL(500),
     2             G(500),      XLNT(500),   XNL(500),    NPT(500),
     3             IND(500),    ZETA(500),   Z0(500),     XMP(500),
     4             SECID(500),  COST(500),   TH(500),     SZETA(20),
     5             AZETA(20),   AXLNT(20),   AC(20)
      NPAGE=1
C
C      *** READ AND PRINT INPUT DATA
C
C      ** PRINT HEADINGS
      PRINT 800
      PRINT 805
      PRINT 810
      PRINT 805
C
C      **INPUT DATA
C
C      TITLE1(L) = ALPHANUMERIC FIELD FOR DESCRIPTION OF PROBLEM.
C      TITLE2(L) = IBIDEM.
      READ(6,815)(TITLE1(L),L=1,6)
      READ(6,815)(TITLE2(L),L=1,6)
      PRINT 816,(TITLE1(L),L=1,6)
      PRINT 817,(TITLE2(L),L=1,6)
C
C      NSW1 = SWITCH TO CONSIDERE BUDGET CONSTRAINTS,
C             IF 0 BUDGET IS NOT CONSIDERED,
C             IF 1 BUDGET IS CONSIDERED.
C      NPER = ANALYSIS PERIOD, YEARS.
      READ(6,820)NSW1,NPER
      PRINT 821,NPER
      IF(NPER-10)101,101,100
  100 PRINT 822
      STOP
C
C      * CHECK OF NSW1 TO FIND OUT IF CONSTRAINTS ARE TO BE
C        READ.
  101 IF(NSW1)104,103,104
  103 PRINT 824
```

```
      GO TO 110
  104 IF(NSW1.EQ.1)GO TO 105
      PRINT 825
      STOP
  105 PRINT 830
C
C     B(J) = BUDGET IN DLLS. FOR EACH YEAR, J=1,NPER.
C             IF NSW1=0 THIS CARD IS NOT REQUIRED.
      READ(6,835)(B(J),J=1,NPER)
      PRINT 836
      PRINT 837,(J,B(J),J=1,NPER)
      PRINT 838
C
C     COL = COST OF OVERLAY, DLLS./IN. PER SQ.FT.
  110 READ(6,840)COL
      PRINT 841,COL
C
C     NSEC = TOTAL NUMBER OF SECTION OF ALL TYPES
C     NI1 = NUMBER OF SECTIONS OF TYPE 1, JCP AND JRCP.
C     NI2 = NUMBER OF SECTIONS OF TYPE 2, CRCP.
      READ(6,845)NSEC,NI1,NI2
      IF(NSEC-NI1-NI2)115,120,115
  115 PRINT 846
      STOP
C
C     NSW2 = SWITCH TO PRINT OUT INPUT INFORMATION
C             IF 0 INPUT IS NOT PRINTED
C             IF 1 INPUT IS PRINTED.
  120 READ(6,850)NSW2
      IF(NSW2.EQ.0)GO TO 130
      IF(NSW2.EQ.1)GO TO 125
      PRINT 851
      STOP
  125 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      PRINT 816,(TITLE1(L),L=1,6)
      PRINT 817,(TITLE2(L),L=1,6)
      PRINT 853
      PRINT 854
      NLINE=26
C
C     ** DISTRESS MANIFESTATIONS AND SECTION INFO.:
C
C     SECID(I) = ALPHANUMERIC SECTION IDENTIFICATION.
C     FOR JCP AND JRCP: DT1(I) = CRACKING AND PATCHING,
C                                FT. PER 1000 SQ.FT.
C                       DT2(I) = JOINTS AND CRACKS SPALLING,
C                                PERCENT.
C                       DT3(I) = FAULTING, IN. PER 1000 FT.
C
C     FOR CRCP: DT1(I) = CRACKING AND PATCHING,
C                        NUMBER PER MILE.
C               DT2(I) = PERCENT MINOR SPALLING.
C               DT3(I) = PERCENT SEVERE SPALLING.
C     AGE(I) = SECTION AGE AT TIME OF CONDITION SURVEY.
C     ESAL(I) = CUMULATIVE EQUIVALENT SINGLE AXLE LOAD
C               APPLICATIONS AT TIME OF CONDITION SURVEY.
C     G(I) = ESAL GROWTH RATE.
C     XLNT(I) = SECTION LENGTH.
C     XNL(I) = NUMBER OF LANES IN SECTION.
C
  130 SUMX=0.0
```

```
      SUMI1=0.0
      SUMI2=0.0
      DO 200 I=1,NSEC
      READ(6,855)SECID(I),DT1(I),DT2(I),DT3(I),AGE(I),ESAL(I),
     1            G(I),XLNT(I),XNL(I)
      IND(I)=I
      TH(I)=0.0
      SUMX=SUMX+XLNT(I)
C     IND(I) = INDICATOR USED IN THE SORTING SUBROUTINE.
      IF(I.GE.NI1+1)GO TO 135
      NPT(I)=1
      SUMI1=SUMI1+XLNT(I)
C     NPT(I) = INDICATOR OF PAVEMENT TYPE:
C              1 FOR JCP AND JRCP,
C              2 FOR CRCP,
C              3 FOR AC OVERLAYS.
      GO TO 140
  135 NPT(I)=2
      SUMI2=SUMI2+XLNT(I)
  140 IF(NSW2.EQ.0)GO TO 200
      PRINT 856,SECID(I),DT1(I),DT2(I),DT3(I),AGE(I),ESAL(I),
     1           G(I),XLNT(I),XNL(I)
      NLINE=NLINE+1
      IF(NLINE-57)200,200,145
  145 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      NLINE=1
  200 CONTINUE
C
      PRINT 823,NI1,SUMI1,NI2,SUMI2,NSEC,SUMX
      J=0
C
      DO 201 I=1,NSEC
      GO TO(146,147)NPT(I)
  146 CALL ZETA1(DT1(I),DT2(I),DT3(I),ZETA(I))
      GO TO 201
  147 CALL ZETA2(DT1(I),DT2(I),DT3(I),ZETA(I))
  201 CONTINUE
C
      IF(NPER.NE.0)GO TO 149
      CALL INDSRT(ZETA,IND,NSEC)
C
C
C     FIRST ALTERNATIVE
C
C     IF NPER=0 A LIST OF PRIORITIZED PAVEMENT SECTIONS,
C     AT THE TIME OF THE CONDITION SURVEY, IS PRINTED.
C
      NPAGE=NPAGE+1
      PRINT 852,NPAGE
      PRINT 816,(TITLE1(L),L=1,6)
      PRINT 817,(TITLE2(L),L=1,6)
      PRINT 2853
 2853 FORMAT(5X,*LIST OF PRIORITIZED SECTIONS AT TIME OF CS*,//)
      PRINT 1903
      PRINT 2855
 2855 FORMAT(3X,*SECTION*,5X,*DISTRESS*,2X,*CUMULATIVE*,6X,*RANK*,/,
     1       6X,*ID*,8X,*INDEX*,8X,*ESAL*,/,
     2       25X,*(MILLIONS)*,/)
      PRINT 1903
      NLINE=22
C
```

```
      DO 202 I=1,NSEC
      K=IND(I)
      PRINT 858,SECID(K),ZETA(K),ESAL(K),I
      NLINE=NLINE+1
      IF(NLINE-57)202,202,1202
 1202 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      NLINE=1
  202 CONTINUE
      PRINT 1903
      GO TO 900
C
C
C     *** COMPUTATIONS
C
  149 IF(J.EQ.NPER)GO TO 901
      J=J+1
      AC(J)=0.0
      AXLNT(J)=0.0
      SZETA(J)=0.0
C
C
      DO 220 I=1,NSEC
      IND(I)=I
      COST(I)=0.0
      GO TO(151,152,153)NPT(I)
  151 CALL PRED1(DT1(I),DT2(I),DT3(I),AGE(I),G(I),ESAL(I))
      CALL ZETA1(DT1(I),DT2(I),DT3(I),ZETA(I))
      GO TO 220
  152 CALL PRED2(DT1(I),DT2(I),DT3(I),AGE(I),G(I),ESAL(I))
      CALL ZETA2(DT1(I),DT2(I),DT3(I),ZETA(I))
      GO TO 220
  153 CALL PRE73(ZETA(I),Z0(I),AGE(I),G(I),ESAL(I),TH(I))
  220 CONTINUE
C
      CALL INDSRT(ZETA,IND,NSEC)
C
C
C     SECOND ALTERNATIVE
C
C     IF BUDGET CONSTRAINTS ARE NOT CONSIDERED, THE SELECTION
C     OF PAVEMENT SECTIONS TO BE OVERLAID IS MADE DEPENDING ON
C     THE MAGNITUD OF THE DISTRESS INDEX.
