TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. CFHR 1-8-69-123-30F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle OVERVIEW OF PAVEMENT MANAGEMENT SYSTEMS DEVELOPMENTS IN THE STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION		5. Report Date January 1976
		6. Performing Organization Code
7. Author(s) W. Ronald Hudson, B. Frank McCullough, Jim Brown, Gerald Peck, and Robert L. Lytton		8. Performing Organization Report No. Research Report 123-30F
9. Performing Organization Name and Address Center for Highway Research The University of Texas at Austin Austin, Texas 78712		10. Work Unit No.
		11. Contract or Grant No. Research Study 1-8-69-123
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation, Transportation Planning Division P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U.S. Department of Transportation Federal Highway Administration. Research Study Title: "A System Analysis of Pavement Design and Research Implementation"

16. Abstract

This report attempts to summarize the findings and output of a research project which lasted seven years and has produced 30 published reports. No attempt is made to summarize each report individually; rather the total approach and program is summarized in several sections. In particular, special attention is given to implementation activities in the project and the benefits which have been and will be derived from the work.

17. Key Words pavement, system, pavement management systems, design, design system, feedback, implementation, rehabilitation, Texas State Department of Highways and Public Transportation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	

Form DOT F 1700.7 (8-69)

OVERVIEW OF PAVEMENT MANAGEMENT SYSTEMS DEVELOPMENTS IN THE STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

by

W. Ronald Hudson, B. Frank McCullough, Jim Brown,
Gerald Peck, and Robert L. Lytton

Research Report Number 123-30F

A System Analysis of Pavement Design
and Research Implementation

Research Project 1-8-69-123

conducted

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

by the

Texas
State Department of Highways and Public Transportation

Texas Transportation Institute
Texas A&M University

Center for Highway Research
The University of Texas at Austin

January 1976

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 final report for Research Project 123, which began in 1968 as a bold cooperative adventure involving the State Department of Highways and Public Transportation and two major universities. Many people said it could not be done administratively. Others said it was impractical and unwieldy, "too difficult to get so many people working together." Nevertheless it has been done. We are now bringing to a close seven years of major research to develop a Pavement Management System. The project has already produced 30 major research reports, which are shown in the reference list. Hundreds of personal contacts and conferences large and small have been held with representatives of all areas of the State Department of Highways and Public Transportation. Dozens of briefings and discussions have been held for visitors from other state highway departments and at least seven foreign countries. Representatives of the project have been called upon to present papers and talks at several dozen national and international meetings.

Perhaps more importantly the project has resulted in significant improvements in the design and management of highway pavements in Texas and has affected design processes in several other states.

It is interesting at the end of the study to reread the original project problem statement, objectives, and research plans, which are reproduced in the appendix or convenience.

In this report we have not attempted to summarize all the work done in the project; that would be impossible. We have merely attempted to highlight the key issues of the concept and point the way toward future improvements.

There are too many people who have made significant contributions to this work to attempt to name them all. Basically most of them are listed as authors of one or more of the previous project reports (Refs 1 through 30). We would be remiss, however, if we did not cite the administrators whose patience with us has helped make the project possible, Robert L. Lewis and John Nixon of the State Department of Highways and Public Transportation, C. J. Keese of the Texas Transportation Institute, and Clyde E. Lee of the

Center for Highway Research. The financial support of The Federal Highway Administration and the State Department of Highways and Public Transportation is gratefully acknowledged.

Finally, while it is not usual to dedicate a research report, it is only fitting to dedicate this one to Frank H. Scrivner, whose vision, intelligence, and good humor helped make this project a reality. He was one of the original founders and principal investigators on the project. He has since retired and been replaced by Robert L. Lytton. Frank, for your long years of effective service in the pavement research field we dedicate this report to you as a small token of appreciation.

W. Ronald Hudson
B. Frank McCullough
Jim Brown
Gerald Peck
Robert L. Lytton

LIST OF REPORTS

Report No. 123-1, "A Systems Approach Applied to Pavement Design and Research," by W. Ronald Hudson, B. Frank McCullough, F. H. Scrivner, and James L. Brown, describes a long-range comprehensive research program to develop a pavement systems analysis and presents a working systems model for the design of flexible pavements, March 1970.

Report No. 123-2, "A Recommended Texas Highway Department Pavement Design System Users Manual," by James L. Brown, Larry J. Buttler, and Hugo E. Orellana, is a manual of instructions to Texas Highway Department personnel for obtaining and processing data for flexible pavement design system, March 1970.

Report No. 123-3, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System," by Arthur W. Witt, III, and B. Frank McCullough, describes the results of a study of the swelling clay parameter used in pavement design system, August 1970.

Report No. 123-4, "Developing A Pavement Feedback Data System," by R. C. G. Haas, describes the initial planning and development of a pavement feedback data system, February 1971.

Report No. 123-5, "A Systems Analysis of Rigid Pavement Design," by Ramesh K. Kher, W. R. Hudson, and B. F. McCullough, describes the development of a working systems model for the design of rigid pavements, November 1970.

Report No. 123-6, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections," by F. H. Scrivner, C. H. Michalak, and William M. Moore, describes a computer program which will serve as a subsystem of a future Flexible Pavement System founded on linear elastic theory, March 1971.

Report No. 123-6A, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections, Part II," by Frank H. Scrivner, Chester H. Michalak, and William M. Moore, is a supplement to Report 123-6 and describes the effect of a change in the specified location of one of the deflection points, December 1971.

Report No. 123-7, "Annual Report on Important 1970-71 Pavement Research Needs," by B. Frank McCullough, James L. Brown, W. Ronald Hudson, and F. H. Scrivner, describes a list of priority research items based on findings from use of the pavement design system, April 1971.

Report No. 123-8, "A Sensitivity Analysis of Flexible Pavement System FPS2," by Ramesh K. Kher, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this system, the relative importance of the variables of the system and recommendations for efficient use of the computer program, August 1971.

Report No. 123-9, "Skid Resistance Considerations in the Flexible Pavement Design System," by David C. Steitle and B. Frank McCullough, describes skid resistance consideration in the Flexible Pavement System based on the testing of aggregates in the laboratory to predict field performance and presents a nomograph for the field engineer to use to eliminte aggregates which would not provide adequate skid resistance performance, April 1972.

Report No. 123-10, "Flexible Pavement System - Second Generation, Incorporating Fatigue and Stochastic Concepts," by Surendra Prakash Jain, B. Frank McCullough, and W. Ronald Hudson, describes the development of new structural design models for the design of flexible pavement which will replace the empirical relationship used at present in flexible pavement systems to simulate the transformation between the input variables and performance of a pavement, January 1972.

Report No. 123-11, "Flexible Pavement System Computer Program Documentation," by Dale L. Schafer, provides documentation and an easily updated documentation system for the computer program FPS-9, April 1972.

Report No. 123-12, "A Pavement Feedback Data System," by Oren G. Strom, W. Ronald Hudson, and James L. Brown, defines a data system to acquire, store, and analyze performance feedback data from in-service flexible pavements, May 1972.

Report No. 123-13, "Benefit Analysis for Pavement Design System," by W. Frank McFarland, present a method for relating motorist's cost to the pavement serviceability index and a discussion of several different methods of economic analysis, April 1972.

Report No. 123-14, "Prediction of Low-Temperature and Thermal-Fatigue Cracking in Flexible Pavements," by Mohamed Y. Shahin and B. Frank McCullough, describes a design system for predicting temperature cracking in asphalt concrete surfaces, August 1972.

Report No. 123-15, "FPS-11 Flexible Pavement System Computer Program Documentation," by Hugo E. Orellana, gives the documentation of the computer program FPS-11, October 1972.

Rerpot No. 123-16, "Fatigue and Stress Analysis Concepts for Modifying the Rigid Pavement Design System," by Piti Yimprasert and B. Frank McCullough, describes the fatigue of concrete and stress analyses of rigid pavement, October 1972.

Report No. 123-17, "The Optimization of a Flexible Pavement System Using Linear Elasticity," by Danny Y. Lu, Chia Shun Shih, and Frank H. Scrivner, describes the integration of the current Flexible Pavement System computer program and Shell Oil Company's program BISTRO, for elastic layered systems, with special emphasis on economy of computation and evaluation of structural feasibility of materials, March 1973.

Report No. 123-18, "Probabilistic Design Concepts Applied to Flexible Pavement System Design," by Michael I. Darter and W. Ronald Hudson, describes the development and implementation of the probabilistic design approach and its incorporation into the Texas flexible pavement design system for new construction and asphalt concrete overlay, May 1973.

Report No. 123-19, "The Use of Condition Surveys, Profile Studies, and Maintenance Studies in Relating Pavement Distress to Pavement Performance," by Robert P. Smith and B. Frank McCullough, introduces the area of relating pavement distress to pavement performance, presents work accomplished in this area and gives recommendations for future research, August 1973.

Report No. 123-20, "Implementation of a Complex Research Development of Flexible Pavement Design System into Texas Highway Department Design Operations," by Larry Buttler and Hugo Orellana, describes the step by step process used in incorporating the implementation research into the actual working operation, June 1973.

Report No. 123-21, "Rigid Pavement Design System, Input Guide for Program RPS2 in Use by the Texas Highway Department," by R. Frank Carmichael and B. Frank McCullough, describes the input of variables necessary to use in the Texas rigid pavement design system program RPS2, January 1974.

Report No. 123-22, "An Integrated Pavement Design Processor," by Danny Y. Lu, Chia Shun Shih, Frank H. Scrivner and Robert L. Lytton, provides a comprehensive decision framework with a capacity to drive different pavement design programs at the user's command through interactive queries between the computer and the design engineer, May 1974.

Report No. 123-23, "Stochastic Design Parameters and Lack-of-Fit of Performance Model in the Texas Flexible Pavement Design System," by Malvin Holsen and W. Ronald Hudson, describes a study of initial serviceability index of flexible pavements and a method for quantifying lack-of-fit of the performance equation, April 1974.

Report No. 123-24, "The Effect of Varying the Modulus and Thickness of Asphaltic Concrete Surfacing Materials," by Danny Y. Lu and Frank H. Scrivner, investigates the effect on the principal stresses and strains in asphaltic concrete resulting from varying the thickness and modulus of that material when used as the surfacing of a typical flexible pavement, October 1974.

Report No. 123-25, "Elastic Layer Theory as a Model of Displacements Measured Within Flexible Pavement Structures Loaded by the Dynaflect," by Frank H. Scrivner and Chester H. Michalak, describes the fitting of an empirical model to the study of 136 (TTI) data, August 1974.

Report No. 123-26, "Modification and Implementation of the Rigid Pavement Design System," by Robert F. Carmichael and B. Frank McCullough, describes the new RPS-3 version of the rigid pavement design system in detail and complete with an input guide, documentation, and listing, January 1975.

Report No. 123-27, "A System Analysis of Pavement Design and Research Implementation," by Ronald R. Bush, includes a treatment of the Delphi process applied to the design of the Pavement Feedback Data System, February 1975.

