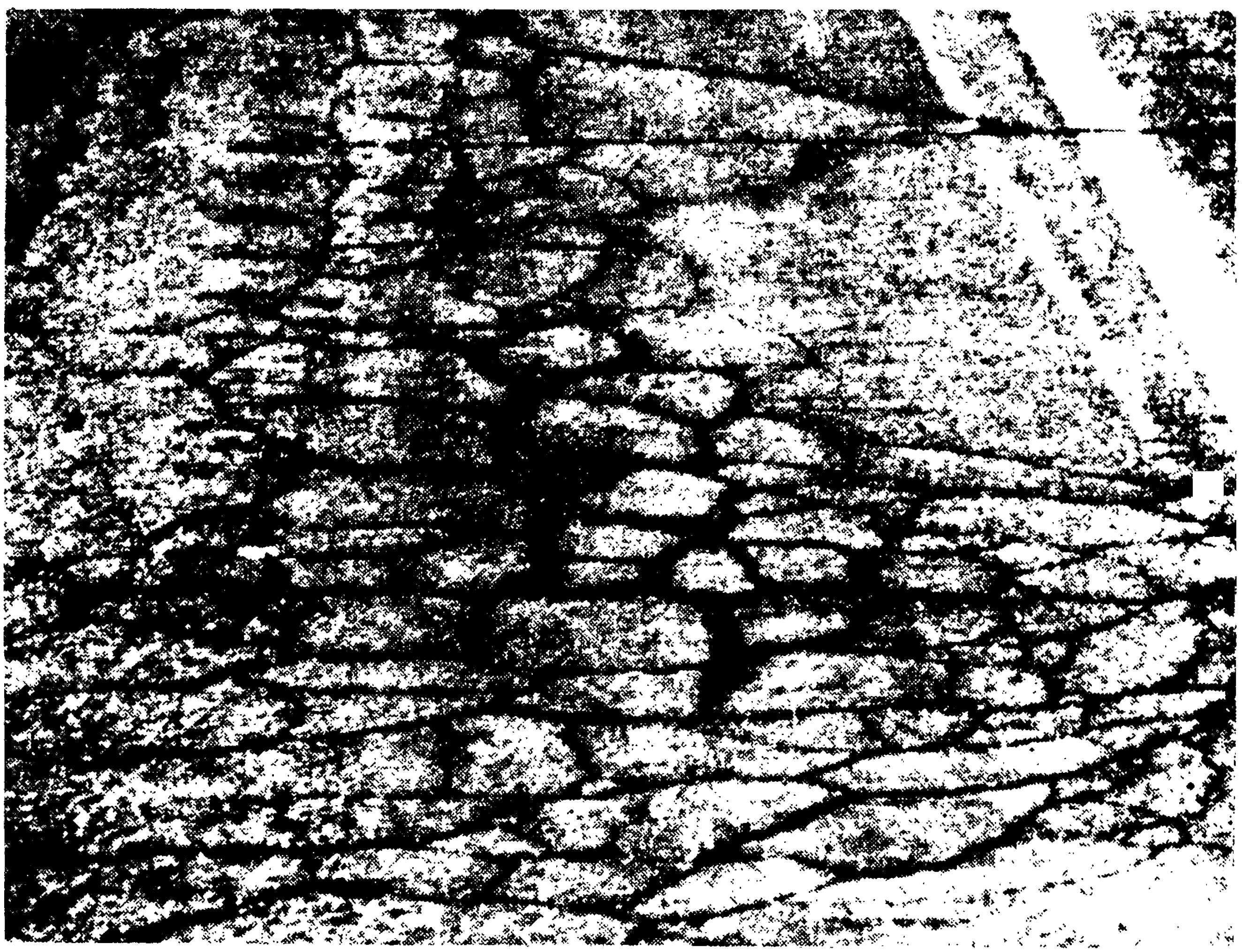
Long-Term Pavement Monitoring Program

Development of Pavement Monitoring

Prepared for Alternative Development Workshop

U.S. Department of Transportation
Federal Highway Administration

October 1984



\14

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Long-Term Pavement Monitoring Program Development of Pavement Monitoring (Prepared for Alternative Development Workshop)	August 1984
	6. Performing Organization Code
7. Author(s) R. L. Lytton, J. B. Rauhut, M. I. Darter	8. Performing Organization Report No.
9. Performing Organization Name and Address Rauhut Engineering Inc. 10214 IH-35, North Austin, TX 78753	10. Work Unit No.
	11. Contract or Grant No. DTFH61-83-C-00164
	13. Type of Report and Period Covered Draft Final Report
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Office of Research Washington, D.C. 20590	
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager - Roger Petzold

16. Abstract

Long-term monitoring efforts have been carried on for a number of years at State and national level and have been generally accepted. However, the shape that it takes in the future will depend very largely upon the decisions that are made in this Workshop concerning the following very basic issues:

1. What questions related to the financing and management of the nation's highways need to be answered and can only be answered with a continuing data monitoring effort?
2. What data need to be collected and evaluated in order to answer these questions?
3. What is the best way to collect and evaluate these data in order to answer a number of basic and important questions?