C
      NPAGE=NPAGE+1
      PRINT 852,NPAGE
      PRINT 816,(TITLE1(L),L=1,6)
      PRINT 817,(TITLE2(L),L=1,6)
      PRINT 1853
      PRINT 1854,J
      PRINT 903
      PRINT 1855
      PRINT 903
      NLINE=23
      IF(NSW1.EQ.1)GO TO 400
C
      DO 230 I=1,NSEC
      K=IND(I)
      IF(ZETA(K))155,155,154
C
C     AT THIS POINT SELECTION CAN BE MADE AMONG VARIOUS
C     MAINTENANCE POLICIES.
```

```
C
  154 XMP(K)=0.0
      SZETA(J)=SZETA(J)+ZETA(K)
      GO TO 230
  155 XMP(K)=1.0
      Z0(K)=ZETA(K)
      NPT(K)=3
      DT1(I)=0.0
      DT2(I)=0.0
      DT3(I)=0.0
      CALL THICK(Z0(K),TH(K))
      COST(K)=TH(K)*XLNT(K)*(63360.0*XNL(K))*COL
      AXLNT(J)=AXLNT(J)+XLNT(K)
      AC(J)=AC(J)+COST(K)
      PRINT 860,SECID(K),ZETA(K),ESAL(K),XLNT(K),COST(K),I
      SZETA(J)=SZETA(J)+ZETA(K)
      NLINE=NLINE+1
      IF(NLINE-57)230,230,1230
 1230 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      NLINE=1
  230 CONTINUE
C
      GO TO 158
C
C
C     THIRD ALTERNATIVE
C
C     IF BUDGET CONSTRAINTS ARE TO BE CONSIDERED, THE SELECTION
C     OF PAVEMENT SECTIONS IS MADE DEPENDING ON BUDGET AVAILABILITY.
C
  400 KOUNT=1
C
      DO 300 I=1,NSEC
      K=IND(I)
      Z0(K)=ZETA(K)
      CALL THICK(Z0(K),TH(K))
      IF(TH(K)-2.0)156,402,402
  402 COST(K)=TH(K)*XLNT(K)*(63360.0*XNL(K))*COL
      AC(J)=AC(J)+COST(K)
      IF(B(J)-AC(J))156,157,157
  157 AXLNT(J)=AXLNT(J)+XLNT(K)
      KOUNT=KOUNT+1
      NPT(K)=3
      XMP(K)=1.0
      DT1(K)=0.0
      DT2(K)=0.0
      DT3(K)=0.0
      PRINT 860,SECID(K),ZETA(K),ESAL(K),XLNT(K),COST(K),I
      SZETA(J)=SZETA(J)+ZETA(K)
      NLINE=NLINE+1
      IF(NLINE-57)300,300,1300
 1300 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      NLINE=1
  300 CONTINUE
C
      GO TO 158
C
  156 AC(J)=AC(J)-COST(K)
      DO 301 I=KOUNT,NSEC
      K=IND(I)
```

```
      SZETA(J)=SZETA(J)+ZETA(K)
      XMP(K)=0.0
C
C     AT THIS POINT SELECTION CAN BE MADE AMONG VARIOUS
C     MAINTENANCE POLICIES.
C
  301 CONTINUE
  150 XNSEC=FLOAT(NSEC)
      AZETA(J)=SZETA(J)/XNSEC
C
      PRINT 903
      PRINT 862,AZETA(J),AXLNT(J),AC(J)
      GO TO 149
C
C
C     FORMATS
C
  800 FORMAT(1H1)
  805 FORMAT(1X,//,20X,30H******************************)
  810 FORMAT(1X,/,25X,*    PROGRAM PRP01      *,
     1           /,25X,*   CTR - UT AUSTIN    *,
     2           /,25X,*  VERSION MAR 10,1982*)
  815 FORMAT(5X,6A10)
  816 FORMAT(1X,///,5X,6A10)
  817 FORMAT(5X,6A10,///)
  820 FORMAT(2I5)
  821 FORMAT(5X,*ANALYSIS PERIOD=*,I2,/)
  822 FORMAT(5X,*ANALYSIS PERIOD SHOULD BE SHORTER THAN 11 YRS.*,/)
  823 FORMAT(5X,*SUMMARY OF SECTIONS CONSIDERED IN THE ANALYSIS*,//,
     1          5X,46H----------------------------------------------,/,
     2          5X,*    SECTION        NO. OF         MILES          *,/,
     3          5X,*      TYPE        SECTIONS                       *,/,
     4          5X,46H----------------------------------------------,/,
     5          5X,*         1             *,I6,10X,F12.2,/,
     6          5X,*         2             *,I6,10X,F12.2,/,
     7          5X,46H----------------------------------------------,/,
     8          22X,I6,10X,F12.2)
  824 FORMAT(5X,*NO BUDGET CONSTRAINTS ARE TO BE CONSIDERED*,/)
  825 FORMAT(5X,*NSW1 SHOULD BE 0 OR 1*,/)
  830 FORMAT(1X,//,5X,*BUDGET CONSTRAINTS FOR EACH YEAR*,/,
     1                5X,*IN THE ANALYSIS PERIOD*,/,
     2                5X,*---------------------*,/)
  835 FORMAT((7F10.0))
  836 FORMAT(5X,*YEAR*,5X,*BUDGET*,/,
     1          5X,*----------------------*,/)
  837 FORMAT(5X,I3,4X,F12.0)
  838 FORMAT(5X,*----------------------*,//)
  840 FORMAT(F10.0)
  841 FORMAT(5X,*UNIT COST OF OVERLAYING=*,F6.3,
     1          1X,*DLLS./IN.PER SQ.FT.*,/)
  845 FORMAT(3I5)
  846 FORMAT(5X,*SOME MISTAKE IN THE NO. OF SECTIONS*,/)
  850 FORMAT(I5)
  851 FORMAT(5X,*NSW2 SHOULD BE 0 OR 1*,/)
  852 FORMAT(1H1,5X,*PROGRAM PRP01*,40X,*PAGE*,I3,///)
  853 FORMAT(5X,*ACCORDING TO YOU INPUT INFORMATION*,/,
     1          5X,*THE FOLLOWING DATA SET WAS READ*,//,
     2          5X,*FROM COL. TO COL.*)
  854 FORMAT(10X,* 1 -  7*,7X,*SECTION IDENTIFICATION*,/,
     1          10X,* 8 - 14*,7X,*DISTRESS TYPE 1*,/,
     2          10X,*15 - 21*,7X,*DISTRESS TYPE 2*,/,
     3          10X,*22 - 28*,7X,*DISTRESS TYPE 3*,/,
```

```
     4          10X,*29 - 35*,7X,*AGE OF PAVT AT CS*,/,
     5          10X,*36 - 42*,7X,*CUMULATIVE AXLE LOADS AT CS*,/,
     6          10X,*43 - 49*,7X,*ESAL GROWTH RATE*,/,
     7          10X,*50 - 56*,7X,*SECTION LENGTH*,/,
     8          10X,*57 - 63*,7X,*NUMBER OF LANES*,///)
  855 FORMAT(1X,A6,8F7.0)
  856 FORMAT(1X,A6,8F7.2)
  858 FORMAT(4X,A6,5X,2F10.3,5X,I5)
  860 FORMAT(4X,A6,2(2X,F10.3),2X,F10.2,2X,F12.0,2X,I3)