Report No. 123-28, "Optimal Flexible Pavement Cross-Section Design Using Quantity-Discount Cost Model," by Danny Y. Lu, Robert L. Lytton, and Chester H. Michalak, describes a fairly general pavement cross-section model and four quantity-discount cost models which have been integrated into the FPS computer program for use by the State Department of Highways and Public Transportation. In addition, a master pavement cross-section model (MPCS) has been devised and coded to calculate the area of any complicate pavement cross-section (being prepared for submission).

Report No. 123-29, "Decision Analysis Model for Flexible Pavement System Design and Management," by W. Robert Selvagne, Jr., and S. S. Shahin describes flexible pavement design decisions which may inc ude technical factors such as costs, service life, and layer thickness but may also involve subjective factors such as adherence to previous practice, energy conservation, public opinion of inconvenience, and personal reputation. Both kinds of factors are combined numerically in a consistent weighting which is determined in this report (being prepared for submission).

Report No. 123-30F, "Overview of Pavement Management Systems Developments in the State Department of Highways and Public Transportation," by W. Ronald Hudson, B. Frank McCullough, Jim Brown, Gerald Peck, and Robert L. Lytton, summarizes the findings and output of a research project which lasted seven years giving the approach and program in several sections. In particular, special attention is given to implementation activities in the project and the benefits which have been and will be derived from the work, January 1976.

ABSTRACT

This report attempts to summarize the findings and output of a research project which lasted seven years and has produced 30 published reports. No attempt is made to summarize each report individually; rather the total approach and program is summarized in several sections. In particular, special attention is given to implementation activities in the project and the benefits which have been and will be derived from the work.

KEY WORDS: pavement, system, pavement management systems, design, design system, feedback, implementation, rehabilitation, Texas State Department of Highways and Public Transportation, Texas Transportation Institute, Center for Highway Research.

IMPLEMENTATION STATEMENT

This project has concentrated on implementation from the outset, as summarized in Chapters 4 and 6 herein. This implementation has included use of the system by several State Departments of Highways and Public Transportation Districts on dozens of problems. The management system has been used on many special studies in the Highway Design Division which have been of direct benefit to the State Department of Highways and Public Transportation.

The computer programs developed are currently in use and it is expected that their use will expand during the next few years.

The ultimate implementation will depend on the organization and activities of the SDHPT. The methods are applicable to pavement rehabilitation, which will be one of the prime activities of the SDHPT for the next decade.

TABLE OF CONTENTS

PREFACE iii

LIST OF REPORTS v

ABSTRACT ix

IMPLEMENTATION STATEMENT x

CHAPTER 1. INTRODUCTION

The Problem 1
Project 123 - The Systems Approach 2
Scope of This Report 4

CHAPTER 2. OVERVIEW OF SYSTEMS DEVELOPMENT

System 1 5
Implementation Plateau 1 6
System 2 9
Implementation Plateau 2 9
System 3 10

CHAPTER 3. CONCEPT OF A PAVEMENT MANAGEMENT SYSTEM 12

CHAPTER 4. IMPLEMENTATION OF PAVEMENT MANAGEMENT SYSTEM

Implementation Phases 17
Summary 19

CHAPTER 5. DATA REQUIRED FOR PAVEMENT MANAGEMENT

Introduction 20
Relationship to Other Functions 21
Future Additions 24
Essential Factors for PFDS 24
Special Research Files 25
Progressive Implementation 25

CHAPTER 6. IMPLEMENTING THE PAVEMENT FEEDBACK DATA SYSTEM

PFDS Information 27
Information for District Management 27
Information for Administration 28
Information for the Research Engineer 28
Strengths and Weaknesses of the Existing Organization 29
Recommended Strategy 30

CHAPTER 7. EVALUATION OF PAVEMENT SYSTEMS METHODOLOGY

Organization 33
Research Coordination 33
Overall Evaluation 34

CHAPTER 8. SUMMARY AND RECOMMENDATIONS 35

REFERENCES 36

APPENDIX 41

CHAPTER 1. INTRODUCTION

In 1968 the State Department of Highways and Public Transportation undertook a research project with two objectives:

(1) to outline briefly a tentative master plan of research in the structural design and evaluation of pavements,

(2) to determine the feasibility of implementing the plan.

This original project was concerned with the study of pavements and pavement research in a systematic manner in order that more comprehensive solutions to the problems encountered could be developed. The work was undertaken by a team of researchers from the State Department of Highways and Public Transportation, the Texas Transportation Institute, and the Center for Highway Research to provide comprehensive coverage of the important areas of interest.

The development of comprehensive pavement systems technology began in 1966 with the initiation of research project NCHRP 1-10. This project developed a systems approach to pavement design (Ref 1). Similar work was being attempted by Hutchinson and Haas (Ref 31) and a basic computer program for calculation of necessary parameters had been developed by Scrivner et al (Ref 32).

The Problem

Many statements of the research "problem" related to pavement systems have been provided by previous authors. The details of initial concepts for this project are presented in Report 123-1 (Ref 1), the first in a series of 30 reports concerning the developments in this project.

Basically, the problem is one of attempting to coordinate into a useful framework empirical and theoretical developments related to a very complicated physical phenomenon. This problem has been complicated over the years by many attempts to "simplify" the solution with easy approaches. By 1968, however, it had become clearly apparent to some people that a systematic approach was needed to the overall problem of pavement design and management.

The word "management" was used to show that the process is not merely one of designing and then forgetting a pavement, but rather that the process involves providing a "serviceable" pavement for the proposed design life of a road facility and that this will involve several phases, such as (1) design, (2) financing, (3) constructing, (4) maintenance, and (5) rehabilitation.

A history of work in pavement research often shows a fragmentary, uncoordinated approach. Some researchers have attempted "theoretical solutions" while others have developed "empirical answers." In each one, a part of the solution may have been developed, but there was time lost in the presentation of these supposed "new concepts." In reality, true research proceeds from empirical data or initial observations to theories or hypotheses to testing of hypotheses and modification as necessary.

Unfortunately the sheer complexity of pavement design problems has made the finding of a solution very difficult. The systems approach provides a framework for collecting and coordinating available information and for moving step-by-step towards a rational solution.

Project 123 - The Systems Approach

Using a systems framework (Fig 1.1) which is by now familiar to all readers, this research project proceeded to develop a series of working computer programs for the design and management of asphalt pavements. This series of programs is modular and may be improved as often as new information becomes available. Its designation is Flexible Pavement Systems (FPS) and an integer is placed after the FPS to designate the latest version of the program, such as, FPS-13. At the present time, FPS-11 is in use by many SDHPT Districts for design and management of pavements. The FPS series is dynamic, as is discussed in detail herein. Future improvements and modifications are anticipated.

In addition to FPS, a management system has been developed for rigid portland cement concrete pavements. It is called RPS and has the same numbering system, e.g., RPS-2. This series of programs provides a set of working models which are being used by the State Department of Highways and Public Transportation.

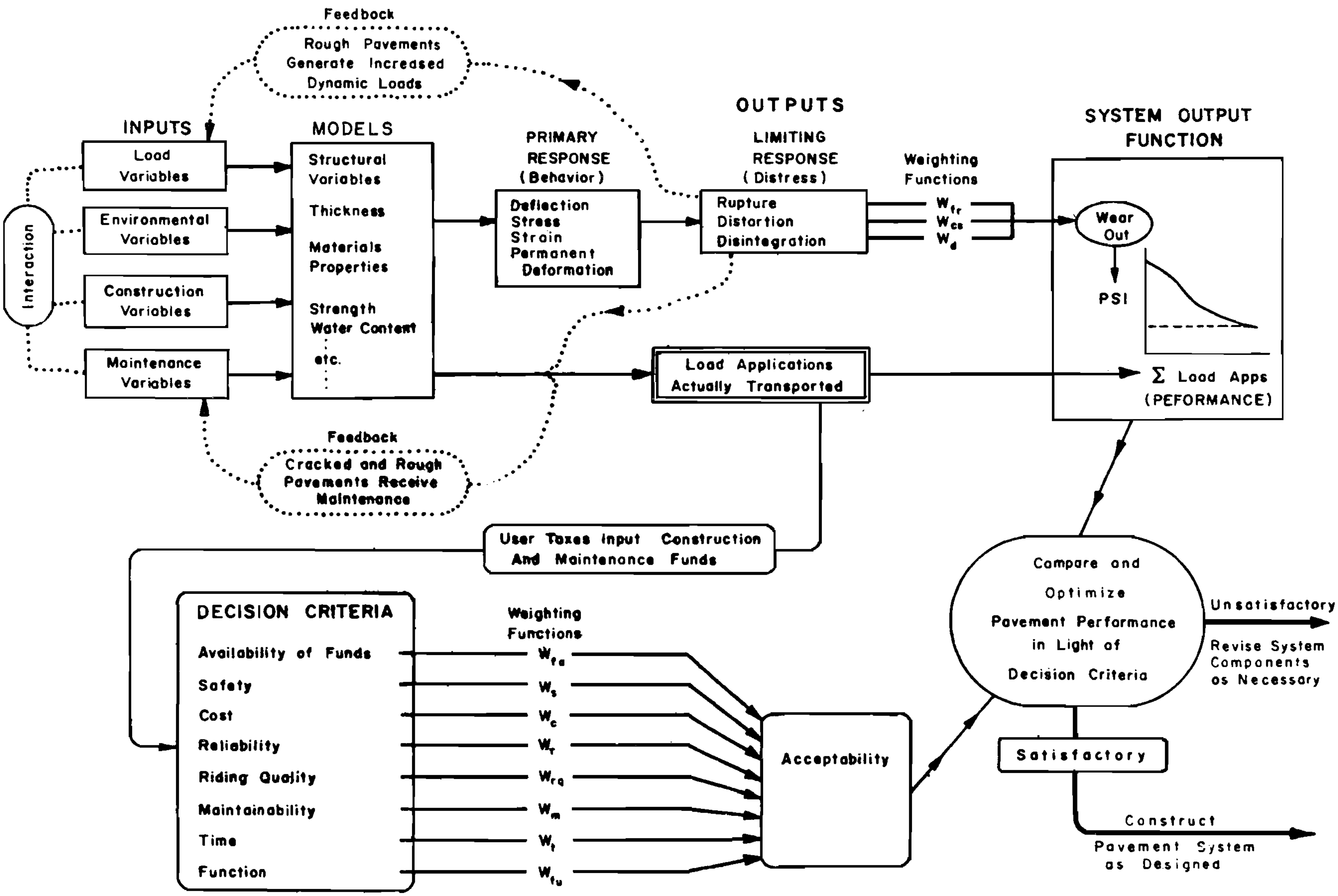

Fig 1.1. Conceptual pavement system (Ref 1).

Scope of This Report

This is the final report in a series of 30 reports describing the findings of this study. The reports cover a variety of topics related to pavement management. Each of these reports has been written to cover a specific aspect of the problem and the integration of the reports into the system has been accomplished as needed within the study.

The purpose of this report is to summarize the findings of this project as it comes to a close and to point out the direction of future research required to continue implementation and use of the pavement systems. We have not attempted to review each report in detail.