The deterioration of the highway infrastructure and the consequent need to use tax dollars wisely to maintain, rehabilitate, and reconstruct the highway system have presented the highway community, the State and national governments with basic policy and technical questions to which, at present, there are only tentative or intuitive answers. Rehabilitated or reconstructed pavements are more difficult to design and construct properly than are new pavements. The composition of the vehicle fleet and vehicle loading distributions, the construction of tires, and the magnitude and distribution of tire pressures are changing rapidly and are expected to have a significant impact on the rate of highway deterioration. There is a growing recognition of the importance of climatic influences on the rate of pavement deterioration. All of

(over)

17. Key Words	18. Distribution Statement
	No restrictions. This document 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	208	

Form DOT F 1700.7 (8-69)

these changes have created a dynamic situation for policy-makers who are attempting to determine cost responsibilities for different highway users and to define equitable means of apportioning the funds that are available for preserving our nation's highway network.

Long-term monitoring of pavements is now being generally accepted by the highway community as essential to the resolution of the policy and technical questions that have arisen. Monitoring of pavements for long periods has been applied on a limited basis and in a variety of ways at State and national level for a number of years, but only recently has there been any attempt to coordinate and expand these efforts, to make as much as possible of the available data, to share data among agencies, and to establish the degree of uniformity in the data that is essential to permit its effective use at the lowest cost. The best way or ways to do this are not yet established. It is not altogether clear what uses are to be made of the data, what kinds of data should be collected uniformly for common use and what kinds are so State or District specific that uniformity is not necessary, and how best to share data among agencies. In short, the overall structure of the Long-Term Monitoring effort has not been fully determined as yet. It is believed that after careful consideration is given to all of these questions in the two Long-Term Monitoring workshops in October 1984 and February 1985, a better understanding of the entire process will emerge, and decisions can be made to determine the future direction of the Long-Term Monitoring process in the states and in the nation.

This document has been prepared to provide background information for the first of these two workshops, the purpose of which is to establish priorities on the objectives and uses of Long-Term Monitoring, to consider several possible alternative means of organizing and structuring the Long-Term Monitoring effort, and to recommend those alternatives which are most likely to satisfy the objectives which are determined to be most important. In order to make these decisions effectively, the workshop participants need to be aware of progress to date for the Long-Term Monitoring program, including the experience gained from past data collection activities of short and long duration.

METRIC CONVERSION FACTORS

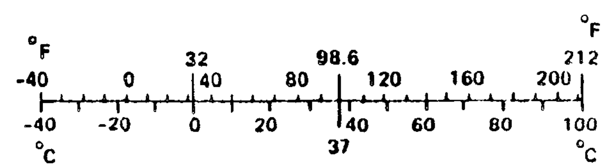
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Long-term monitoring has been carried on for a number of years at both State and National level. The major impetus for these activities was the AASHO Road Test and subsequent satellite and environmental studies which were begun by several States in the 1960's. Subsequently, other Long-Term Monitoring efforts were initiated in the areas of traffic, construction quality, and staffing, overall highway performance, predictive modeling, cost allocation, cost apportionment, and others.

The emphasis at present is toward the development of empirical models with sound statistical bases, and on the establishment of data collection activities to provide sufficient data for serious model-building in the future. The establishment of a statistically sufficient national data base is one of the primary reasons for the proposed Long-Term Pavement Monitoring Program, as well as one of its primary goals.

In 1981, the FHWA Offices of Highway Planning and Engineering developed concepts for the LTM Program, drawing strongly on the opinions and ideas from other offices of the FHWA. It was decided to approach LTM as a cooperative program between the FHWA, an AASHTO Advisory Panel (consisting of the Pavement Management Task Group of AASHTO Joint Task Force on Pavements), and participating State DOT's. The authors of this background document were asked to write two papers to make initial recommendations on data to be collected and on structuring the data collection effort by State DOT's. These papers were presented in June 1981 to a meeting of the FHWA and the AASHTO Long-Term Monitoring Advisory Panel as working papers for consideration and revision to produce an approved plan for funded LTM activities.

Initial pilot studies were established by the FHWA, in cooperation with the AASHTO and selected states, to assess the problems in building a data base that can develop improved pavement damage relationships, as well as to make a beginning in LTM. The initial pilot study has been structured as a cooperative program between the FHWA, AASHTO, and eight selected States to demonstrate and share information on innovative pavement monitoring techniques and to establish a core number of case study sites (minimum of 10 sites per State) to be monitored over at least 10 years. If this pilot study shows sufficient promise, the study will be placed on a firm statistical basis and State participation expanded to establish a broad-based Long-Term Monitoring (LTM) program to develop a national data base.

The FHWA Office of Planning developed in early 1982 a draft "Long-Term Pavement Monitoring Program Data Collection Guide" for use by participating State DOT's. This guide was preliminary and drew heavily on other data collection systems such as COPES for guidance and data collection forms. This data collection guide was distributed to participating State DOT's, and then a coordination meeting was held in Kansas City in April 1982 to identify and resolve potential problems in the pilot study effort. This meeting included interested

FHWA personnel and representatives of the participating State DOT's.

The authors of this background document were contracted with to review the preliminary data collection guide, coordinate proposed revisions with the FHWA, and to develop a finished data collection guide for use in future LTM activities. This has been done.

Another meeting of the LTM Program Advisory Panel was held in Arlington, Texas during December 1982 to discuss FHWA planning for LTM and a variety of ideas from the participants. The participants in this meeting included representatives of the FHWA, FHWA regional offices, State DOT's, the NCHRP, and four private consultants. The invited consultants were Drs. Rauhut, Darter, Lytton, and Hudson.