  862 FORMAT(1X,//,12X,F10.3,14X,F10.2,2X,F12.0)
 1853 FORMAT(5X,*LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY*)
 1854 FORMAT(5X,*YEARS AFTER CONDITION SURVEY=*,I3,////)
 1855 FORMAT(3X,*SECTION*,5X,*DISTRESS*,3X,*CUMULATIVE*,
     1          4X,*SECTION*,5X,*OVERLAY*,4X,*RANK*,/,
     2          5X,*ID*,10X,*INDEX*,8X,*ESAL*,
     3          7X,*LENGTH*,7X,*COST*,/,
     4          26X,*(MILLIONS)*,4X,*(MILES)*,5X,*(DLLS)*,//)
C
C
C      PRINTING OF SUMMARY TABLE FOR ALTERNATIVES 2 AND 3
C
  901 NPAGE=NPAGE+1
      PRINT 852,NPAGE
      PRINT 816,(TITLE1(L),L=1,6)
      PRINT 817,(TITLE2(L),L=1,6)
      PRINT 902
      PRINT 903
      PRINT 907
      PRINT 903
      SUMA1=0.0
      SUMA2=0.0
      SUMA3=0.0
      DO 904 J=1,NPER
      PRINT 905,J,AZETA(J),AXLNT(J),AC(J)
      SUMA1=SUMA1+AZETA(J)
      SUMA2=SUMA2+AXLNT(J)
      SUMA3=SUMA3+AC(J)
  904 CONTINUE
      PRINT 903
      XNPER=FLOAT(NPER)
      ASUMA1=SUMA1/XNPER
      PRINT 906,ASUMA1,SUMA2,SUMA3
  902 FORMAT(1X,///,15X,* SUMMARY TABLE *,///)
  907 FORMAT(5X,*YEAR*,11X,*AVG. DI*,8X,*LENGTH*,14X,*BUDGET*,/,
     1          35X,*(MILES)*,13X,*(DLLS)*,//)
  903 FORMAT(1X,35H-----------------------------------,
     1          35H-----------------------------------)
 1903 FORMAT(1X,25H-------------------------,
     1          25H-------------------------)
  905 FORMAT(1X,/,5X,I4,7X,F8.3,7X,F8.2,12X,F12.0)
  906 FORMAT(16X,F8.3,7X,F8.2,12X,F12.0)
C
C
  900 CALL EXIT
      END
C
C *****************************************************************
C
C
      SUBROUTINE PRED1(CRK,PS,FLT,AGE,G,ESAL)
C
C      THE FUNCTION OF SUBROUTINE PRED1 IS TO CALCULATE FUTURE
```

```
C      DISTRESS CONDITION OF THE JOINTED PAVEMENT SECTIONS
C      (JCP AND JRCP).
C
C      PARAMETERS:
C      CRK = CRACKING,FT PER 1000 SQ FT,
C      PS = PERCENT SPALLED JOINTS AND CRACKS,
C      FLT = FAULTING IN WHEELPATH,IN PER 1000 FT,
C      AGE = AGE OF PAVEMENT SECTION IN YEARS,
C      G = ESAL GROWTH RATE,
C      ESAL = CUMULATIVE EQUIVALENTE SINGLE AXLE LOADS.
C
       IF(CRK.EQ.0.0)CRK=1.0
       CRK=CRK*((AGE+1.0)*ESAL*(1.0+G)/(AGE*ESAL))
       BETA=((AGE+1.0)/AGE)*ALOG(1.0-PS/100.0)
       PS=100.0*(1.0-EXP(BETA))
       FLT=FLT*((1.0+G)**0.45)
       AGE=AGE+1.0
       ESAL=ESAL*(1.0+G)
       RETURN
       END
C
C *****************************************************************
C
C
       SUBROUTINE PRED2(FPM,PMS,PSS,AGE,G,ESAL)
C
C      THIS SUBROUTINE IS USED TO PREDICT THE FUTURE DISTRESS
C      CONDITION OF THE CRCP PAVEMENT SECTIONS.
C
C      PARAMETERS:
C      FPM = FAILURES PER MILE,
C      PMS = PERCENT MINOR SPALLING,
C      PSS = PERCENT SEVERE SPALLING,
C      AGE = AGE OF PAVEMENT SECTION IN YEARS,
C      G = ESAL GROWTH RATE,
C      ESAL = CUMULATIVE EQUIVALENTE SINGLE AXLE LOADS.
C
       IF(FPM.EQ.0.0)FPM=0.5
       FPM=(FPM+1.0)**((AGE+1.0)/AGE)-1.0
       BETA1=((AGE+1.0)/AGE)*ALOG(1.0-PMS/100.0)
       PMS=92.357-87.764*(EXP(BETA1))
       BETA2=((AGE+1.0)/AGE)*ALOG(1.0-PSS/100.0)
       PSS=93.804-92.857*(EXP(BETA2))
       AGE=AGE+1.0
       ESAL=ESAL*(1.0+G)
       RETURN
       END
C
C *****************************************************************
C
C
       SUBROUTINE PREZ3(ZETA,Z0,AGE,G,ESAL,TH)
C
C      THIS SUBROUTINE CALCULATES THE FUTURE DISTRESS
C      INDEX OF AN AC OVERLAID RIGID PAVEMENT SECTION.
C
C      PARAMETERS:
C      ZETA = DISTRESS INDEX,
C      Z0 = DISTRESS INDEX OF THE SECTION CONSIDERED
C           BEFORE OVERLAY WAS PLACED,
C      AGE = AGE OF PAVEMENT SECTION IN YEARS,
C      G = ESAL GROWTH RATE,
```

```
C      ESAL - CUMULATIVE EQUIVALENTE SINGLE AXLE LOADS,
C      TH - THICKNESS OF THE OVERLAY, INCHES.
C
       GAMMA=0.104*((1.0/TH)**2.0)
       ZETA=(GAMMA*Z0)+(1.0-GAMMA)
       AGE=AGE+1.0
       ESAL=ESAL*(1.0+G)
       RETURN
       END
C
C *************************************************************
C
C
       SUBROUTINE ZETA1(CRK,PS,FLT,ZETA)
C
C      THIS SUBROUTINE DETERMINES THE DISTRESS INDEX FOR
C      JOINTED PAVEMENT SECTIONS USING DISTRESS VALUES AS AN
C      INPUT.
C
       ZETA=1.0-0.028*CRK-0.006*PS-0.019*FLT
       RETURN
       END
C
C *************************************************************
C
C
       SUBROUTINE ZETA2(FPM,PMS,PSS,ZETA)
C
C      THIS SUBROUTINE DETERMINES THE DISTRESS INDEX FOR
C      CRC PAVEMENT SECTIONS USING DISTRESS VALUES AS AN
C      INPUT.
C
       ZETA=1.0-0.065*FPM-0.015*PMS-0.010*PSS
       RETURN
       END
C
C *************************************************************
C
C
       SUBROUTINE THICK(Z0,TH)
C
C      THIS SUBROUTINE CALCULATES A RECOMMENDED THICKNESS
C      FOR AC OVERLAYS ON RIGID PAVEMENTS. THIS THICKNESS
C      IS APPROXIMATE AND NEEDS TO BE CORROBORATED BY MORE
C      ACCURATE DESIGN PROCEDURES.