The report has several major sections. Chapter 2 presents an overview of the systems development process. Chapter 3 presents the total concept of pavement management systems. Chapter 4 discusses implementation of the pavement management system concept. Chapter 5 discusses data requirements for implementation and verification of the system. Chapter 6 discusses system implementation, particularly implementation of the feedback data system. Chapter 7 presents an evaluation of the systems concept and the project as a whole, including a discussion of how successful we have been and the limitations of the systems approach. Chapter 8 presents recommendations for future developments which will benefit the design system as a whole. A good beginning has been made but much work remains to be done.

CHAPTER 2. OVERVIEW OF SYSTEMS DEVELOPMENT

A pavement design system is a computerized assembly of pavement design functions that are normally done, either explicitly or intuitively, by experienced pavement designers. The development of any design system will naturally start with the more explicit functions or variables such as thickness, strength, traffic, and cost analysis. When a system or method at this stage is given trial use by experienced designers, several glaring deficiencies may begin to appear. Items such as traffic delay costs due to maintenance work, nontraffic damage to the pavement, salvage values of the materials in place, interest rates, and routine maintenance costs all must be added to give the pavement system the scope which should be achieved in true design. A big step was required to make explicit in the pavement management system the consideration of the factors not normally considered to be "design" functions. Clearly, however, this research study has shown that it is possible to accept this step for practicing engineers. Once revisions are made, another trial run of the design system may or probably will indicate still more discrepancies, but these will probably be of a more subtle nature, and uncertainty, intuition, and judgment must also begin to be included in the design process.

In addition, it becomes apparent that better data are needed, not only to operate the system but to effect some important economies in pavement construction. Practically speaking, this is the way a useful design or management system must develop: it requires successive cycles of program development, implementation, and revision with input from practicing designers and from people familiar with systems concepts.

Experience has shown that no one person or group of persons can foresee all the intricacies that will be a part of the perfect or final system. It has become apparent that a workable system must be developed in successive stages; each period of development is succeeded by a plateau during which the system is implemented, that is, it is put into practice to see whether it can really produce useful results.

System 1

The plateau diagram in Fig 2.1 shows a time-wise development of the Texas Flexible Pavement Design System. The initial system was developed in Study 2-8-62-32, "Extension of AASHO Road Test Results," which was concluded in 1968 and included the following concepts:

(1) performance as measured by the serviceability index and predicted by an empirical equation based on AASHO Road Test data;

(2) structure of the pavement as characterized by thickness and stiffness of various materials and its deflection under a standard load;

(3) traffic loading as represented by the total 18-kip single axle equivalent loads applied to the pavement at any time;

(4) economics of traffic delay at an overlay operation, salvage value of materials in place at the end of the analysis period, and calculation of the present value of all future cost;

(5) costs of initial construction, overlay construction, and routine maintenance; and

(6) swelling clay reduction of pavement performance.

Implementation Plateau 1

The basic design method had been assembled by the end of Study 32, but it had not been tried out to see if the best designs it selected, considering least total cost as the criterion, really represented pavements that were feasible for construction. It also became obvious that the method needed to be developed further within a conceptual systems framework that assured that all relevant factors would be considered, as shown in Fig 2.2. Ideally, the Study 32 pavement design program should have been developed only after the conceptual framework had been worked out, but, in fact, they were worked out independently at Texas Transportation Institute and the Center for Highway Research. The next phase of the implementation and system development, Study 1-8-69-123, "A System Analysis of Pavement Design and Research Implementation," was initiated to provide this method of implementation and system development.

One of the first tasks undertaken in Project 123 was to see whether realistic designs could be produced by the system as it stood. Designers were asked to compare the pavement thicknesses they would normally expect to use with those indicated by the Flexible Pavement System (FPS) using the same inputs. The FPS results were always thinner in structural section. The

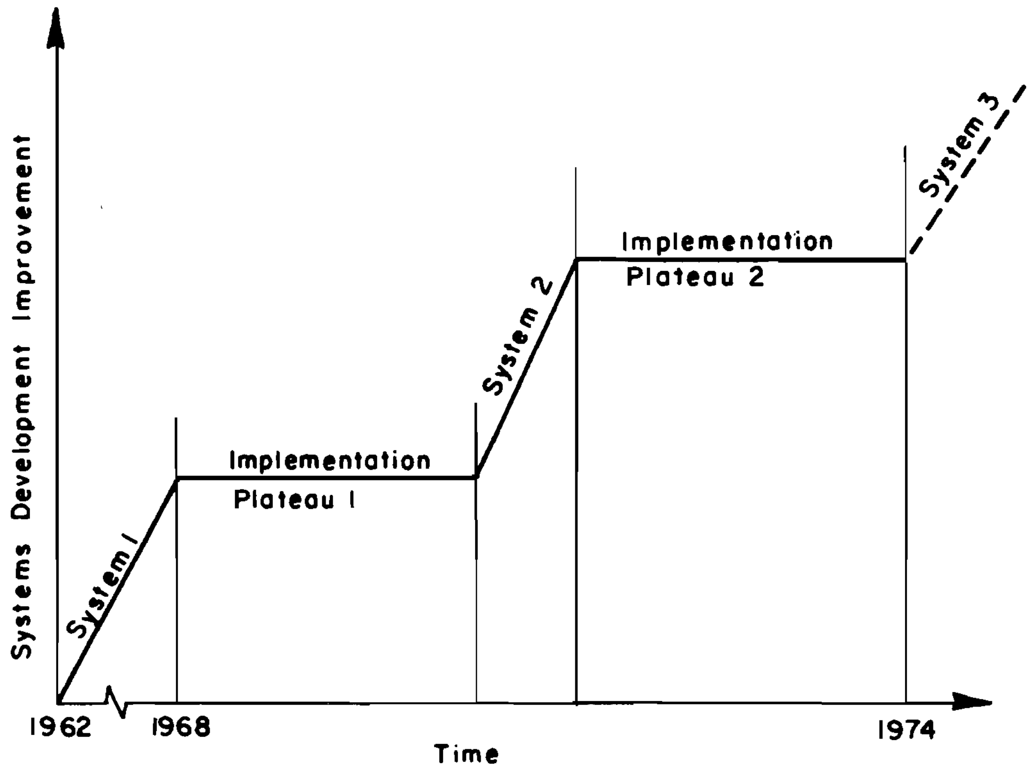

Fig 2.1. Development of the Pavement Management System in Texas.

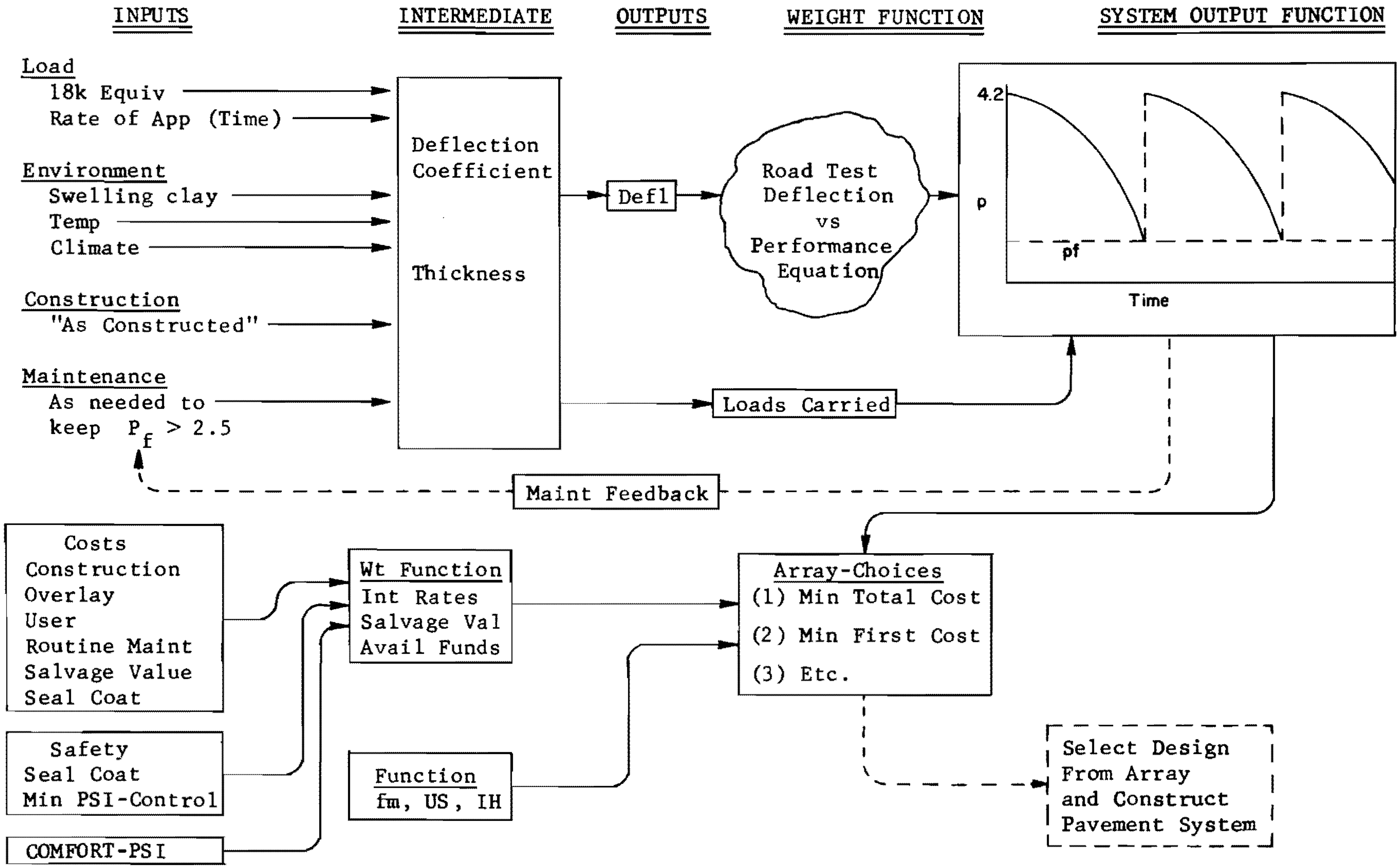

Fig 2.2. Working pavement system.

questions raised by this and other discrepancies noted in the course of implementation furnished the impetus for the second stage of design system development.

System 2

The major additions in the second design system were as follows.

(1) The Rigid Pavement Design System was developed, although as a separate computer program.

(2) Stochastic prediction of time to overlay was developed. This scheme considers the variations of material properties, performance variables, and the error in the empirical equations used to predict serviceability loss. By increasing the required level of certainty, the optimum pavements become thicker and approach those that, in the opinion of the State Department of Highways and Public Transportation designers, have performed well in the past.

(3) Environmentally-caused serviceability loss was included as a revised swelling clay model.

(4) Various subsystems were developed, not for immediate implementation within the design system but to see how successfully they could predict various forms of distress, such as fatigue, rutting, and thermal cracking of the asphaltic surface course. All of these came as a result of project personnel monitoring the development of theory that had been reported in the literature.