As the first year of the pilot study data collection activities by the eight State DOT's approached completion, the FHWA contracted with Brent Rauhut Engineering, Inc. (and ERES Consultants, Inc. as a subcontractor) to augment the FHWA technical staff during the evaluation phase. This technical assistance has included the development of a scheme for the initial LTM data bank, entry of data into the data bank, evaluation of the LTM pilot study activity to date, and preparation of this and other documents in preparation for the "Alternative Development Workshop."

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

CHAPTER 1

INTRODUCTION

Long-term monitoring stands at a crossroads. Long-term monitoring efforts have been carried on for a number of years at State and national level and has been generally accepted. However, the shape that it takes in the future will depend very largely upon the decisions that are made in this Workshop concerning the following very basic issues:

1. What questions related to the financing and management of the nation's highways need to be answered and can only be answered with a continuing data monitoring effort?
2. What data need to be collected and evaluated in order to answer these questions?
3. What is the best way to collect and evaluate these data in order to answer a number of these basic and important questions.

The deterioration of the highway infrastructure and the consequent need to use tax dollars wisely to maintain, rehabilitate, and reconstruct the highway system have presented the highway community, the State and national governments with basic policy and technical questions to which, at present, there are only tentative or intuitive answers. Rehabilitated or reconstructed pavements are more difficult to design and construct properly than are new pavements. The composition of the vehicle fleet and vehicle loading distributions, the construction of tires, and the magnitude and distribution of tire pressures are changing rapidly and are expected to have a significant impact on the rate of highway deterioration. There is a growing recognition of the importance of climatic influences on the rate of pavement deterioration. All of these changes have created a dynamic situation for policy-makers who are attempting to determine cost responsibilities for different highway users and to define equitable means of apportioning the funds that are available for preserving our nation's highway network.

Long-term monitoring of pavements is now being generally accepted by the highway community as essential to the resolution of the policy and technical questions that have arisen. Monitoring of pavements for long periods has been applied on a limited basis and in a variety of ways at State and national level for a number of years, but only recently has there been any attempt to coordinate and expand these efforts, to make as much use as possible of the available data, to share data among agencies, and to establish the degree of uniformity in the data that is essential to permit its effective use at the lowest cost. The best way or ways to do this are not yet established. It is not altogether clear what uses are to be made of the data, what kinds of data should be collected uniformly for common use and what kinds are so State or District specific that uniformity is not necessary, and how best to share data among agencies. In short, the overall structure of the Long-Term Monitoring effort has not been fully determined as yet. It is believed that after careful consideration is given to all of these questions in the two Long-Term Monitoring workshops in October 1984 and February 1985, a better understanding of the entire process will emerge, and decisions can be made to determine the future direction of the Long-Term Monitoring process in the states and in the nation.

This document has been prepared to provide background information for the first of these two workshops, the purpose of which is to establish priorities on the objectives and uses of Long-Term Monitoring, to consider several possible alternative means of organizing and structuring the Long-Term Monitoring effort, and to recommend those alternatives which are most likely to satisfy the objectives which are determined to be most important. In order to make these decisions effectively, the workshop participants need to be aware of progress to date for the Long-Term Monitoring program, including the experience gained from past data collection activities of short and long duration.

CHAPTER 2

HISTORICAL DEVELOPMENT OF THE LONG-TERM MONITORING INITIATIVE

EMPHASIS ON PAVEMENT MANAGEMENT

A major reason for the very strong interest in Long-Term Monitoring is its potential for becoming an essential part of pavement management, which is practiced at several different levels: project level, District network level, State highway program level, and Federal highway program level. Each level has its own requirements for information that can be furnished by Long-Term Monitoring. Brief summaries of the kinds of information needed at each level are given below.

Project Level Pavement Management

At this level of pavement management, decisions are made to select a specific action for a specific location, taking into account the previous construction history and traffic, the future anticipated traffic, the current distressed condition and riding quality of the pavement, the current safety record, and the current annual cost of routine maintenance. Deflection tests that may be made on the section will reveal the current structural capacity of the pavement. All decisions will take into account the likely effects of the weather, drainage, active subgrade soils such as expansive clays or frost-heaving soils, cracks or joints that can be activated by temperature cycles, and passing traffic. The selection of a specific action will take into account the materials properties and unit costs of various available alternative materials, the construction operations that are required to produce and place them, the quality control that can be achieved with them, and previous experience with each alternative plan. Design calculations will be made to select the best thickness of each layer. Detailed considerations of all of these factors are usually made in some form or another on each project in the course of arriving at a final decision of what to do. Even though all of this information may be collected in one form or another, very little of it will be stored for use in future project decisions, and it is well that it should not, for in a very short time the accumulation of such data would form an unmanageable mass, the bulk and inertia of which would become too expensive to store and retrieve. Therefore, Long-term monitoring of such data must be limited to significant data representative of typical sections of pavement. It is concerned with measuring and recording systematically data that can be used to establish trends, develop or improve design equations, and record for future reference the distress, deflection, performance, safety and cost history of a particular typical type of pavement, so that future decisions may be based upon actual, objective, and accurate measurements. Long-term monitoring at project level <u>requires</u> a careful selection of pavement sections to be made so that the number of measurements made, the costs, and manpower can be reduced to a manageable minimum. Project level monitoring is wasted if its efforts are spent on exotic experiments which are not intended for eventual widespread use.