C
       TH=5.69*(1.0-Z0)**0.5
       RETURN
       END
C
C *************************************************************
C
C
       SUBROUTINE INDSRT(X,IND,N)
C
C      INDSRT ACCEPTS AN ARRAY OF KEYS OR DATA ITEMS AND RETURNS
C      AN ASSOCIATED ARRAY OF INDICES SORTED ACCORDING TO THE
C      ORDER OF THE KEYS.
C
C      PARAMETERS:
C      X - ARRAY OF KEYS IN RELATION TO WHICH THE INDICES ARE
C          TO BE SORTED IN ASCENDING ORDER (X IS NOT MODIFIED);
```

```
C       IND = ARRAY OF INDICES POINTING TO ELEMENTS OF X;
C       N = NUMBER OF ELEMENTS IN ARRAYS X AND IND,
C            IF N IS NEGATIVE, IND IS NOT INITIALIZED AND THE ORDER
C            OF ANY PREVIOUS SECONDARY SORTS IS PRESERVED.
C
C       ALGORITHM TAKEN FROM GROGONO,*PROGRAMMING IN PASCAL*,P.168.
C
        DIMENSION X(N),IND(N)
        LOGICAL DONE
C
C
C       ** INITIALIZE ARRAY OF INDICES
        IF (N .LT. 0)  GO TO 6
        DO 5 I=1,N
      5 IND(I) = I
      6 CONTINUE
C
        JUMP = IABS( N/2 )
C
C       ** JUMP-SIZE LOOP
     10 CONTINUE
C
C       ** LOOP TO SCAN ARRAY UNTIL NO MORE INTERCHANGES ARE POSSIBLE
C
C       ** WITH CURRENT VALUE OF  JUMP .
     20 CONTINUE
        DONE=.TRUE.
C
C             ** LOOP TO MAKE ONE SCAN OF DATA
              DO 30 I=1,(N-JUMP)
                 J = I+JUMP
                 IF ( X(IND(I)) .LE. X(IND(J)) )  GO TO 30
C
C                ** MAKE INTERCHANGE
                 ITEMP = IND(I)
                 IND(I) = IND(J)
                 IND(J) = ITEMP
                 DONE = .FALSE.
     30       CONTINUE
        IF(.NOT.DONE)GO TO 20
        JUMP=JUMP/2
        IF(JUMP.GT.0)GO TO 10
        RETURN
        END
C
C
C ****************************************************************
```

APPENDIX C

INPUT GUIDE TO THE PROGRAM PRPØ1

APPENDIX C. INPUT GUIDE TO THE PROGRAM PRP01

DESCRIPTION

The computer program PRP01 prioritizes a set of rigid pavements (JCP, JRCP and CRCP) for rehabilitation within a specified time period. The input data are distress condition survey information on the current state of the pavement sections to be analyzed. The prioritization procedure is based on a distress index which results from the combination of several distress types. Future condition of the pavement is estimated using distress predicition models. In addition, budget constraints can be considered in the prioritization procedure.

LIMITATIONS

(1) Only rigid pavements (JCP, JRCP, and CRCP) are processed by the computer program.
(2) The analysis period should be less than 10 years.
(3) The maximum number of pavement sections is 500.

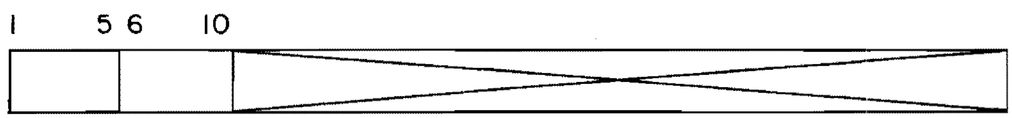
INPUT CARDS

The notation CC refers to card columns, with the range of columns being inclusive. All REAL values are punched with a decimal point as a part of the value and all INTEGER values are punched without a decimal point and right justified in the data field.

Card Type 1 (2 cards)

CC 6-60 (ALPHANUMERIC) any combination of alphanumeric characters may be used to identify the problems to be solved.

Card Type 2



CC 1-5 (INTEGER) switch to specify if budget constraints are to be considered; if 0 budget is not considered, if 1 budget is considered.

CC 6-10 (INTEGER) analysis period, years; from 0 to 10 years are processed by the program.

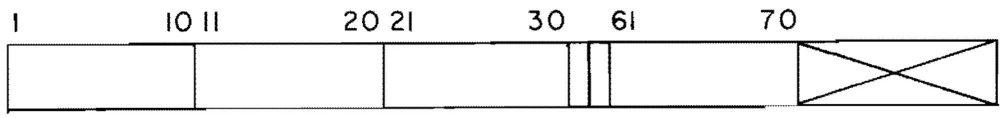
The program provides for the following alternatives:

(a) Prioritized list of pavement sections for rehabilitation using the condition survey information; thus alternative is run by making the analysis period equal to zero.

(b) Multiperiod rehabilitation schedule without budget constraints; to run this alternative the budget switch should be euqal to zero.

(c) Multiperiod rehabilitation schedule with budget constraints; to run this alternative the budget switch should be equal to one.

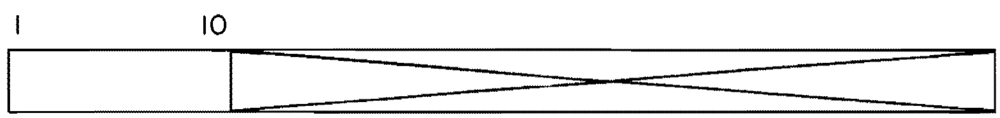
<u>Card Type 3</u> (one or two cards, as needed; cards required only if the budget switch in Card Type 2 is equal to one)



CC 1-10 (REAL) budget constraint specified for the first year in the analysis period. CC 11-20 (REAL) budget constaint specified for the second year in the analysis period.

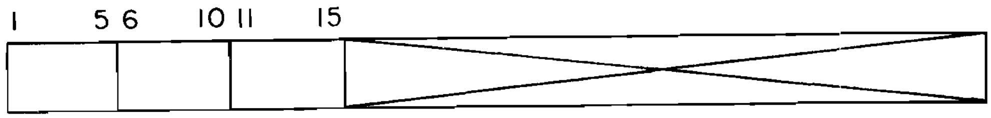
CC 61-70 (REAL) budget constraint specified for the seventh year in the analysis period.

<u>Card Type 4</u>



CC 1-10 (REAL) cost of overlay, dlls./in per square foot; a detailed analysis needs to be carried out to determine this cost figure which should include all of the agency costs.

Card Type 5

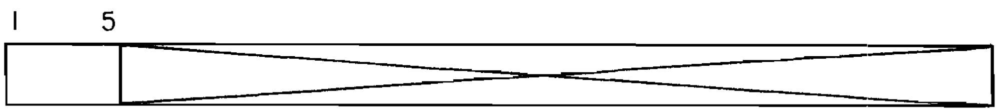


CC 1-5 (INTEGER) total number of pavement sections to be processed by the program.

CC 6-10 (INTEGER) number of jointed sections (JCP and JRCP).

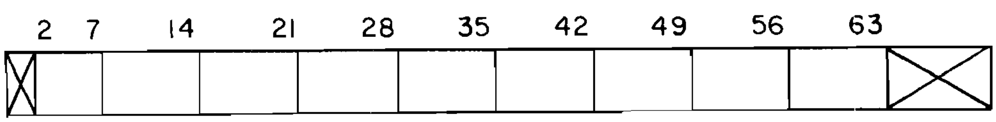
CC 11-15 (INTEGER) number of continuous sections (CRCP).