(5) Economic analyses of speed, roughness, exhaust pollution, noise, and various direct and indirect costs were made using the pavement systems concept as a framework.

(6) Feedback data system concepts were initiated.

All of these were additions or investigations that were suggested by the constructive criticism received from many sources in Implementation Plateau 1.

Implementation Plateau 2

Study 123 applied a concentrated effort in implementing the revised flexible pavement design system, with emphasis upon voluntary schools for SDHPT district design personnel. After the schools were completed, the districts began to use the design system in a variety of ways; some for design, some for cost estimating, some for determining pavement design strategies. This implementation plateau has provided much useful information and some of the more important findings are given in the following paragraphs.

It has become obvious that various pavement types will perform differently and it is reasonable to expect to use a different performance equation for an overlaid pavement than for one in its first performance period, for a pavement on a stabilized base-course than for one on a water-bound flexible base, and so on.

It is also apparent that not all of the relevant variables have been incorporated in the design system. An attempt has been made to determine, from the opinions of a wide selection of experts in the various aspects of pavement design, financing, administration, research, and maintenance, what kinds of variables should be included in the pavement feedback data system. The Delphi technique (Ref 28) has been adopted for the selection process.

It is also clear that designers will not always choose the least total cost as the only criterion for selection of the best pavement design strategy. A study of decision criteria was initiated in Study 123, in an attempt to determine the weight that designers will apply to various cost and non-cost factors in deciding which pavement will be built.

It is certain that the amount of money in the construction budget for an entire district is considered in determining which pavement is to be built, which is to be overlaid or seal-coated, and how thick the new pavement will be. It is a major concern, not only to designers but to district engineers, that the money should be put where it will do the most good.

All of these findings come either directly or indirectly from efforts applied to Implementation Plateau 2 of Project 123. Some have been investigated and some have not. However, the next set of improvements required for the pavement management system is now apparent.

System 3

The next pavement system to be developed and implemented within the State of Texas should include some of the following characteristics:

(1) performance equations based upon type of pavement or rehabilitation method used,

(2) more explicit decision criteria,

(3) systems analysis of pavement surface characteristics which considers such factors as skid number, tire wear costs, accident rates and costs, and relationships between speed and serviceability index,

(4) method of considering the most cost effective way of spending construction dollars to maintain an acceptable level of performance of a district's pavement network, and

(5) better consideration of the kinds of pavement distress that cause a loss of performance in different climates and on various types of pavement and subgrade.

The design system should begin to rely more upon the data collected and analyzed in a feedback data system.

Activity of the implementation plateau following these system developments would probably be concentrated on making the system more accessible to its users by more schools and by simplifying input and output and streamlining problem storage and recall within the computer.

Because of the stage-wise nature of system development, it is hard to see what design system 4 would include although, without doubt, a number of essential improvements would have to be made.

CHAPTER 3. CONCEPT OF A PAVEMENT MANAGEMENT SYSTEM

As all of the aspects of pavement design are considered in their proper context, it becomes obvious that the proper design of a pavement requires good management of the information and resources available to the constructing agency. A pavement management system is not a computer program, as a pavement design system may be. Rather, it includes the computer program as one of the tools that aid in making good management decisions. A pavement management system is necessarily tied to the organization that uses it. It has the same sort of objective as any true "system," that is, to find an optimum strategy while operating within a set of practical constraints. The pavement management system in Texas is geared to the design, construction, and maintenance operations of a district, the smallest organization within the state that is virtually autonomous in carrying out all aspects of pavement management. Study 123 has been concerned with only one major aspect of this kind of pavement management system, that is, providing an adequate pavement section for the expected traffic while taking into account in a reasonable manner a variety of realistic constraints on the cost, performance, construction, maintenance, and public annoyance characteristics of the pavement. "Public annoyance" refers to the time lost by the travelling public in detouring around maintenance work as well as the professional embarassment of having to overlay or otherwise rework a section of road sooner than expected.

Operation of a pavement design system is, in the final analysis, a simpler and less complicated task than that of pavement management. Pavement management is an attempt to systematize the collection of information useful to design, the practical synthesis of methods of predicting pavement performance and costs, the development of relevant research to provide needed information and to tell how to use it best, and the dissemination to designers of the way to use what has been developed. The objective of a pavement design management system is to provide the designer with an optimized list of pavement sections which can reasonably be expected to perform as well as predicted under the influence of the predicted traffic and the climate. The decision as to whether to build a new pavement or to overlay an existing pavement still must rest with the designer.

The pavement management system requires the operation and interaction of several components:

(1) working design system or computer program,

(2) pavement feedback data system,

(3) data collection and updating,

(4) subsystem updating,

(5) pavement research in systems, economics, materials, distress, performance, and condition evaluation, and

(6) schools, refresher courses, and computerized instruction in the use of the working design system.

The major emphasis in Study 123 has been in areas 1, 5, and 6 although some work was done on all items. The working system is at the center of all of the other tasks since it contains all of the equations or models developed and makes use of the design data assembled. It is divided into several subsystems for at least two practical reasons.

(1) Each subsystem should operate separately so that it can be replaced with a minimum of effort when one which is more suitable is developed.

(2) Each subsystem allows experts in its own area to contribute the latest information and to keep the subsystem updated.

The major subsystems in both the rigid and the flexible pavement design systems (shown in Fig 3.1) are

(1) <u>Traffic Subsystem</u>. This predicts the amount of load or equivalent loading that will have been applied to a pavement at any given time.

(2) <u>Pavement Support Subsystem</u>. This calculates the properties of the subgrade and base courses as they are influenced by loads, the environment, and construction.

(3) <u>Environmental Effects Subsystem</u>. This calculates the changes in the temperature, moisture, and volume of the pavement and the supporting soil.

(4) <u>Structural Subsystem</u>. This calculates the deterioration of a given pavement with time and traffic. It makes use of material properties and their variances and calculates a predicted pavement performance. It estimates the time at which some form of rehabilitation must be done.

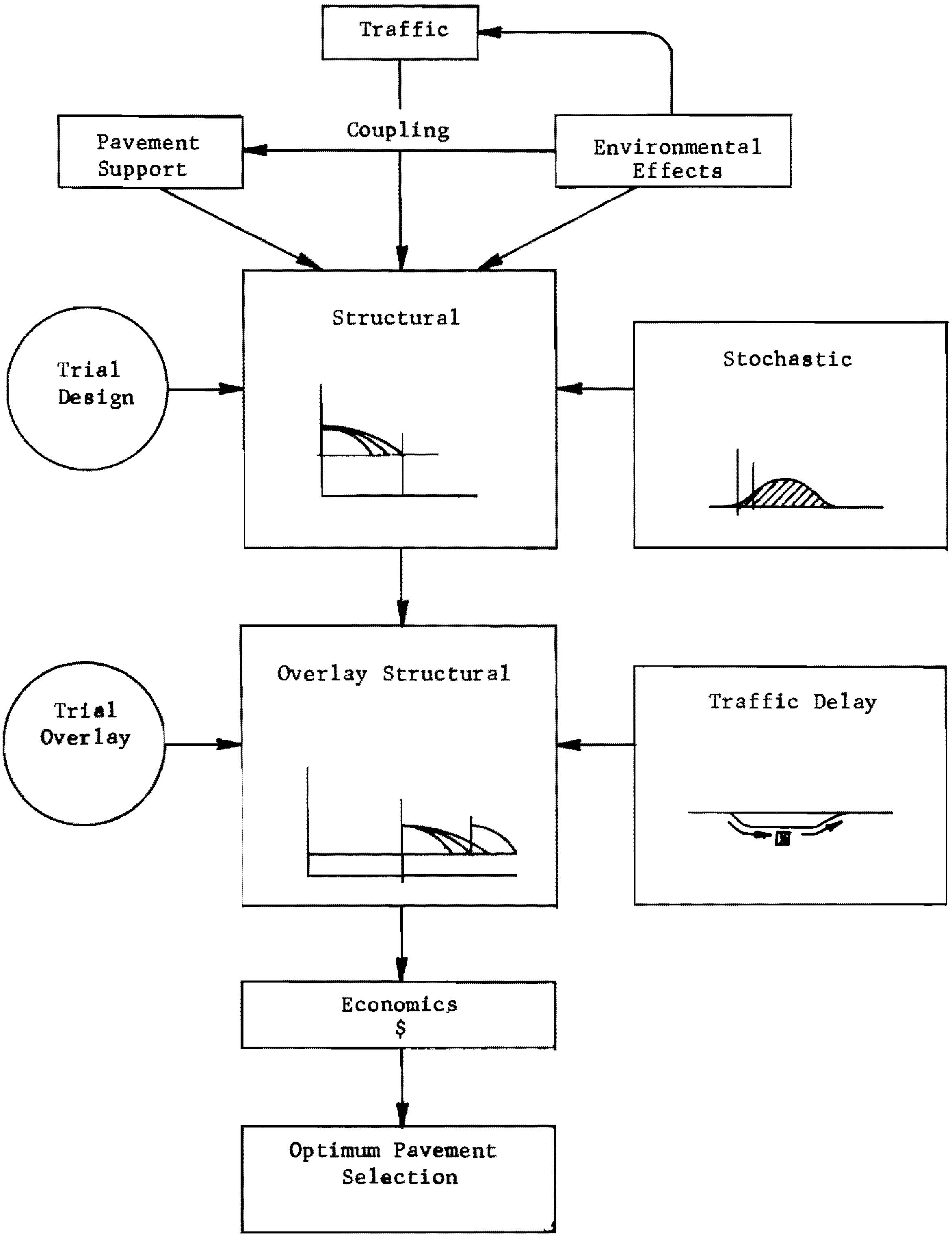

Fig 3.1. Major subsystems contained in both the rigid and flexible pavement design systems.

(5) Stochastic Subsystem. This calculates the properties that are used by the structural and overlay subsystems. This subsystem employs probability density functions and required levels of certainty (or risk) to determine the values of pavement variables to be used.

(6) Overlay Structural Subsystem. This calculates the time to overlay for any combination of overlay thicknesses used.

(7) Traffic Delay Subsystem. This calculates the time delay to traffic that is rerouted along a detour around an overlay operation. This subsystem rarely becomes an important factor until traffic becomes heavy.

(8) Economics Subsystem. This is a name for a collection of cost calculations that must be accomplished to

  (a) estimate the initial cost of construction, time delay costs, overlay costs, and salvage values of materials in place at the end of a given analysis period,

  (b) estimate the cost of routine maintenance activities,

  (c) estimate other costs to the public, such as tire wear, accidents attributable to pavement condition, to general roughness, and

  (d) estimate the total cost of each pavement at the present time, assuming that all future costs must be discounted at a reasonable long term interest rate.

(9) Optimum Pavement Selection Subsystem. This keeps in order the least costly designs which meet all of the design constraints. It is expected that future developments of this subsystem should include weighting factors for various decision criteria which may re-rank the pavement selection while maintaining a relatively low cost.

All nine subsystems have received a considerable amount of attention in Study 123, some resulting in unique and notable contributions to concepts of pavement analysis. But, as noted previously, more improvement can be expected as more and better data become available, as research produces better models, and as more constructive criticism is offered in the implementation of this working design system.