District Network Level Pavement Management

At this level of pavement management, specific projects are selected for funding and construction in a specific period of time. The projects may include routine or preventive maintenance, rehabilitation, reconstruction, widening or realignment, or in some cases, new construction. The decisions that are made at District network level take into account the relative condition of each candidate pavement section, the traffic and population it serves, the alternative construction strategies that may be employed on each section and the expectation of how long each will last, the relative costs, and the expected levels of riding quality and distress that each alternative will experience over its useful life. At this level, consideration of all of these factors results in a list of projects in order of priority over a period of years. The list may change from year to year as the needs of each section shift relative to one another.

In some states, the process is taken one step farther to establish an optimal set of strategies to adopt for each section of pavement. There are several different ways of determining an optimum list of projects depending upon the management objectives such as minimizing cost or maximizing benefit, but each method requires a knowledge of how long a typical new or rehabilitated pavement will last under the anticipated traffic, as well as the cost of each alternative that is feasible for each project.

Long-term monitoring at District level will be primarily concerned with developing sufficient data on each typical type of pavement or rehabilitation alternative to be able to satisfactorily predict either:

1. Its survival rate with time or with traffic, i.e. the probability that it will still be in service after a specified number of years or number of axle loads, or
2. The rate at which it changes condition with time or with traffic.

As with project level long-term monitoring, the emphasis at District network level is with collecting data carefully on a sufficient number of typical pavement sections in order to be able to define accurately the survival rate or the rate of change of condition which is essential in either rationally setting priorities or in selecting an optimal list of projects.

State Level Pavement Management

At this level of pavement management, decisions are made to distribute available funds to different political subdivisions of a State based upon a variety of criteria including estimated needs for purposes of safety, increased capacity or improved alignment, rehabilitation, reconstruction, or new construction. The other criteria may include traffic and population served, geographical distribution factors, distribution of lane-miles of different functional classes of highway, and others. In some cases, decisions at this level may be concerned with specific projects of major importance to the spine network of the State.

The needed funds may be estimated based upon the current condition of a sample of the pavement network. The size of sample that is required to represent accurately the condition and needed funds for a particular functional class of highway varies with the number of lane-miles of that functional class, with the percent of the total decreasing as the total number of lane-miles increases.

Also, at the State level of pavement management, projections of needed funds are made a number of years into the future with annual expenditures being estimated 5, 10, or 20 years from the current date. There are two basic ways of making these estimates:

1. Starting with the current condition of each section of pavement in an adequate sample, predict when its condition will reach an unacceptable level, determine using a decision tree what is the appropriate rehabilitative action and its cost, and then predict the next time that section will require funds. Add to this total the funds that are required annually for routine maintenance and occasionally for preventive maintenance. The total funds that are required year after year provide an estimate of the total funds that are needed for the entire State network. An example of this is the Pavement Evaluation System (PES) used in Texas.

2. Starting with a number of "typical" pavement sections that are representative of different functional classes of pavements and a distribution of the ages of all pavements in each class, predict the distribution of times when rehabilitation will be required for the "average" pavement

of each age. Estimate the distribution of costs of rehabilitation for each pavement, and start over again predicting the distribution of times and costs when rehabilitation will be required once more. This process is repeated for each "typical" pavement and the costs incurred in each year are added up to give an estimated total cost for each year within a specified planning horizon. Examples of this are the FHWA NULOAD program and the Texas RENU program that was developed from it.

The two methods will give different estimated total costs because of the different assumptions that underlie each of them, but both estimates should be realistic if a sufficiently large sample of the Statewide pavement network is represented. These projections are used to assist in budgetary planning and in preparing and justifying requests for revenues from the State legislature.

These same two methods of estimating funding needs at the State network level are capable of answering "what if" questions concerning the impact of legislation permitting changes in maximum axle weights and truck sizes and of different fund distribution options.

Thus, at State network level it is possible, and usually desirable, to be able to estimate current needs, to project future needs, and to investigate the impacts of future funding and legislative policies.

Long-term monitoring at State network level is concerned with having sufficient data to develop the predictive equations that are needed for making funding estimates and policy studies. This means that the predictive equations that are used should be representative of the State's pavements and should be chosen among the principal types of pavement in the State on an unbiased or random basis. The predictive equations may or may not be the same as the design equations that are used at project level, and they will include other types of equations such as survivor curves or matrices indicating the rate of change of pavement condition for the principal types of pavement and rehabilitation methods that are in use in the State.

National Level Pavement Management

The National level of pavement management is concerned with establishing an equitable basis for raising revenues and for distributing the funds to the States, and with ascertaining whether the distributed funds are producing reasonably acceptable results among all of the States. Individual projects are rarely considered at this highest policy level. The distribution of funds among the States is dictated by formulas that include a number of factors such as total lane-miles of different functional classes of highway, traffic, mail routes, and other areas of federal responsibility. Frequently, the United States Congress requires special studies to be made concerning, for example, the impact of the different environmental zones in the United States upon the deterioration rates of pavements in order to establish whether some climatic factor or factors should be included in determining an equitable distribution of Federal funds among the States. Other studies may be concerned with cost responsibilities of different vehicle classes, and investigate the relative damage done by each class of vehicle or the relative costs that should be borne by each vehicle class in order to provide a pavement that will provide serviceable performance for all classes of vehicle. Other studies may investigate the economic impact of having different regulations of vehicle sizes and weights from State to State. Still other studies may attempt to determine the overall cost effectiveness of the quality of construction that can be achieved with the different methods of applying construction specifications. All of these studies have a practical result in view: to continually adjust Federal participation in the construction and rehabilitation of the nation's transportation network to become as equitable and as cost effective as possible. Even though the Federal participation, as described above, acts in a supporting, rather than a directing, role in assisting the States in managing the nation's highways, it nevertheless serves an important function in pavement management.