Card Type 6



CC 1-5 (INTEGER) switch to print input informations; if 0 input is not printed, if 1 input is printed.

Card Type 7 (as many cards as number of sections specified)



CC 2-6 (ALPHANUMERIC) section identification.

If jointed pavement section (JCP and JRCP):

CC 7-13 (REAL) cracking and patching, number per mile.

CC 14-20 (REAL) joint and crack spalling, percent.

CC 21-27 (REAL) faulting, number per mile.

If continuous pavement sections (CRCP):

CC 7-13 (REAL) punchouts and patching, number per mile.

CC 14-20 (REAL) percent minor spalling.

CC 21-27 (REAL) percent severe spalling.

CC 28-34 section age at time of condition survey, years.

CC 35-41 cumulative equivalent single axle load applications at time of survey, ESAL-18R.

CC 42-48 ESAL growth rate.

CC 49-55 section length, miles.

CC 56-62 width of the pavement section including shoulders.

APPENDIX D

SAMPLE INPUT AND OUTPUTS OF THE PROGRAM PRPØ1

APPENDIX D. SAMPLE INPUT AND OUTPUTS TO THE PROGRAM PRP01

This appendix contains sample input and outputs of the program PRP01 as follows:

(1) Sample INPUT.

(2) Sample OUTPUT using alternative 1, i.e., printing of a prioritized list of pavement sections for rehabilitation using the condition survey directly.

(3) Sample OUTPUT using alternative 2, i.e., printing of a multiperiod rehabilitation schedule without considering budget constraints.

(4) Sample OUTPUT using alternative 3, i.e., printing of a multiperiod rehabilitation schedule taking into acount budget constraints.

The information contained in the sample INPUT is real CRCP field information collected in east Texas in 1980. Therefore, the runs presented are of direct use to the Texas State Department of Highways and Public Transport to assess the current condition of its CRCP network and the needs of rehabilitation in the next few year presented.

SAMPLE INPUT

```
      PRIORITY LIST OF TX CRCP FOR REHABILITATION
      INPUT DATA FROM 1980 CONDITION SURVEY
    1    10
30000000. 30000000. 30000000. 30000000. 30000000. 30000000. 30000000.
30000000. 30000000. 30000000.
     9.25
  139      139
```

101 EB	6.00	30.00	.70	17.00	5.92	.08	5.80	2.00
101 WB	2.30	33.00	.20	17.00	5.92	.08	5.60	2.00
102 EB	8.90	34.60	.40	17.00	5.45	.08	1.80	2.00
102 WB	11.10	28.20	.40	17.00	5.45	.08	1.80	2.00
104 EB	2.20	35.80	1.10	16.00	5.44	.08	5.40	2.00
104 WB	2.20	55.50	.50	16.00	5.44	.08	5.40	2.00
105 EB	2.50	39.60	.60	15.00	5.03	.09	5.20	2.00
105 WB	4.80	56.80	.70	15.00	5.03	.09	5.40	2.00
108 NB	4.00	30.30	1.70	14.00	3.25	.04	9.00	2.00
108 SB	13.20	27.70	1.70	14.00	3.25	.04	9.20	2.00
112 NB	1.00	13.80	3.60	11.00	2.56	.05	2.00	2.00
113 NB	1.20	20.10	4.60	10.00	2.56	.05	10.20	2.00
113 SB	2.50	16.90	1.10	10.00	2.56	.05	2.00	2.00
904 NB	8.90	20.20	2.90	16.00	7.22	.06	1.90	2.00
904 SB	36.10	16.00	5.20	16.00	7.22	.06	1.80	2.00
905 NB	8.70	18.60	1.00	16.00	6.76	.16	.80	2.00
905 SB	3.70	19.00	2.40	16.00	6.76	.16	.80	2.00
907 NB	20.00	8.90	4.20	14.00	5.83	.14	1.00	2.00
907 SB	0	12.70	9.00	14.00	5.83	.14	1.00	2.00
908 NB	0	8.20	0	10.00	5.60	.08	.80	2.00
908 SB	0	11.10	.60	10.00	5.60	.08	.80	2.00
1007EB	20.60	63.50	1.30	15.00	5.83	.06	4.80	2.00
1001EB	21.80	68.20	5.00	18.00	5.70	.07	4.00	2.00
1005EB	3.90	53.00	.90	16.00	4.99	.08	8.20	2.00
1004EB	9.40	55.60	6.80	17.00	5.68	.07	8.00	2.00
1002EB	4.50	60.10	.60	17.00	5.86	.07	6.60	2.00
1003EB	10.50	38.90	1.00	17.00	5.95	.06	6.20	2.00
1009EB	8.00	42.10	.50	15.30	5.61	.05	7.60	2.00
1010EB	14.70	51.50	1.10	15.00	5.13	.06	7.40	2.00
1014EB	29.50	50.20	2.40	15.00	5.16	.10	8.20	2.00
1008EB	19.80	31.40	.20	15.00	4.44	.15	4.80	2.00
1011EB	6.50	38.90	.40	14.00	4.63	.13	4.00	2.00
1012EB	5.60	39.70	.60	14.00	5.98	.09	6.40	2.00
1013EB	2.20	31.30	.10	14.00	5.72	.09	1.80	2.00
1011WB	9.30	48.50	.20	14.00	4.63	.13	4.00	2.00
1008WB	1.70	37.20	.40	15.00	4.44	.15	4.80	2.00
1014WB	15.10	57.50	.60	15.00	5.16	.10	8.40	2.00
1013WB	1.10	44.60	.40	14.00	5.72	.09	1.80	2.00
1010WB	8.80	57.40	1.20	15.00	5.13	.06	7.40	2.00
1009WB	5.40	50.60	.80	15.00	5.61	.05	7.80	2.00
1003WB	3.10	38.10	1.40	17.00	5.95	.06	6.20	2.00
1002WB	2.30	54.30	.90	17.00	5.86	.07	6.60	2.00
1004WB	18.40	61.10	8.10	17.00	5.68	.07	8.10	2.00
1005WB	1.80	57.10	.60	16.00	4.99	.08	8.40	2.00
1001WB	20.30	39.00	3.60	18.00	5.70	.07	3.60	2.00
1007WB	30.20	74.50	4.30	15.00	5.83	.06	5.00	2.00
1006WB	26.50	63.00	2.00	15.00	5.94	.06	5.20	2.00
1315EB	2.70	21.30	.50	9.00	1.65	.04	5.60	2.00
1315WB	3.00	26.60	.80	9.00	1.65	.04	5.60	2.00
1313EB	2.10	30.30	.90	11.00	1.91	.06	5.60	2.00