CHAPTER 4. IMPLEMENTATION OF PAVEMENT MANAGEMENT SYSTEM

Implementation is perhaps the most important part of the Pavement Management System. While the problem is somewhat like the "chicken-or-the-egg" question, it seems that implementation is more important because the development of a pavement management system without implementation is meaningless. The importance of implementation has been understood from the beginning of this study. Early orientation meetings and discussions were held with appropriate groups and field personnel within the State Department of Highways and Public Transportation, thus insuring their knowledge of the work and their early input toward effective implementation.

In modern research, there is considerable concern with implementation. This has resulted in the creation of "Implementation Sections" or divisions of groups of various sorts. This approach works well if implementation involves "selling" a concept or a detail such as breakaway signs. It is inadequate, however, for the implementation of the Pavement Management System, where implementation within the highway agency must be carried on almost simultaneously with program development and revision, as well as with the assembly of input information by almost the same highway personnel as those among whom the system is being implemented. In this project implementation had the following phases:

(1) early introductory meetings and briefings,
(2) trial implementation and writing of a User's Manual,
(3) introduction of the system to SDHPT administration and field personnel,
(4) training of design personnel (FPS schools);
(5) revising the system,
(6) additional training of design personnel, and
(7) training in and incorporation of the flexible pavement system by all SDHPT districts.

Each of these phases is summarized below in order to illustrate the associated activities.

Implementation Phases

(1) Early Introductory Meetings and Briefings. Early implementation activities involved several meetings with administration and field personnel; these ranged in size from 3 to more than 50 persons. These meetings were necessary to size up their receptivity to the system and exchange ideas for a practical approach to an implementation program.

(2) Trial Implementation and Writing of a User's Manual. Before any implementation was begun, a sensitivity analysis was run in the program to check the effect of the various input variables on the program outputs. The sensitivity study gave the researchers a working knowledge of the program which enabled the staff members to apply better the FPS program to an actual design problem (Report 123-8).

At the same time that the sensitivity analysis was being performed a set of handy and simplified written instructions to be used as a reference by the program users was conceptualized in the form of a User's Manual. Specifically, this was written to provide instructions to the State Department of Highways and Public Transportation operating personnel for the collecting and processing of data for use in the SDHPT Flexible Pavement Design System (Report 123-2).

The project staff began a trial implementation in District 19 with the design of the pavement structure for US 59, south of Texarkana, Texas. The trial design required the measurement of deflections and the collection of data for costs, maintenance, seal-coats, traffic, etc. These data were analyzed for use with the computer program. The outputs were used as an aid in choosing a design strategy.

Many difficulties were encountered in using the SDHPT Flexible Pavement System program to represent an actual problem in the field. The main problem was that the program had been developed to design a new pavement on a new location while the design problem at hand was the reconstruction of an existing pavement. Overall, this trial implementation served to correct some errors and make modifications to the program.

(3) Introduction (or Presentation) of the System to SDHPT Administration and Field Personnel. With the pilot study and a User's Manual in hand, the project staff was ready to make a formal presentation of the system to administration and field personnel of various disciplines in the SDHPT. For this purpose, two meetings were held in which a working FPS model was presented (to show that the approach was feasible for flexible pavements). The project staff also asked for some volunteers to try the system in their respective districts.

(4) Training of Design Personnel (FPS schools). Training of personnel encompassed two things, (1) a design school and (2) working of actual problems in the field.

Thirteen of the 26 SDHPT districts volunteered to try the system. Out of 13, five were selected for trial implementation. These five districts (2, 5, 14, 17, and 19) were selected on the basis that they had a variety of materials, traffic, and environmental conditions.

Research Report 123-2 (the User's Manual) was used as a textbook. The 3-day school included sessions on collecting and processing design data, coding of sample problems, and interpretation of the outputs. At this school it was required that each participant on returning to his district engage in the actual design of a project, make an evaluation of the strengths and weaknesses of the system, and feed this information back to the project staff (Report 123-20).

(5) Revising the System. In January 1971, a Feedback Workshop was held. Attending were both the researchers who had developed the system and the field personnel who had tried it. The designers presented the results of the system and the difficulties they had. The main problem they had was related to thickness of the pavement and they also argued that the swelling clay model and other parts were only crude approximations.

The workshop served its purpose well in defining the weakest points in the system and it laid the groundwork for revising the system (Report 123-12).

(6) Additional Training of Design Personnel. The success of the first school, the Feedback Workshop and promising results from the revisions prompted the project staff to choose five additional districts for training sessions. From the original volunteers to try the system, Districts 1, 8, 11, 15, and 21 were chosen, and the original five districts were invited to send participants for a refresher course and an explanation of the revisions.

"The Texas Highway Department Pavement Design System, Part I, Flexible Pavement Designer's Manual," was used as a textbook for the school. At this school a general concept of the system was given, each major subsystem was explained briefly, and the revisions to the system were discussed briefly for the benefit of those that were already using the system. The major part of the time was spent working problems and explaining how to gather the necessary inputs to be used with the FPS program.

(7) Training of all SDHPT Districts in the Flexible Pavement System. Prior to holding these training schools (in the summer and fall of 1974) the Department administration had officially approved the use of the Flexible Pavement System as a design tool to be included in the Manual of Design Procedures for the design of flexible pavements.

Eight regional FPS schools were held during the summer and fall of 1974 to train personnel of the districts that had not been introduced to the system. Invitations were also extended to those districts that were already using the system or had been trained to use it.

These schools were held at the headquarters of Districts 3, 6, 10, 12, 16, 18, and 23 and in Austin, the latter hosted by the Highway Design Division (D-8). Attendance at those schools varied from 20 to 36 persons and included personnel from the host district and 2 or 3 adjacent districts. A special effort was made to have as many Resident Engineers as possible from each of the districts.

For these schools, minor revisions were made to the Flexible Pavement Designer's Manual, Part I, and the revised 1974 edition was distributed to all participants to be used as the basic textbook and reference.

These 2-1/2-day schools followed a slightly different format from the previous schools. The participants were divided into 5 or 6 working groups, each group having representatives from the participating districts. The group designated a leader to be their spokesman in making the presentation of the solutions to their design problems. After a short presentation of the material, distribution of manuals and pertinent literature, the participants were asked to start were on a practical design problem concerning their respective area of the state. This teaching method had the advantage of motivating the engineer to read the manual, to input some thinking to the solution of the problem, and at the same time to formulate some questions and generate some discussions. At the request of the FHWA, an additional FPS school was held at the SDHPT Headquarters Annex in Austin. This 2-1/2-day school was held for FHWA engineers who worked in the Texas area.

Summary

A great deal of implementation has gone on, but much more is needed. The development and implementation of a Pavement Management process is a continuing, integral process.

CHAPTER 5. DATA REQUIRED FOR PAVEMENT MANAGEMENT

Introduction

It has become evident in dealing with the decisions faced by pavement engineers that there is a vast amount of experience which, if available, would be of great benefit in future decisions. Perhaps the most practical method of making such information readily available is to use a computerized data base.

Through the process of storing data from in-service pavements and adding data from new construction as soon as it becomes available, an inventory of the Texas pavement network can be established in the form of a computerized data base. The resulting pavement feedback data system (PFDS) can then be used for research, design, and maintenance functions. It is intended that this information will supplement the pavement engineer's judgement and assist him in making better pavement decisions.

Project work on management information systems (MIS) has stressed simplicity and the importance of collecting and storing only relevant data. A determined effort has been made to abide by these principles in the PFDS research. Like business executives, engineers have often been drowned in information, and the result may be manifested somewhat by the lingering reluctance of highway engineers to use computer-based information systems. Stacks of unused computer output have all too frequently been the visible evidence of a working MIS. The HRB Workshop on Structural Design of Asphalt Concrete Pavement Systems (Ref 33) recognized this situation as "data pollution" and concluded that it is a primary factor in abuse and misuse of data systems. Thus, this stage of PFDS development is perhaps the most important of all. The term "essential" has, therefore, been employed to convey the idea that only those factors absolutely necessary for an operating feedback data system are to be included. The decisions to exclude are difficult ones.

Relationship to Other Functions

Just as there are many types of highway maintenance efforts that have nothing to do with the pavement, so are there many considerations other than pavement structural adequacy that determine when a highway must be reconstructed. Figure 5.1 illustrates some elements of this puzzle. The highway system managers use all the pieces to arrive at a decision. It is not an objective herein to suggest the relative sizes of these pieces of the puzzle. All efforts are bent to furnishing the best possible pavement, one that is derived from logical analysis of the synthesis of the pavement system components.

Early in this project, Haas (Ref 4) provided some introductory concepts relative to a pavement feedback data system that give the problem an overall dimension. He showed that pavement performance, described by serviceability index (SI), was a function of at least three factors:

(1) climate,
(2) traffic, and
(3) pavement.

Each of these factors is, of course, composed of several components or subfactors, some of which have been defined and some of which probably have not yet been identified. Conceptually, the prediction of pavement performance can be represented as shown in Fig 5.2. The solid lines enclose factors and subfactors already recognized and identified as important while the dotted lines enclose factors not yet identified or adequately described.

Within the framework of Study 123, models and submodels have been defined to express, as well as the present state-of-the-art will allow, the activity within each pavement performance component. These models are derived from a vast reservoir of past research findings and are adapted to conditions in Texas. The basic underlying foundation is the AASHO Road Test conducted in 1959-62 (Ref 34). This was followed by work at the Texas Transportation Institute, the State Department of Highways and Public Transportation, and the Center for Highway Research (Refs 35 and 36). Superimposing the results of this work on the conceptual representation of the problem in Fig 5.2, we can now give names to the models, factors, and subfactors that make up our pavement design problem.