Long-term monitoring at Federal level is concerned with having sufficient data available on a representative sample of the nation's highways to be able to produce definitive and unbiased answers to the questions asked and the policy studies that are mandated by the Congress. These studies may be very detailed in nature, involving the prediction of the appearance and growth of several types of distress in each of a large variety of pavement types in different climates, or it may be very broad in scope involving a computerized study of the condition of pavements in the entire country using the single riding quality statistic that is recorded in the Highway Performance Monitoring System. The studies may range over a variety of topics, requiring access to quantities of detailed data on pavements, traffic, materials, climatic factors, costs, distress, riding quality, safety, and so on. The most important aspect of Long-Term Monitoring at the National level is to have available a representative sample of detailed information on all aspects of pavements with the sample composed of a sufficient number of the principal types of pavements in each of the States. A good distribution of these pavements is essential to eliminate, as much as is practical, any bias that may find its way into the conclusions of a study due to the use of a set of pavements that are not representative.

Different Objectives of Long-Term Monitoring

It is apparent from the previous discussion that the needs for data from Long-Term Monitoring are different at the different levels of pavement management. Project level data needs are focused on developing and continually updating detailed design equations whereas the data needs at higher network levels are concerned with developing and continually updating reliable relations that will permit accurate estimates of present and future costs and the consequences of changes in policy or fund distribution options. The two types of data needed are not mutually exclusive and for the most part may be taken from the same carefully constructed data base, or may be taken from several such data bases provided that the data have been measured and recorded in a uniform way.

Tables 1 and 2 summarize the types of data that are collected in long-term monitoring, the types of equations and other relations that

TABLE 1. Types and Uses of Long-Term Monitoring Data

TYPES OF LONG-TERM MONITORING DATA	USES OF LONG-TERM MONITORING DATA										
	DESIGN EQUATIONS	PREDICTIVE EQUATIONS	Distress	Performance	Safety	Maintenance Costs	DECISION TREES	DECISION CRITERIA	SURVIVOR CURVES	TRANSITION MATRICES	TRAFFIC DISTRIBUTIONS
INVENTORY DATA											
Section ID	X	X	X	X	X	X	X	X	X	X	X
Geometric and Thickness Details	X	X	X	X			X		X		
Drainage Details	X		X				X	X			
Environmental Data	X	X	X	X	X		X	X	X	X	
Prior Traffic and Axle Loads	X	X	X	X	X	X	X	X	X	X	X
Material Properties	X										
Subgrade Properties	X	X	X	X			X				
Construction Costs						X					
Rehabilitation Costs						X					
MONITORING DATA											
Distress	X	X	X				X	X	X	X	
Performance	X	X		X			X	X	X	X	
Traffic and Axle Loads	X	X	X	X	X	X	X	X	X	X	X
Deflections	X	X	X	X			X	X			
Safety Measures		X			X			X			
Dates of Maintenance, Rehabilitation		X	X	X		X	X		X	X	

TABLE 2. Uses of Long-Term Monitoring Data at the Different Levels of Pavement Management

LEVELS OF PAVEMENT MANAGEMENT	USES OF LONG-TERM MONITORING DATA: DESIGN EQUATIONS	PREDICTIVE EQUATIONS	Distress	Performance	Safety	Maintenance Costs	DECISION TREES	DECISION CRITERIA	SURVIVOR CURVES	TRANSITION MATRICES	TRAFFIC DISTRIBUTIONS
PROJECT LEVEL	X	X	X	X	X	X		X			
DISTRICT LEVEL		X	X	X	X	X	X	X	X	X	
STATE PROGRAM		X	X	X	X	X	X	X	X	X	X
FEDERAL PROGRAM		X	X	X	X	X		X	X	X	X

are developed from these data (Table 1), and the levels of pavement management where these relations are used (Table 2). Inventory data are those data which characterize a pavement section and do not change with time or accumulated traffic. Monitoring data are those data which do change with time or traffic. The categories of data shown in Table 1 will be broken down into much more detail in a later section of this document.

FHWA, NCHRP, AASHTO, and State Interests in Long-Term Monitoring

Numerous studies, research projects, implementation efforts, and demonstration projects have been conducted by the FHWA, the NCHRP, the AASHTO, and by various States in subjects that relate to the broad area of pavement management and some of these have been directly related to the subject of Long-Term Monitoring. The FHWA has funded an eight-state pilot study of long-term monitoring, current results of which will be summarized in this document and reported more fully in a separate report and in the course of the workshop. The NCHRP has funded the development of the Concrete Pavement Evaluation System (COPES), which will also be summarized in this document. Several States, by using Highway Planning and Research (HP&R) funds, have developed computerized long-term monitoring data bases, including Arizona, Idaho, Indiana, Kansas, Maine, Texas, and Washington. In every case, the data base was an essential part of the development of a pavement management system. Other long-term monitoring efforts have been initiated by the Federal Highway Administration to address several major questions concerning highway performance, bridge condition, and quality of highway construction. The development of these data bases, information they contain, the questions they were attempting to answer, and some of the studies that have been made with them are described in the next section.

NATIONAL ISSUES ADDRESSED BY MONITORING DATA IN THE PAST

In this section, the development and content of several FHWA data bases will be described along with the results of some of the studies that have been made with them. The data bases include:

1. The Highway Performance Monitoring System (HPMS)
2. The National Bridge Inspection Standard System (NBIS)
3. The Highway Condition and Quality of Highway Construction Survey.