1313WB	10.90	44.30	1.80	11.00	1.91	.06	5.80	2.00
1314EB	0	17.30	0	11.00	1.15	.06	.40	2.00
1314WB	0	41.50	0	11.00	1.15	.06	.20	2.00

1311EB	.20	52.40	.70	12.00	1.22	.07	6.20	2.00
1311WB	4.40	52.70	1.20	12.00	1.22	.07	6.20	2.00
1306EB	3.60	38.40	6.70	12.00	1.82	.07	5.00	2.00
1306WB	14.20	46.60	3.10	12.00	1.82	.07	5.00	2.00
1307EB	2.20	46.30	4.50	12.00	1.51	.06	10.40	2.00
1307WB	8.30	44.50	3.80	12.00	1.51	.06	10.20	2.00
1303EB	14.50	52.80	12.90	18.00	2.02	.07	12.40	2.00
1303WB	15.70	64.50	8.50	18.00	2.02	.07	12.10	2.00
1312SB	1.10	34.60	18.60	12.00	1.16	.06	3.80	2.00
1325SB	0	24.00	.20	9.00	1.16	.06	.60	2.00
1305SB	6.00	58.60	41.40	13.00	1.49	.08	8.80	2.00
1305NB	1.90	37.30	39.50	13.00	1.49	.08	8.80	2.00
1308SB	1.30	45.10	11.00	12.00	1.40	.07	3.20	2.00
1308NB	.90	41.10	7.20	12.00	1.40	.07	3.40	2.00
1310SB	1.30	58.20	17.20	12.00	1.31	.07	1.60	2.00
1310NB	.60	53.70	18.60	12.00	1.31	.07	1.80	2.00
1309SB	1.00	34.10	6.60	12.00	2.67	.06	1.00	2.00
1309NB	1.00	46.70	16.80	12.00	2.67	.06	1.00	2.00
1702NB	.90	13.20	0	17.00	7.77	.06	13.80	2.00
1702SB	1.40	17.30	.10	17.00	7.77	.06	13.80	2.00
1703NB	2.30	7.30	1.00	13.00	5.74	.07	12.80	2.00
1703SB	8.50	11.60	2.00	13.00	5.74	.07	12.80	2.00
1704NB	2.10	9.50	3.80	13.00	5.74	.07	6.10	2.00
1704SB	6.60	10.60	8.40	13.00	5.74	.07	5.60	2.00
1707NB	.60	9.10	0	11.00	5.10	.07	16.20	2.00
1707SB	2.20	9.10	.10	11.00	5.10	.07	16.00	2.00
1710NB	4.70	12.80	.30	9.00	4.78	.05	17.20	2.00
1710SB	5.40	20.80	.30	9.00	4.78	.05	17.00	2.00
1709NB	0	21.40	0	9.00	4.82	.06	.60	2.00
1709SB	0	26.70	.10	9.00	4.82	.06	.70	2.00
1708NB	3.30	7.80	.10	10.00	4.38	.06	12.20	2.00
1708SB	9.30	25.90	.40	10.00	4.38	.06	12.00	2.00
1706NB	7.10	35.00	.10	12.00	5.49	.06	2.40	2.00
1706SB	10.40	34.20	.90	12.00	5.49	.06	2.30	2.00
1901EB	3.30	15.50	1.70	16.00	6.55	.07	7.00	2.00
1902EB	26.10	12.70	17.00	16.00	5.77	.06	5.60	2.00
1904EB	11.20	31.40	0	15.00	6.16	.06	8.20	2.00
1905EB	.40	23.30	.10	14.00	4.87	.07	9.60	2.00
1906EB	36.30	44.20	1.90	14.00	5.31	.06	7.00	2.00
1907EB	6.70	29.10	0	14.00	5.31	.06	.30	2.00
1908EB	67.40	63.10	14.90	14.00	5.48	.08	9.80	2.00
1909EB	5.90	56.90	.50	14.00	6.42	.08	7.10	2.00
1911EB	1.10	5.30	42.90	14.00	4.40	.05	4.60	2.00
1914EB	1.50	2.20	7.90	13.00	3.76	.05	2.60	2.00
1915EB	7.40	40.20	.70	13.00	3.24	.14	3.40	2.00
1917EB	1.30	11.60	.20	10.00	3.90	.05	7.00	2.00
1918EB	1.30	14.30	0	9.00	3.47	.05	7.00	2.00
1919EB	1.60	13.30	.20	10.00	3.49	.05	10.00	2.00
1901WB	3.40	14.80	3.80	16.00	6.55	.07	7.10	2.00
1902WB	16.80	17.80	10.60	16.00	5.77	.06	6.20	2.00
1904WB	10.50	35.10	2.90	15.00	6.16	.06	8.20	2.00
1905WB	1.30	16.80	.40	14.00	4.87	.07	9.40	2.00
1906WB	23.40	31.70	1.00	14.00	5.31	.06	6.80	2.00
1908WB	39.70	36.40	8.90	14.00	5.48	.08	10.00	2.00
1909WB	2.30	63.80	.60	14.00	6.42	.08	7.00	2.00
1911WB	2.40	12.20	45.40	14.00	4.40	.05	4.20	2.00
1914WB	2.00	16.30	13.50	13.00	3.76	.05	3.00	2.00
1915WB	3.20	26.90	.50	13.00	3.24	.14	3.40	2.00
1917WB	.70	7.70	0	10.00	3.90	.05	7.00	2.00
1917WB	.70	7.70	0	10.00	3.90	.05	7.00	2.00
1918WB	1.00	8.10	0	9.00	3.47	.05	7.00	2.00
1919WB	1.70	10.50	.40	10.00	3.49	.05	10.00	2.00

2002NB	.70	5.90	1.80	18.00	4.75	.04	1.40	2.00
2005NB	1.10	9.40	3.10	17.00	3.72	.08	1.80	2.00
2006NB	3.30	6.30	2.80	17.00	5.17	.04	.90	2.00
2012NB	3.00	8.90	2.70	16.00	4.03	.07	1.00	2.00
2022NB	0	9.20	9.60	12.00	.73	.02	1.20	2.00
2023NB	0	8.80	1.30	10.00	4.71	.07	2.20	2.00
2002SB	1.90	3.60	1.50	18.00	4.75	.04	1.60	2.00
2005SB	1.30	14.00	4.60	17.00	3.72	.08	1.60	2.00
2006SB	1.10	13.10	6.80	17.00	5.17	.04	.90	2.00
2011SB	.90	2.30	.60	16.00	4.92	.07	3.20	2.00
2012SB	2.00	4.20	1.60	16.00	4.03	.05	1.00	2.00
2013SB	0	0	0	16.00	2.93	.07	.40	2.00
2015SB	11.40	10.30	16.70	14.00	4.39	.07	2.20	2.00
2022SB	2.50	1.90	2.50	12.00	.73	.02	1.20	2.00
2023SB	2.30	3.20	.60	10.00	4.71	.07	2.20	2.00
2009FB	22.50	29.40	.60	16.00	3.16	.05	8.00	2.00
2017FB	0	2.80	27.50	14.00	.86	.04	.70	2.00
2018FB	.70	7.10	27.40	14.00	.86	.04	2.80	2.00
2021FB	2.00	17.80	19.20	11.00	.64	.04	4.40	2.00
2001WB	12.00	11.10	14.30	18.00	1.40	.07	.50	2.00
2003WB	6.80	10.70	15.00	18.00	1.78	.07	4.00	2.00
2009WB	26.30	23.30	.30	16.00	3.16	.05	5.60	2.00
2019WB	.40	3.30	.20	13.00	1.65	.08	2.40	2.00
2026WB	1.70	3.50	1.10	9.00	1.35	.05	.60	2.00

SAMPLE OUTPUT - ALTERNATIVE 1

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        PROGRAM PRP01
       CTR - UT AUSTIN
     VERSION MAR 10,1982

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

ANALYSIS PERIOD=-0

NO BUDGET CONSTRAINTS ARE TO BE CONSIDERED

UNIT COST OF OVERLAYING= .250 DLLS./IN.PER SQ.FT.