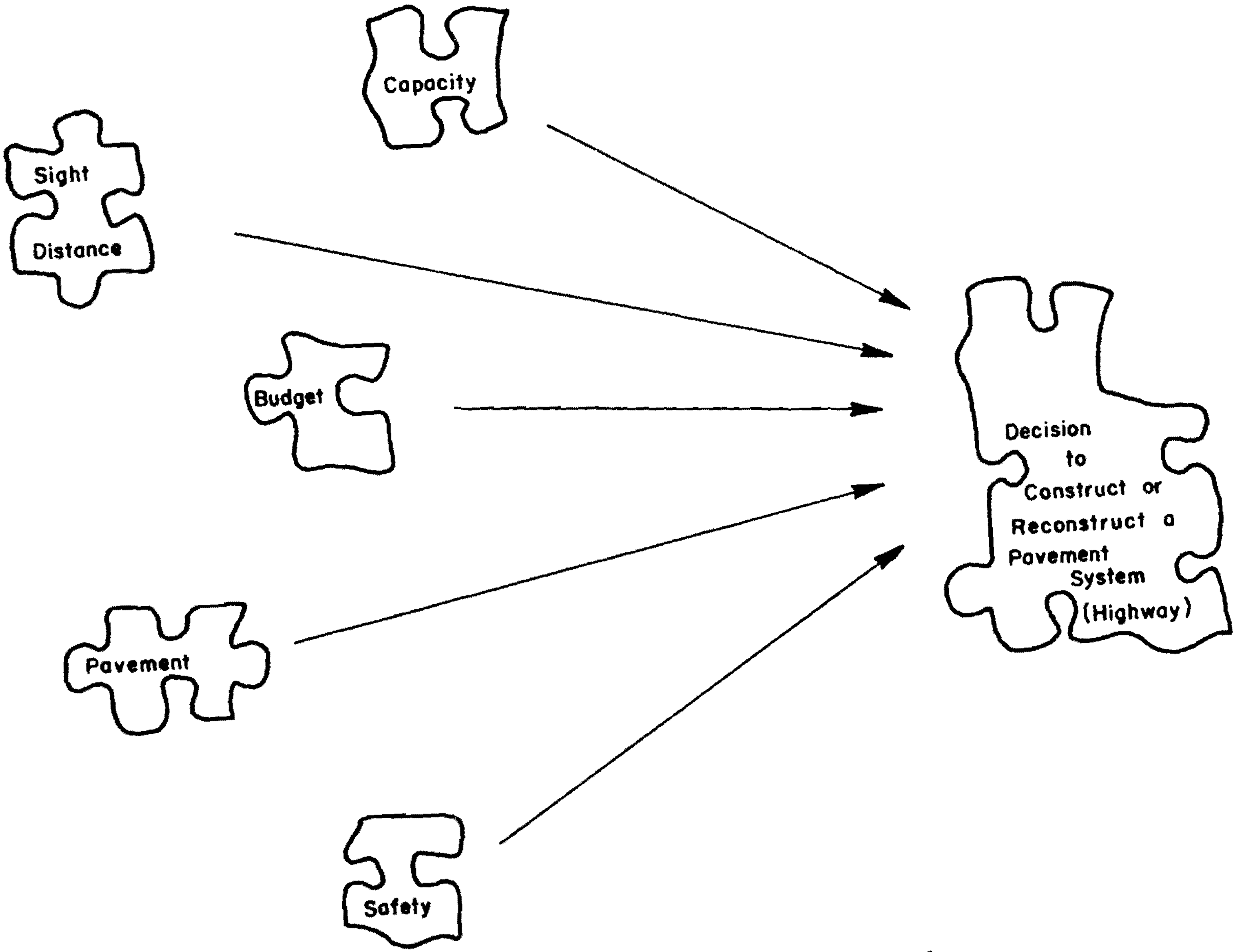

Fig 5.1. The highway management puzzle.

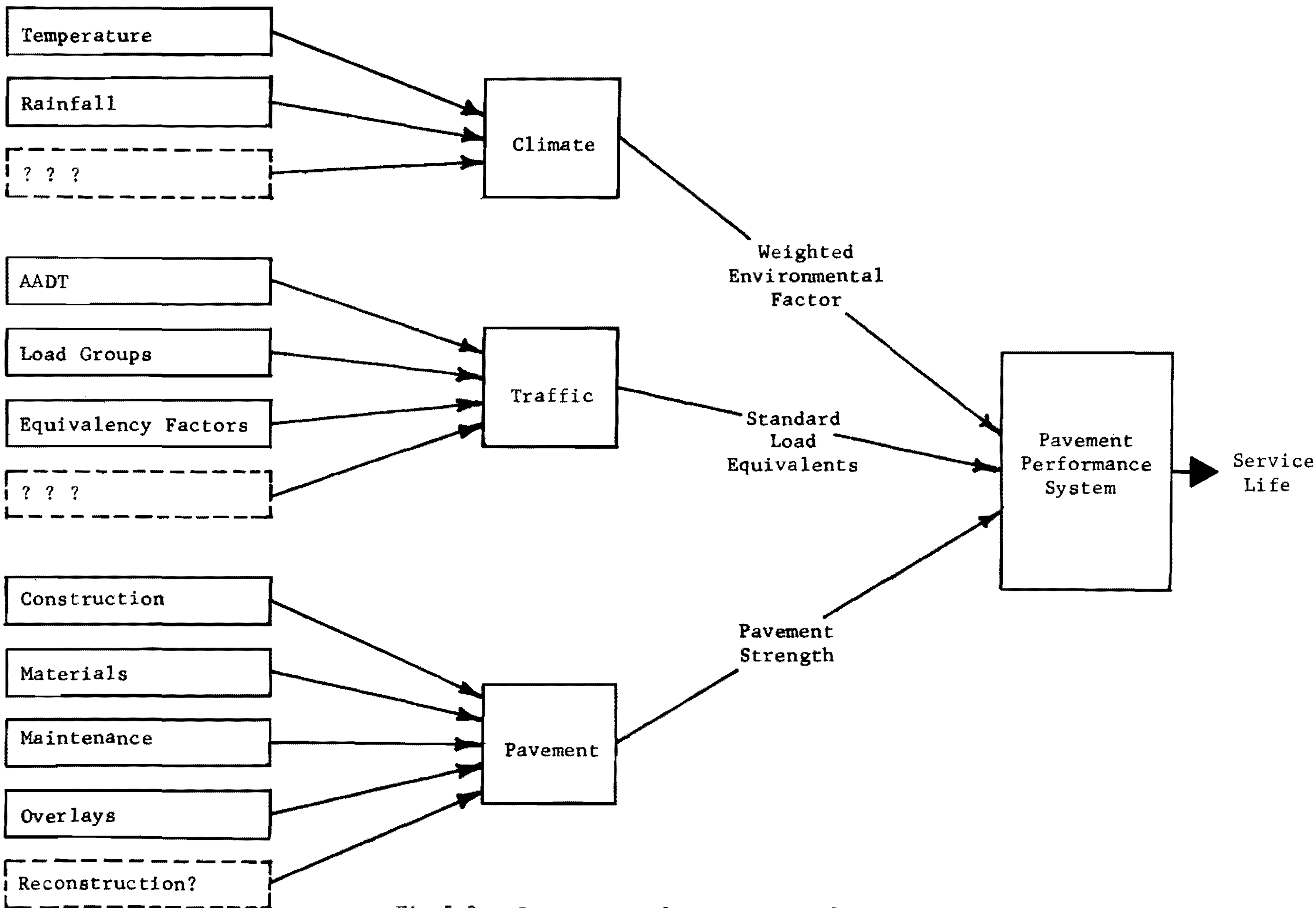

Fig 5.2. Components of pavement performance.

Future Additions

This PFDS research has precipitated a philosophy about pavement design in general and the PFDS in particular. Specifically and with some carefully selected exceptions the variables or factors identified in the described process of model analysis are the only ones for which data will be collected and stored at the start. The initial goal of PFDS is to provide fundamental research and management tools, later maturing them into a design and a more complete management complement. However, the first data inserted into PFDS will be used primarily for selected management functions and to check the various design models. During this model checking process, it is important that results of other research-in-process, even though directly related, not be inserted into the operational design methods until a distinct need for such is indicated by performance data. Even though some theoretical breakthroughs may be apparently concluded during this period of performance data collection and analysis, implementation should be effected only upon demonstration of an ommission or change in performance prediction that calls for a rational revision to the applicable model(s). Such a policy should help to prevent premature changes in design procedures and assure that modifications to models are made in the proper priority.

Essential Factors for PFDS

The basis for selecting variables to be included in PFDS must necessarily come from FPS and RPS input variables to those programs. However, these factors have both a time and a space dimension that must also be sampled. All factors will exhibit variability as we progress down a roadway; for example, as-built surface thickness will vary around some mean value, possibly the design or plan quantity. Other factors will vary with time; for example, serviceability index will tend to decline with time from some high initial value.

Specific recognition of the time and space dimensions of the factors and the formation of a plan to sample accordingly provide the raw data needed to further the probabilistic and reliability concepts now being actively pursued in the Flexible Pavement System (FPS) (Refs 11, 13, and 19). Darter (Ref 19) considers three types of variability in his reliability concepts:

(1) variability within a project, such as pavement thickness and material strength;

(2) variability between design (plan) quantities and as-built values; and

(3) variability due to lack-of-fit of design models in FPS-11.

Recognition of these sources of variation serves as an important second development parameter for PFDS, specifically the need to be adequately responsive to the active research in reliability and stochastic applications in FPS.

Just as important in any sampling plan is the determination of methods or techniques for taking data measurements. The methods must be standardized as far as possible so that direct comparisons are valid. For example, the serviceability index of all highways must be determined by devices which are all calibrated to a common reference device, as is done in the Texas method. Another example is in testing for the Texas Triaxial Class, a material property that is fundamental to a standard design procedure used in Texas. Because the cost of this test is high, the Texas Triaxial Class is often determined by one of several possible shortcut techniques. Therefore, the record must specify the method which was actually used. This is also done for any other type of data.

Special Research Files

Most of the special research projects discussed in various Study 123 reports involve acquisition and analysis of varying quantities of data. It may be advantageous to utilize computer processing of such data, and consideration should be given to definition of temporary files within PFDS to serve each research project. MARK IV, a programming technique, makes creation of temporary and working files relatively simple and this capability should be exploited fully.

Progressive Implementation

It has been recognized in Study 123 that to wait for development and implementation of the ultimate system is unrealistic and delays the payoff from improvements. A progressive or staged implementation of the data system is more logical and useful and can incorporate improvements on a step-wise basis. The requirements for such a staged implementation are as follows:

(1) Selection of One or More Short Representative Evaluation Segments of Each Pavement Section Designed by the Study 123 System. Because annual construction programs are specific, choosing these evaluation segments will inherently provide an orderly annual addition to the total inventory covered by the data system.

(2) Output (Retrieval) Reports of an Initial, Finite, and Standard Form. The software development for retrieving data is a major task, and it is not initially possible to foresee all possible correlations and analyses that may be performed on the data. Consequently, this development is of a continuing nature and may initially involve only relatively common statistical summary outputs.

(3) The Provision for Adding New Data Fields in the Future. Initially, only a limited number of data items may be included, but it may be foreseen that additions will be needed in the future. For example, the use of layered, structural analyses for predicting stresses and strains must have reliable stiffness parameters. Since the stiffness of the asphalt layers varies greatly with temperature, several data fields relating to temperature measurements may be included in the system. These may not be used immediately but can be if the need arises.

CHAPTER 6. IMPLEMENTING THE PAVEMENT FEEDBACK DATA SYSTEM

PFDS Information

The fundamental purpose of PFDS is to provide the engineer manager with "information", not just "data". While data are simply various forms of facts, information is the intelligence of retrieved data when put to use in context. This important distinction is that the information system (PFDS) should require focusing on the management functions in addition to the pure data processing activities. It is vital in implementation to illustrate how PFDS addresses the information needs of the highway engineer users. In some respects, it could be considered the most important part of this report.

It is appropriate to recognize three distinct groups of potential PFDS users:

(1) the District Engineer and his staff,

(2) the administrative headquarters and divisions, and

(3) researchers.