Three of the studies that have been made include the 3-R Needs Study (1976), the Cost Allocation Study of 1977, and the Study of the Size and Weight of Trucks. These studies will illustrate the types of objectives that the FHWA attempts to meet with Long-Term Monitoring data.

Highway Performance Monitoring System

The Highway Performance Monitoring System (HPMS) is a complete computerized information system which includes data collection and policy planning analytical tools. It was developed to make a periodic assessment of the highway systems with respect to extent (system mileage) and physical condition; the safety, efficiency, and economy of the systems in serving the movement of goods and people; and the impacts of existing national programs and policies. In addition, the HPMS addresses the need to assess the potential impacts of proposed programs, policies and alternatives.

In a cooperative effort to develop the HPMS integrated data base, various organizations within the Office of Highway Planning have merged independent data collection efforts into a single data reporting system.

The purposes of the HPMS are as follows:

a. To provide current data necessary to meet legislative requirements and agency needs in a timely manner. Legislative requirements include the Biannual Reports to the Congress on the status of the Nation's Highways, Interstate 4R Apportionments, and the Section 207 Safety Report to the Congress.

b. To provide current statistics on the mileage and extent of the various systems.

c. To evaluate highway programs by monitoring changes in highway characteristics and performance based on detailed section-specific data obtained on a sample basis.

d. To minimize the State reporting burden, the need for special data requests, and special national studies.

e. To be compatible with other data systems to permit meaningful comparisons.

In the HPMS, three major types of data are reported: universe mileage data, sample data, and area-wide data. Each of these are described below.

Universe Mileage Data.

This includes a complete inventory of mileage classified by system, jurisdiction, and selected operational characteristics. These data are reported for all mileage.

Sample Data.

In contrast to universe data, sample data are reported for a small portion of the highway mileage and contain more extensive information regarding physical characteristics, condition, and operation of sampled sections of highway. The sample data serves as a base for evaluating changes in data element values over time, thereby providing a basis for the analysis of the performance of the Nation's highways. The sampled sections form "fixed" panels of highway sections which are monitored from year to year. The panels of sections were established using a statistically designed sampling plan based on the random selection of road sections within predetermined average annual daily traffic (AADT) volume groups (strata) for each functional highway classification in the rural, small urban, and urbanized areas of a State. There are approximately 94,000 sample sections nationwide. Capital improvement data are also part of the sample section data requirements. This consists of all improvements made on the sample panels of sections, including costs and type of improvement. Additionally, six categories of accident data are reported for the sample sections.

Areawide Data.

Control totals for mileage, travel, accidents, and local functional class data are provided via areawide forms. The areawide mileage and travel figures are consistent with the mileage and travel figures developed from the universe and sample data. Areawide data is reported annually for rural, total small urban, and individual urbanized areas.

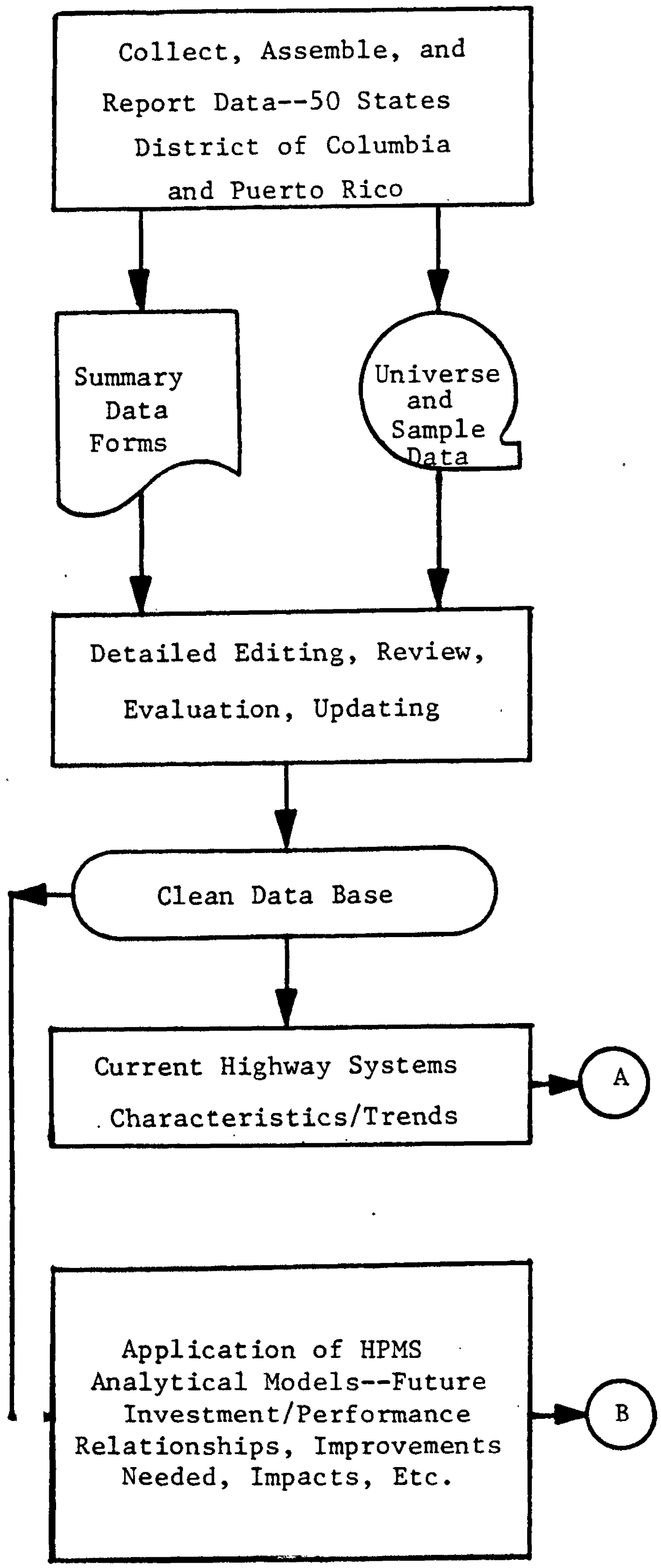
Data on capital expenditures by State and geographic area are reported on the PR-534 form, Highway Capital Outlay and Maintenance Expenditures. The FHWA-534 report was developed in conjunction with the HPMS and is used to measure State and local investment priorities on the arterial and collector highway systems. The FHWA-534 is designed to expand on highway capital outlay and maintenance expenditures by State and local governments by classifying expenditures by system (functional class, Federal-aid, and non-Federal-aid) and by type of improvement. The FHWA-534 is required annually for State highway expenditures and biennially for local government expenditures.