SUMMARY OF SECTIONS CONSIDERED IN THE ANALYSIS

SECTION TYPE	NO. OF SECTIONS	MILES
1	-0	0
2	139	756.50
	139	756.50

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PRIORITIZED SECTIONS AT TIME OF CS

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	RANK
1908EB	-4.476	5.480	1
1908WB	-2.215	5.480	2
1007WB	-2.124	5.830	3
1906EB	-2.041	5.310	4
1014EB	-1.694	5.160	5
1006WB	-1.688	5.940	6
904 SB	-1.652	7.220	7
1001EB	-1.490	5.700	8
1007EB	-1.304	5.830	9
1004WB	-1.194	5.680	10
1303WB	-1.073	2.020	11
2009WB	-1.062	3.160	12
1902EB	-1.057	5.770	13
1906WB	-1.007	5.310	14
1001WB	-.941	5.700	15
2009EB	-.909	3.160	16
1303EB	-.864	2.020	17
1014WB	-.850	5.160	18
1008EB	-.760	4.440	19
1010EB	-.739	5.130	20
1305SB	-.683	1.490	21
1306WB	-.653	1.820	22
1004EB	-.513	5.680	23
907 NB	-.475	5.830	24
1902WB	-.465	5.770	25
1010WB	-.445	5.130	26
1313WB	-.391	1.910	27
1011WB	-.334	4.630	28
108 SB	-.290	3.250	29
1003EB	-.276	5.950	30
1307WB	-.245	1.510	31
1909EB	-.242	6.420	32
1904WB	-.238	6.160	33
1002EB	-.200	5.860	34
1904EB	-.199	6.160	35
1706SB	-.198	5.490	36

105 WB	-.171	5.030	37
1009EB	-.157	5.610	38
102 WB	-.149	5.450	39
1310SB	-.130	1.310	40
1009WB	-.118	5.610	41
1909WB	-.113	6.420	42
102 EB	-.101	5.450	43
1915EB	-.091	3.240	44
2001WB	-.090	1.400	45
1311WB	-.089	1.220	46
1305NB	-.078	1.490	47
2015SB	-.063	4.390	48
1005EB	-.058	4.990	49
1310NB	-.031	1.310	50
1011EB	-.010	4.630	51
1708SB	.003	4.380	52
1706NB	.013	5.490	53
104 WB	.019	5.440	54
1005WB	.021	4.990	55
1002WB	.027	5.860	56
1012EB	.035	5.580	57
1309NB	.067	2.670	58
904 NB	.090	7.220	59
1307EB	.118	1.510	60
1306EB	.123	1.820	61
1907EB	.128	5.310	62
1308SB	.129	1.400	63
905 NB	.146	6.760	64
101 EB	.153	5.920	65
1311EB	.194	1.220	66
1911WB	.207	4.400	67
1003WB	.213	5.950	68
1312SB	.223	1.160	69
105 EB	.238	5.030	70
2003WB	.248	1.780	71
1308NB	.253	1.400	72
1703SB	.253	5.740	73
1013WB	.256	5.720	74
108 NB	.269	3.250	75
104 EB	.309	5.440	76
1008WB	.327	4.440	77
1704SB	.328	5.740	78
1710SB	.334	4.780	79
101 WB	.353	5.920	80
1309SB	.358	2.670	81
1314WB	.377	1.150	82
1915WB	.383	3.240	83
1013EB	.391	5.720	84
1315WB	.398	1.650	85
1313EB	.400	1.910	86
2021EB	.411	.640	87
1911EB	.420	4.400	88
905 SB	.451	6.760	89
1914WB	.490	3.760	90
1710NB	.499	4.780	91
1315EB	.500	1.650	92
1901WB	.519	6.550	93

1901EB	.536	6.550	94
113 SB	.573	2.560	95
2018EB	.574	.860	96
113 NB	.574	2.560	97
1709SB	.596	4.820	98
1905EB	.623	4.870	99
1325SB	.638	1.160	100
2012NB	.644	4.030	101
1702SB	.648	7.770	102
2005SB	.660	3.720	103
1905WB	.660	4.870	104
2006NB	.663	5.170	105
2006SB	.664	5.170	106
1708NB	.667	4.360	107
1709NB	.679	4.820	108
2017EB	.683	.860	109
1704NB	.683	5.740	110
112 NB	.692	2.560	111
1919EB	.695	3.490	112
1918EB	.701	3.470	113
1707SB	.719	5.100	114
907 SB	.720	5.830	115
1919WB	.728	3.490	116
1703NB	.731	5.740	117
1917EB	.740	3.900	118
1314EB	.740	1.150	119
1702NB	.743	7.770	120
2005NB	.757	3.720	121
2022NB	.766	.730	122
2022SB	.784	.730	123
1914EB	.790	3.760	124
2012SB	.791	4.030	125
2023SB	.796	4.710	126
2002SB	.808	4.750	127
1707NB	.824	5.100	128
2026WB	.826	1.350	129
908 SB	.828	5.600	130
1917WB	.839	3.900	131
1917WB	.839	3.900	132
2002NB	.848	4.750	133
2023NB	.855	4.710	134
1918WB	.874	3.470	135
908 NB	.877	5.600	136
2011SB	.901	4.920	137
2019WB	.922	1.650	138
2013SB	1.000	2.930	139

SAMPLE OUTPUT - ALTERNATIVE 2

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        PROGRAM PRP01
       CTR - UT AUSTIN
     VERSION MAR 10,1982

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1984 CONDITION SURVEY


ANALYSIS PERIOD=10

NO BUDGET CONSTRAINTS ARE TO BE CONSIDERED

UNIT COST OF OVERLAYING=  .250 DLLS./IN.PER SQ.FT.

SUMMARY OF SECTIONS CONSIDERED IN THE ANALYSIS
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SECTION TYPE	NO. OF SECTIONS	MILES
1	0	0
2	139	756.50
	139	756.50

PROGRAM PRPM1 PAGE 2

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 1

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1908EB	-6.037	5.918	9.80	4686232.	1
1908WB	-3.055	5.918	10.00	3629770.	2
1906EB	-2.784	5.629	7.00	2454482.	3
1007WB	-2.617	6.180	5.00	1714050.	4
904 SB	-2.322	7.653	1.80	591402.	5
1014EB	-2.218	5.676	8.20	2651398.	6
1006WB	-2.123	6.296	5.20	1656546.	7
1001EB	-1.749	6.099	4.00	1195507.	8
1007EB	-1.617	6.180	4.80	1399609.	9
1902EB	-1.522	6.116	5.60	1603083.	10
2009WB	-1.522	3.318	5.60	1602953.	11
1906WB	-1.357	5.629	6.80	1921479.	12
1004WB	-1.426	6.078	8.10	2274259.	13
2009EB	-1.287	3.318	8.00	2180830.	14
1303WB	-1.241	2.161	12.10	3265159.	15
1001WB	-1.225	6.099	3.60	967917.	16
1008EB	-1.106	5.106	4.80	1255741.	17
1014WB	-1.067	5.676	8.40	2176828.	18
1303EB	-1.033	2.161	12.40	3187053.	19
1010EB	-.958	5.438	7.40	1866743.	20
1306WB	-.933	1.947	5.00	1253184.	21
907 NB	-.877	6.646	1.00	246949.	22
1305SB	-.755	1.609	8.80	2101669.	23
1902WB	-.750	6.116	6.20	1478541.	24
1313WB	-.622	2.025	5.80	1331354.	25
1004EB	-.615	6.078	8.00	1832703.	26
1010WB	-.554	5.438	7.40	1662639.	27
108 SB	-.532	3.380	9.20	2052866.	28
1011WB	-.476	5.232	4.00	876016.	29
1003EB	-.421	6.307	6.20	1332374.	30
1706SB	-.410	5.819	2.30	492294.	31
1904WB	-.408	6.530	8.20	1753988.	32
1307WB	-.400	1.601	10.20	2175739.	33
1904EB	-.386	6.530	8.20	1740206.	34
132 WB	-.318	5.886	1.80	372433.	35

1909EB	-.315	6.934	7.10	1467837.	36
2015SB	-.288	4.697	2.20	450067.	37
2001WB	-.281	1.498	.50	102014.	38
1009EB	-.277	5.891	7.60	1548188.	39
1002EB	-.233	6.270	6.60	1321222.	40
1708SB	-.233	4.643	12.00	2401506.	41
102 EB	-.230	5.886	1.80	359914.	42
1915EB	-.223	3.694	3.40	677844.	43
165 WB	-.223	5.483	5.40	1076418.	44
1009WB	-.188	5.891	7.80	1532554.	45
1311WB	-.161	1.305	6.20	1204129.	46
1319SB	-.150	1.402	1.60	309301.	47
1706NB	-.132	5.819	2.40	460305.	48
1305NB	-.126	1.609	8.80	1683397.	49
1909WB	-.126	6.934	7.00	1339066.	50
1011EB	-.120	5.232	4.00	763149.	51
1005EB	-.100	5.389	8.20	1550444.	52
904 NB	-.065	7.653	1.90	353485.	53
1012EB	-.061	6.082	6.40	1188348.	54
1310NB	-.052	1.402	1.80	332781.	55
935 NB	-.048	7.642	.80	144818.	56
104 WB	-.002	5.875	5.40	974142.	57

-.004		339.80	84224926.