Information for District Management

This user group is considered first for a very good reason. In most respects, the highway engineering job is being done by these district personnel and PFDS must, therefore, answer their needs first. As is pointed out, the districts have been consulted early in the pilot implementation phase to insure that their needs will be satisfied.

The District Engineer is constantly faced with the judicious allocation of his men, money, and material resources to maintain the best possible highway system for the traveling public. The PFDS can help him do this.

Serviceability index (SI) and skid resistance coefficient are two of the most important indicators of how well a highway pavement serves the public. Therefore, when either or both of these factors begin exhibiting minimum acceptable values, it is time to perform some kind of maintenance or reconstruction. If this condition is further complicated by relatively high traffic, the need for corrective action may become urgent.

Assuming sufficient pavement data have been taken on the district highway network, the retrieval of the roughest (low SI) or most slippery (low skid resistance coefficient) or highest traffic (AADT) highway sections would be a relatively time consuming task if the records are in manual form. Compound this situation by requesting the retrieval of all pavement sections satisfying a specified constraint for each of the three parameters and the task becomes significantly large.

Information for Administration

Within the administrative user group are the Highway Commission, State Highway Engineer, headquarters divisions, and District Engineers. Their needs for various kinds of information are often related to vital policy or programming actions and are, therefore, important in support of district efforts.

One relatively common activity is the review of pavement and highway designs accomplished by the districts. By combining their experience with all districts, the headquarters design review staff can help to identify and suggest means of avoiding potential problems; they serve as a background upon which individual district problems can be projected to secure new, more reliable perspectives.

Information for the Research Engineer

The specific interests of the research engineer are served by PFDS as well. Just as the other groups of users can be assured of comprehensive data screening, the researcher can be confident that he has access to all the data collected. He need not fret that someone's "block book" was overlooked in his specific study area.

An example from the research realm might be a data retrieval and analysis operation to evaluate the theory that pavements exhibiting equal surface curvature indices (SCI) are equal in their traffic carrying capacity, regardless of their individual structural configuration.

Strengths and Weaknesses of the Existing Organization

It has been stated that good decisions about pavements are made when the decision-maker has had experience with the materials, traffic, construction, maintenance, and environment that the pavement will encounter. Bad decisions are made when his experience is incomplete. Most Departmental decision-makers have in excess of twenty years of experience in their areas. (It should be noted that at the time key decisions were being made about early IH pavements, experience with high-speed, controlled access, heavy truck-trafficked facilities was virtually nil. New solutions were frequently sought -- with varying success.) The greatest strength of Departmental decision-makers lies in their knowledge of local conditions.

As a decision-maker becomes farther removed from a familiar local condition, he must either depend on someone else's experience or use quantified data. For example, as funds are apportioned at the state level, there has been much dependence on the expressed local need -- as there should be. However, one must ask, "What controls exist to prevent the 'squeakiest wheel' from getting the grease?" It seems apparent that the system has worked reasonably well because most people in Texas believe we have a balanced highway network. However, these demands on management coupled with availability of technology may require us to implement some changes.

During the last 20 years, great strides have been made toward explaining many of the phenomena associated with pavement behavior and other factors that should affect decisions about pavements. Much has been learned about the fundamental mechanisms associated with fatigue, environmental cracking, roughness from swelling clays, rutting, and many other factors that explain pavement behavior. This information is being disseminated through technical meetings (such as those of the Transportation Research Board), college courses (primarily advanced degree courses), and technical literature. During this same 20-year period, the deparmental engineer has been completely occupied trying to build an Interstate Highway System and coping with new problems such as financial and ecological constraints. He has had little time or inducement to attend technical meetings or study new technical findings. Further, the college courses were essentially unavailable and they were not designed for his needs. Additionally, few young graduates were hired during this period -- certainly none with advanced degrees in pavement courses. (Very few engineers had courses in pavement when they received their first degrees.)

This weakness is magnified when one examines rehabilitation design as compared to design of new structures. Good practice for rehabilitation design requires that the proposed solution treat the cause(s) of failure rather than the symptom(s). Assessment of causes requires knowledge of fundamental mechanisms. Learning and applying these fundamentals to rehabilitation design should finally result in a signficant return on our research investment.

Recommended Strategy

It is recommended that the increased efficiency be achieved by better organizing and training. This needs to be accomplished while usage of that knowledge of local conditions now enjoyed by most Departmental personnel is retained.

To achieve better management--to insure that funds are allotted to the districts, then to the roadways, and finally to the specific spot on the roadway where work is needed - the following steps are recommended:

(1) Implement a pavement condition inventory which is sufficiently detailed (1) to assist central office headquarters to apportion funds to the districts and (2) to assist districts in selecting on which projects to spend the apportioned funds. The selection of specific sections within a project should be determined later during detailed engineering of the rehabilitation. In addition to helping management allot funds, the survey can generate hard data for management to use in obtaining funds from the Legislature.

It is pointed out that this inventory should be tailored to the needs of the central office because the central office is so removed from local conditions that it has no other adequate way to determine the relative needs of the districts. It probably follows that such an inventory must be conducted (funded and managed) by the central office since it is primarily a tool for management's use in monitoring district operations.

It is also noted that Research Studies 2, 21, 45, 123, 151, 177, 199, and 207 have worked toward development of various portions of this inventory. The findings of all these studies should be refined into this inventory. It is also noted that personnel accustomed to using test equipment and following laboratory procedures could be more easily trained to do this task than others.

(2) Once specific projects have been funded, authorize engineering studies to select specific sections of raodways to receive rehabilitation even if the work is to be done by Departmental forces. These studies should further delimit where the money is to be spent within a project.

To achieve solutions to rehabilitation projects that have a higher probability of success -- better engineering -- the following steps are recommended.

(1) Establish a pavement specialists' group in the central office with the following assignments:

(a) Assist district personnel with the design of all major rehabilitation projects on an approximately 50/50 basis. It is believed this group should be involved at all stages of design (not detailed plan preparation, but solution generation and selection).

(b) Develop and implement a training program in pavements to upgrade the basic knowledge of all engineers involved with pavement decision-making and to intensively train those engineers discussed in number 2 below.

This group will need to be supported by an adequate set of tools consisting of library materials, computer programs for stress and cost analysis, opportunity to learn new developments from industry and other states, additional education as needed, and specialized testing equipment to conduct both field and laboratory investigations.

(2) Designate one or more pavement specialists in each district whose prime responsibility is pavements.

(3) Establish the necessary communications channels so that the central office specialists' group can easily work with the district specialists.

How many engineers will be required to do this job? Three considerations are important in answering this question: the volume of work, the nature of the work, and the initial expertise of the engineers. Studies have indicated the volume of work to be large, costing roughly 250 million dollars annually. The nature of the work is that each project must be considered unique. Failure analysis and repair design in any field requires more engineering than design of new facilities because each situation is different. Standard designs cannot be used if economical solutions are sought. As mentioned earlier, expertise is excellent in some areas and low in others. Some initial training is needed. In summary, the job is large; however, the personnel are available provided they are selected, organized, trained, and charged to do the job. They merely need to be reassigned from the task of building pavements to operating them.

CHAPTER 7. EVALUATION OF PAVEMENT SYSTEMS METHODOLOGY

To date, by far the greatest benefit from using the systems approach has resulted from better "defining the problem." Over the years most disagreements among pavement designers, researchers, and administrators about the details of a particular design solution have originated because the individuals are solving different problems. One person may be trying to prevent a particular type of distress, e.g., fatigue cracking, while another may be trying to provide the best pavement service from available funds. Development of the systems formulation and its utilization has forced us to look at the whole picture. Designers now better understand the administrators' point of view and researchers are working more on the critically important problems.

Formulation of the pavement management problem has also created an awareness of just how big a role experience still must play in pavement-related decisions. As we have come to a more complete conceptual description of the pavement management problem, we have become more aware of the complexity of it and more aware of the inadequacy of our technology to treat this complexity. It is believed that good judgement based on experience will always be valuable in the pavement decision process. It is further believed that more people now accept this statement as a result of efforts to formulate a pavement management system.

There are many benefits from the use of a Pavement Management System (PMS). There are also several so-called limitations which should be considered. The major problem with considering these limitations of the management system is that they are really physical limitations on the design problem which were inherent in the physical situation but are seen more clearly in the light of rational systems formulation. As an example, many people say, "The pavement system requires too much data." This is not true, since this conviction comes from the fact that existing methods unavoidably omit many variables which should be considered.

Thus, the Pavement Management System makes explicit many variables and many omissions which were implicit and ignored in existing design methods. Paradoxically, this is not only one of its primary strengths but one of its apparent (but not real) weaknesses. Let us consider strengths, limitations, and weaknesses in the three categories of organization, research coordination, and overall evaluation.

Organization

Benefits. Properly adapted and developed, a PMS readily points up the organizational and administrative needs of the agency involved in order to properly implement the system and to obtain maximum utility and economy in highway construction and maintenance. Since the pavement system is merely a subsystem of the overall highway system, the application of the methodology points out the need for appropriate interaction with other phases of highway design. Application of the method points out areas of needed coordination within the existing organizational structure, which will always tend to become more rigid with time.

Limitations. The systems approach, such as developed in Study 123,is no panacea. It is limited by the data available for use in it and by the attitudes and interest of the persons involved. It is most effectively applied in an organizational structure which is willing to experiment and alter its structure to achieve more efficiently coordination and cooperation among all persons and divisions involved.

Research Coordination

Benefits. As noted in the appendix, the first major reason for developing the PMS was to have a research management tool. Once the working system is developed, it is possible to conduct sensitivity analyses on the variables to evaluate the state of uncertainty which exists and the need for research on a particular part of the model. Thus, it is possible to set research priorities with some degree of accuracy. In addition, it is possible to provide better coordination of on-going research, particularly among the several agencies which may be involved in a particular project. These benefits are direct and tangible and can result in better research output for fixed budgets.

Limitations. Pavement Management Systems can not make final decisions with respect to anything, certainly not research. The comparisons are only as good as the input data, and the results can be manipulated if desired by the program user, Thus, again we must say that the PMS is no panacea; nevertheless, it is probably the best tool available to date to assist in research management.

Overall Evaluation

Considering factors overall, FPS and RPS, the two series of Pavement Management Systems begun and implemented in Study 123, must be evaluated as good to excellent. The benefits available to the using agency far outweigh the limitations if the methods are properly understood and applied. The project staff heartily recommend the continued development and use of these pavement management tools by the State Department of Highways and Public Transportation of the State of Texas and by other appropriate agencies.

CHAPTER 8. SUMMARY AND RECOMMENDATIONS

There are a great many reasons to continue the use and development of the Pavement Management System developed in Study 123. A great deal has been accomplished, as outlined in the 30 project reports produced to document the research finding. Many districts have applied the methods directly and many others have noted the methods for future use and modification of existing designs. It should be remembered that changes of this magnitude do not take place rapidly nor are they accomplished unanimously.

The project staff recommends that a direct and immediate effort be made to continue implementation of the Pavement Management System. Likewise, the development and improvement of the system should be continued. A coordinating committee should be set up within the Department to monitor and coordinate the future activities. If at all possible, representatives of the Texas Transportation Institute and the Center for Highway Research should be invited to sit as members of this committee since they will continue to serve as important members of the research team.