The HPMS is a joint effort of the Federal, State, and local governments. The HPMS organization, guidance, and analyses are the responsibility of the FHWA. Data reporting for the HPMS are accomplished by the State Highway Agencies (SHAs) in cooperation with local governmental units, metropolitan planning organizations (MPOs), and other organizations. Annual data submittals are made by the States. Update cycles for areawide and section data vary from 1 to 5 years, depending on how much the items change with time and upon the importance of having the information current.

Figure 1 illustrates the HPMS procedure starting with the data collection and reporting and concluding with various reports and other principal uses.

There is a wide variety of data collected in the HPMS, including costs that are reported on the PR-534 form for Highway Capital Outlay and Maintenance Expenditures. These data elements and costs are listed below.

Sample Number
Sample Subdivision
AADT Volume Group Identifier
Expansion Factor
Surface/Pavement Type
Pavement Section
SN or Slab Thickness
Pavement Condition
Access Control
Lane Width
Approach Width (Urban only)
Shoulder Type
Shoulder Width
Median Type
ROW Width
Widening Feasibility
Horizontal Alignment Adequacy (Rural only)
Curves by Class
Vertical Alignment Adequacy (Rural only)
Grades by Class
% Passing Sight Distance (Rural only)
Speed Limit
Average Highway Speed (Rural only)
Year
State Code
County Code
Rural/Urban Designation
Urbanized Area Code
Type of Section/Grouped Data ID
Section/Grouped Data Identification
Functional Class
Federal-Aid System
Federal-Aid System Status
Route Signing
Route Number
Governmental Level of Control



A

1.) Biennial Reports to the Congress--Present Condition/Performance Summary Data; Trends.
2.) Sec. 207 Safety Report to the Congress--Fatal and Injury Accident Rates.
3.) Apportionment of Interstate 4R Funds--Interstate lane-miles and vehicle-miles of travel.
4.) "Highway Statistics" and other statistical publications.
5.) Apportionment of Certain Safety Funds-Official Records of Public Road Mileag
6.) Official Records of Federal-Aid Systems Mileage.
7.) FHWA/DOT Data Needs/Services to fulfi organizational goals; data services to gamit of State, Industry, public/private USERS.

B

1.) Biennial Reports to the Congress.
2.) Support of Legislative Initiatives.
3.) Accruing Future Highway Systems Deficiencies and Investment Requiremen s.
4.) Program Review/Development.
5.) Policy Review/Development.

Figure 1. Highway Performance Monitoring System (HPMS) Procedure and Principal Uses

Federal, State, and Local Domain
Special Systems
Type of Facility
Trucks/Commercial Vehicles
Toll
Section/Group Length
AADT
Number of Interstate Lanes Open to Traffic 5 or More Years
Number of Through Lanes
Record Continuation Code
Percent Trucks (Peak and Off-Peak)
K-Factor
Directional Factor
Capacity (Peak and Off-Peak)
Prevailing Signalization (Urban only)
Typical Percent Green time (Urban only)
Parking (Urban only)(Peak and Off-Peak)
Future AADT
Drainage Adequacy
Type of Terrain (Rural only)
Type of Development
Urban Location
No. of Grade Separated Interchanges
No. of Major Commercial/Recreational/Industrial Access Points
No. of Structures
No. of At-Grade Railroad Crossings
Structure Identification Numbers
At-Grade Railroad Crossing Identification Numbers
Type of Improvement
Capital Improvement Costs
Accident Data

The costs that are reported as Highway Capital Outlay and Maintenance Expenditures on the PR-534 form are in one of four categories: Federal-aid projects, non-Federal-aid projects, non-Federal-aid system, and total. The costs that are reported are listed below.

Right-of-Way Costs
Engineering Costs
New Route Costs
Relocation Cost
Reconstruction Cost
Major Widening Cost
Minor Widening Cost
Restoration/Rehabilitation Cost
Resurfacing Cost
Bridge Replacement Cost

Bridge Rehabilitation Cost
Safety/Traffic Operations Cost
Environment Related Cost
Total Capital Outlay
Physical Maintenance Cost
Traffic Service Cost
Total Maintenance Costs

In addition to these data elements, it is currently being proposed by the FHWA that vehicle classification data be obtained on a statistically drawn subset of the HPMS sections (approximately 15,000 sections) and that vehicle weight data be obtained from a sample of the vehicle classification sections (approximately 1000-1500 sections). Such additional information will greatly enhance the FHWA's ability to estimate vehicle type, volumes using the highway systems, and vehicle loads on these systems.