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 2

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1703SB	-.133	6.572	12.80	2456138.	1
1907EB	-.132	5.966	.30	57531.	2
1710SB	-.006	5.270	17.00	3074274.	3
2003WB	-.002	2.038	4.00	721689.	4
1309NB	-.000	3.000	1.00	180285.	5
	.744		35.10	6489917.	

PROGRAM PRP01 PAGE 5

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 3

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1704SL	-.157	7.032	5.60	1085772.	1
1307EB	-.026	1.798	10.40	1899263.	2
1911KR	-.908	5.094	4.20	760055.	3
	.741		20.20	3745090.	

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1984 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 0

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1710NB	-.192	5.810	17.20	3384971.	1
130ASG	-.013	1.835	3.20	580532.	2
	.727		20.40	3965503.	

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 5

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1915WR	-.028	6.238	3.40	621482.	1
	.710		3.40	621482.	

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

SUMMARY TABLE

YEAR	AVG. DI	LENGTH (MILES)	BUDGET (DLLS)
1	-.094	339.80	84224926.
2	.744	35.10	6489917.
3	.741	20.20	3745090.
4	.727	20.40	3965503.
5	.710	3.40	621482.
6	.686	20.40	3805514.
7	.682	14.10	2612384.
8	.673	11.70	2134072.
9	.693	40.10	7379061.
10	.722	27.00	4979300.
	.628	532.20	119957249.

SAMPLE OUTPUT - ALTERNATIVE 3

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PROGRAM PRP01
CTR - UT AUSTIN
VERSION MAR 10,1982

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

ANALYSIS PERIOD=10

BUDGET CONSTRAINTS FOR EACH YEAR
IN THE ANALYSIS PERIOD

YEAR	BUDGET
1	15000000.
2	15000000.
3	15000000.
4	15000000.
5	15000000.
6	15000000.
7	15000000.
8	15000000.
9	15000000.
10	15000000.

UNIT COST OF OVERLAYING= .250 DLLS./IN.PER SQ.FT.

SUMMARY OF SECTIONS CONSIDERED IN THE ANALYSIS

SECTION TYPE	NO. OF SECTIONS	MILES
1	-0	0
2	139	756.50
	139	756.50

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PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 1

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1908EB	-6.037	5.918	9.80	4686232.	1
1908WB	-3.055	5.918	10.00	3629770.	2
1906EB	-2.784	5.629	7.00	2454482.	3
1007WB	-2.617	6.180	5.00	1714050.	4
904 SB	-2.322	7.653	1.80	591402.	5
	-.094		33.60	13075936.	

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1982 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 2

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1014EB	-2.868	6.244	8.20	2906949.	1
1006WB	-2.668	6.674	5.20	1795225.	2
1002EB	-2.074	6.483	5.60	1769767.	3
2009WB	-2.070	3.484	5.60	1768659.	4
1001EB	-2.064	6.526	4.00	1262079.	5
1006WB	-2.007	5.966	6.80	2125731.	6
1007EB	-2.001	6.551	4.80	1498947.	7
	-2.066		40.20	13127357.	

PROGRAM PRP01 PAGE 4

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 3

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
2309EB	-2.263	3.658	8.00	2604807.	1
1304WB	-2.037	6.958	8.10	2544698.	2
1008EB	-2.005	6.753	4.80	1499847.	3
1001WB	-1.935	6.983	3.60	1111691.	4
907 NB	-1.925	8.637	1.00	308296.	5
1306WB	-1.688	2.230	5.00	1477803.	6
1303WB	-1.679	2.475	12.10	3569961.	7
	-.9013		42.60	13117103.	

PROGRAM PRP01 PAGE 5

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 4

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1014WB	-2.907	7.555	8.40	2625724.	1
1010EB	-1.887	6.477	7.40	2266492.	2
1902WB	-1.982	7.284	6.20	1897150.	3
1303EB	-1.716	2.648	12.40	3683411.	4
1313WB	-1.631	2.411	5.80	1695970.	5
108 SB	-1.505	3.802	9.20	2624958.	6
	.040		49.40	14793704.	

PROGRAM PRP01 PAGE 6

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY
YEARS AFTER CONDITION SURVEY= 5

SECTION ID	DISTRESS INDEX	CUMULATIVE ESAL (MILLIONS)	SECTION LENGTH (MILES)	OVERLAY COST (DLLS)	RANK
1708SB	-1.717	5.861	12.00	3565491.	1
1706SB	-1.677	7.347	2.30	678337.	2
2015SB	-1.514	6.157	2.20	628841.	3
1904EB	-1.405	8.243	8.20	2292338.	4
1904WB	-1.327	8.243	8.20	2254754.	5
1307WB	-1.286	2.021	10.20	2780204.	6
1011WB	-1.279	8.530	4.00	1088553.	7
2001WB	-1.225	1.964	.50	134431.	8
	.075		47.60	13422948.	

PRIORITY LIST OF TX CRCP FOR REHABILITATION
INPUT DATA FROM 1980 CONDITION SURVEY

SUMMARY TABLE

YEAR	AVG. DI	LENGTH (MILES)	BUDGET (DLLS)
1	-.094	33.60	13075936.
2	-.066	40.20	13127357.
3	-.013	42.60	13117103.
4	.040	49.40	14793704.
5	.075	47.60	13422948.
6	.148	50.80	13910914.
7	.225	46.10	12372706.
8	.325	59.40	14969859.
9	.402	64.80	14489676.
10	.498	71.80	14693569.
	.154	506.30	137973772.

THE AUTHORS

Manuel Gutierrez de Velasco was born in Mexico City, Mexico, on November 3, 1951. He received the degree of Bachelor of Science with a major in Civil Engineering from the University of Guadalajara in 1974. He was awarded a Master's degree from the University of Mexico (UNAM) in 1976. His practical experience includes working with several construction companies and with the Cement and Concrete Institute in Mexico. In September 1978, he entered the Graduate School of The University of Texas at Austin. Since that time he has been employed by the Center for Transportation Research (CTR) as a Research Assistant. His areas of interest include concrete pavements and pavement management systems.

B. Frank McCullough is a Professor of Civil Engineering at The University of Texas at Austin, and is Director of the Center for Transportation Research. He has strong interests in pavements and pavement design and has developed design methods for continuously reinforced concrete pavement currently used by the State Department of Highways and Public Transportation, U. S. Steel Corporation, and others. He has also developed overlay design methods now being used by the FAA, U. S. Air Force, and FHWA. During nine years with the State Department of Highways and Public Transportation he was active in a variety of research and design activities. He worked for two years with Materials Research and Development, Inc., in Oakland, California, and for the past nine years for The University of Texas at Austin. He participates in many national committees and is the author of over 250 publications.