An effective effort should be made to accelerate development of the feedback data system. This data base will really be a key to future improvements in the system. It is essential that the SDHPT Automation Division (D-19) take the leadership in this important task.

Finally, it seems essential that the efforts underway to develop an effective Maintenance Management System should be coordinated with the Pavement Management System. The two efforts have a great many common factors and can reinforce each other greatly. The whole support of the major functional divisions of the Department will be required to accomplish the tasks ahead.

REFERENCES

1. Hudson, W. Ronald, B. Frank McCullough, F. H. Scrivner, and James L. Brown, "A Systems Approach Applied to Pavement Design and Research," Research Report 123-1, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, March 1970.

2. Brown, James L., Larry J. Buttler, and Hugo E. Orellana, "A Recommended Texas Highway Department Pavement Design System User's Manual," Research Report No. 123-2, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, March 1970.

3. Witt, Arthur W., III, and B. Frank McCullough, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System," Research Report No. 123-3, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, August 1970.

4. Haas, R. C. G., "Developing a Pavement Feedback Data System," Research Report No. 123-4, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, August 1970.

5. Kher, Ramesh K., and W. R. Hudson, "A Systems Analysis of Rigid Pavement Design," Research Report 123-5, published jointly by the Texas Highway Department Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, September 1970.

6. Scrivner, F. H., C. H. Michalak, and William M. Moore, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections," Research Report No. 123-6, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, March 1971.

7. Scrivner, Frank H., Chester H. Michalak, and William M. Moore, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections, Part II," 123-6A, a supplement to Research Report 123-6, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, December 1971.

8. McCullough, B. Frank, James L. Brown, W. Ronald Hudson, and F. H. Scrivner, "Annual Report on Important 1970-71 Pavement Research Needs," Research Report No. 123-7, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, April 1971.

9. Kher, Ramesh K., B. Frank McCullough, and W. Ronald Hudson, "A Sensitivity Analysis of Flexible Pavement System FPS2," Research Report No. 123-8, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, August 1971.

10. Steitle, David C., and B. Frank McCullough, "Skid Resistance Considerations in the Flexible Pavement Design System," Research Report No. 123-9, published jointly by the Texas Highway Department; Texas Transportation Institute; and the Center for Highway Research, The University of Texas at Austin, April 1972.

11. Jain, Surendra Prakash, B. Frank McCullough, and W. R. Hudson, "Flexible Pavement System Computer Program Documentation," Research Report No. 123-10, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, (preliminary).

12. Schafer, Dale, "Flexible Pavement System Computer Program Documentation," Research Report No. 123-11, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, April 1972.

13. Strom, Oren G., W. Ronald Hudson, and James L. Brown, "A Pavement Feedback Data System," Research Report No. 123-12, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, May 1972.

14. McFarland, W. Frank, "Benefit Analysis for Pavement Design System," Research Report No. 123-13, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, April 1972.

15. Shahin, Mohamed Y., and B. Frank McCullough, "Prediction of Low-Temperature and Thermal-Fatigue Cracking in Flexible Pavements," Research Report No. 123-14, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, March 1970.

16. Orellana, Hugo E., "FPS-11 Flexible Pavement System Computer Program Documentation," Research Report No. 123-15, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, October 1972.

17. Yimprasert, Piti, and B. Frank McCullough, "Fatigue and Stress Analysis Concepts for Modifying the Rigid Pavement Design System," Research Report No. 123-16, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, October 1972.

18. Lu, Danny Y., Chia Shun Shih, and Frank H. Scrivner, "The Optimization of a Flexible Pavement System Using Linear Elasticity," Research Report No. 123-17, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, March 1973.

19. Darter, Michael I., and W. Ronald Hudson, "Probabilistic Design Concepts Applied to Flexible Pavement System Design," Research Report No. 123-18, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, May 1973.

20. Smith, Robert P., and B. Frank McCullough, "The Use of Condition Surveys, Profile Studies, and Maintenance Studies in Relating Pavement Distress to Pavement Performance," Research Report No. 123-19, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, August 1973.

21. Buttler, Larry, and Jugo Orellana, "Implementation of a Complex Research Development of Flexible Pavement Design System into Texas Highway Department Design Operations," Research Report No. 123-20, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, June 1973.

22. Carmichael, R. Frank, and B. Frank McCullough, "Rigid Pavement Design System, Input Guide for Program RPS2 in Use by the Texas Highway Department," Research Report No. 123-21, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, January 1974.

23. Lu, Danny Y., Chia Shun Shih, Frank H. Scrivner, and Robert L. Lytton, "An Integrated Pavement Design Processor," Research Report No. 123-22, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, May 1974.

24. Holsen, Malvin, and W. Ronald Hudson, "Stochastic Design Parameters and Lack-of-Fit of Performance Model in the Texas Flexible Pavement Design System," Research Report No. 123-23, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, April 1974.

25. Lu, Danny Y., and Frank H. Scrivner, "The Effect of Varying the Modulus and Thickness of Asphaltic Concrete Surfacing Materials," Research Report No. 123-24, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, Oct. 1974.

26. Scrivner, Frank H., and Chester H. Michalak, "Elastic Layer Theory as a Model of Displacements Measured Within Flexible Pavement Structures Loaded by the Dynaflect," Research Report No. 123-25, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, August 1974.

27. Carmichael, Robert F., and B. Frank McCullough, "Modification and Implementation of the Rigid Pavement Design System," Research Report No. 123-26, published jointly by the Texas Highway Department; Texas Highway Research, The University of Texas at Austin, January 1975.

28. Bush, Ronald R., "Influence of Cognitive Style in a Methodology for Data Base Design," Research Report No. 123-27, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, February 1975.

29. Lu, Danny Y., Robert L. Lytton, and Chester H. Michalak, "Optimal Flexible Pavement Cross-Section Design Using Quantity-Discount Cost Model," Research Report No. 123-28, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University at Austin, (being prepared for submission).

30. Salvagno, Robert W. Jr., and C. S. Shih, "Decision Analysis Model for Flexible Pavement System Design and Management," Research Report No. 123-29, published jointly by the Texas Highway Department; Texas Transportation Institute, Texas A&M University; and the Center for Highway Research, The University of Texas at Austin, (being prepared for submission).

31. Hutchinson, B. G., and R. C. G. Haas, "A Systems Analysis of the Highway Pavement Design Process," Highway Research Record No. 239, Highway Research Board, 1968.

32. Scrivner, F. H., W. M. Moore, W. F. McFarland, and G. R. Carey, "A Systems Approach to the Flexible Pavement Design Problem," Research Report 32-11, Texas Transportation Institute, Texas A&M University; 1968.

33. Hudson, W. R., "Structural Design of Asphalt Concrete Pavement Systems," Special Report 126, Highway Research Board, December 1970.

34. "The AASHO Road Test, Report 5, Pavement Research," Special Report 61E, Highway Research Board, 1962.

35. Scrivner, F. H., and W. M. Moore, "An Empirical Equation for Predicting Pavement Deflections," Research Report 32-12, Texas Transportation Institute, Texas A&M University; 1968.

36. Scrivner, F. H., and W. M. Moore, "Some Recent Findings in Flexible Pavement Research," Research Report 32-9, Texas Transportation Institute, Texas A&M University, 1967.

APPENDIX

A STUDY OF THE FEASIBILITY OF SYSTEMATIC PAVEMENT RESEARCH

APPENDIX. A STUDY OF THE FEASIBILITY OF SYSTEMATIC PAVEMENT RESEARCH.*

A. Research Problem Statement:

The volume of research sponsored or conducted by the State Department of Highways and Public Transportation in the area of the structural design and evaluation of pavements has multiplied many times in the past few years. Faced with the responsibility of periodically recommending new ventures in this field, and assisting in the implementation of completed research, the Department's Area 3 Committee have, through their chairmen, indicated their need for a general plan to cover their entire area of research.

The need for a general or master plan has arisen because without it--

(1) The intelligent assignment of priorities to the financing of new pavement research is made unnecessarily difficult.

(2) A systematic statewide collection and storage of valuable research data from the existing highway system cannot be initiated and maintained.

(3) A long-term commitment to the systematic observation of experimental sections cannot be made.

(4) The systematic implementation of research findings is unnecessarily difficult (because of haphazard timing).

Thus it would appear that a master plan is essential to the most effective functioning of the Committee and the researchers working under its general guidance. But such a master plan is not easily arrived at, and even if adopted might not be feasible within the operational framework of the Department. The problem to be attacked in this one-year research study is the resolving of this question of the feasibility of the use of an overall plan of research in the area of the structural design and evaluation of pavements.

B. Objectives:

1. To outline briefly a tentative master plan of research in the structural design and evaluation of pavements.
2. To determine the feasibility of implementing the plan.

---

*Extracted from Study 123 Research Study Proposal 1968-69.

C. Plan of Research:

1. In the development of an outline for the master plan of research attention will be given to the following partial listing of the needs which such a plan should fulfill.

   (a) Results emanating from individual projects should be combined as necessary to provide useful design information. (Example: One project may provide information as to the maximum tensile strain a material can withstand; another project may provide a method for estimating the tensile strains in the pavement structure caused by a moving wheel load. These two results must be combined if they are to be useful to the design engineer.)

   (b) Gaps in pavements technology should be filled in an orderly manner (Example: The two projects mentioned in paragraph (a) should be scheduled for completion at about the same time.)

   (c) Research findings must be regarded as hypothesis until proved on the highway system. Thus the master plan must provide means for establishing experimental sections, and for systematically observing the performance of these sections over long periods of time. (Example: In one project the results of research in the deflection of pavements indicated a strong regional effect, immediately suggesting that thinner designs could be used in some areas. But the measurements spanned only two years. Observations on selected sections over a ten-year--or longer-- period are needed to confirm or refute the results of this research.)

   (d) A computer-oriented information and retrieval system should be established for the storage of design, materials tests, construction, maintenance, performance and cost information on the research test sections, with the thought of eventually adopting a statewide system for research and management use. (Example: One research study will produce this year a computerized flexible pavement design procedure that requires estimated maintenance costs as one of the inputs; but information on which to base an estimate of maintenance costs is not now available).

   (e) An adequate permanent staff, reporting to the Area 3 Committee, must be provided for initiating and maintaining the systematic flow of information envisioned in the master plan.

   In developing the master plan the researchers intend to make use of the principles of systems engineering, and to consult with experts in this field as may be necessary.

2. After a master plan of research for Area 3 has been outlined, it will be possible to attack the question of the feasibility of implementation. In this phase of the work the researchers intend to make estimates of

   (a) The permanent staff required to implement and maintain the operating of the plan.

   (b) Changes that might be necessary in the present system of record keeping, and the impact of these changes on the routine operations of the Department.

   (c) The general nature of the experiment design for long-time research on experimental sections, and the funds required for maintaining this research.

   (d) The additional time required to refine the plan to the point when implementation could begin.

   The above-mentioned estimates will form the basis for judging the feasibility of implementing the master plan.