HPMS Analytical Process.

As stated previously, the HPMS analytical process is a policy planning tool useful for statewide analysis at the functional system level. The validity of any analysis attempted at a lower level, such as a highway district, will depend on the validity of the highway sample at that particular level.

Forecast Highway System Needs. The HPMS process forecasts highway needs and provides summaries of miles and costs of each type of highway improvement for each functional system. The need for an improvement is determined for each sample section by comparing highway conditions year by year with specified minimum tolerable conditions. Costs are based on the simulated improvements selected to correct all deficiencies which are identified within a specified analysis period (up to 20 years).

Simulate Highway System Conditions. The HPMS data base contains the existing conditions of the sampled highway systems for the base year. The models simulate changes which would be expected to occur during an analysis period. Pavement deterioration and traffic exposure data are used to determine the conditions that are expected to occur in any future year during the analysis period. If an improvement is simulated, changes are made in the data items (e.g., lane width and pavement condition) that would be affected by the improvement. The process continues until the target year (last year of analysis period) is reached. Target year conditions are also simulated under the assumption that no improvement is made. This allows comparison of target year conditions with and without the selected capital improvements.

Analyze Investment Strategies. The HPMS provides for analyses using specific levels of funding by functional system for specified analysis periods. The models estimate the miles and costs of each improvement type funded under a given investment level, as well as the conditions of the highway systems resulting from these expenditures. Up to four consecutive periods (maximum total of 20 years) may be analyzed, with funding for each period provided by the user. In this way, different total levels of investment and different distributions of funds among the functional systems can be compared.

The effect of each investment level can also be evaluated with respect to other variables. For example, various minimum tolerable conditions can be specified while holding other variables constant.

This technique can be used to emphasize certain types of improvements and to show which types of improvements are most cost effective.

Estimate User Costs. Estimated user costs for the base year and the target year may be analyzed under any scenario. The user cost measures include fuel consumption, vehicle operating costs, average overall travel speed, emissions, and accidents. The model simulates these costs for seven separate vehicle types on each functional system.

HPMS Outputs.

The printed output summaries from HPMS are separate for each functional system in rural, small urban, and urbanized areas.

Miles and Costs by Improvement Type. The miles and costs for each improvement type are listed for each analysis period and level of investment.

Composite Index Values (Sufficiency Ratings). The ratings for condition, safety, service, and the composite value are displayed. These values are shown in two ways--weighted by mileage and by travel. The values may be displayed for the base year and projected for the target year. Distributions of these index values are also displayed, indicating what portions of mileage and travel fall within each specific range of the index values.

Investment/Performance Conditions. Percentage of miles and travel by pavement type, pavement condition, lane width, cross section, volume/capacity ratio, and peak hour operating speed are shown for each investment level. These values, along with the composite index values, illustrate the potential results of various investment scenarios.

Distribution of Investment. The miles and costs of the improvements funded in a particular scenario are listed. The same data are also shown for needed improvements selected by the model but not funded by that particular investment level.

User Costs. User costs are simulated for each of seven vehicle types. The "costs" are represented by average overall travel speed, fuel consumption, vehicle operating costs, emissions, and accidents. These may be produced for the base year and for various investment levels.

Multiple Deficiencies. The mileage of certain types of deficiency and of certain fixed combinations of these deficiencies are listed. The specific deficiencies addressed are pavement condition, geometric (rural only), roadway cross section, operational, and access control (Interstate only). A comparison may be made among (1) the deficiencies resulting from a particular level of investment, (2) the deficiencies that would exist without capital improvements for the analysis period, and (3) the deficiencies already existing in the base year.

Deferred Costs. When resurfacing or widening improvements are deferred for lack of funds, it is possible that by the time the improvement is funded, the original improvement type may no longer be adequate. Some type of reconstruction may be needed. This analysis shows costs for the improvements initially selected but not simulated and costs for the later improvement which was actually simulated.

This gives an indication of the increase in construction cost resulting from deferment of the initial improvement. Inflation costs are not considered.

Types of Analysis by HPMS.

HPMS performs three basic types of analysis: needs, investment, and impact. Each of these is summarized below.

Needs Analysis.

1. Travel Projection. Using the current and future average annual daily traffic data items, travel is projected for each year of the analysis period.

2. Pavement Deterioration. Using a modification of the AASHTO Road Test equations and 18-kip equivalent axle loads, pavement deterioration is simulated over time. A normal level of maintenance is assumed.

3. Capacity Calculation. Using methods based on the Highway Capacity Manual (1965), capacities are calculated for future conditions and simulated improvements.

4. Deficiency Identification. Deficiencies are identified by comparing the conditions of each sample highway section with the minimum tolerable conditions specified for that type of highway.

5. Improvement Type Simulation. Based on the identified deficiencies, the model selects one of twelve possible types of improvement for each highway section. Changes are made to the section record to simulate the changes that would be

made by the type of improvement selected.

6. Cost Estimation. Construction and right-of-way costs are based on the improvement type and the number of lanes after improvement. Rural costs are also based on functional class and terrain type. Urban costs are based on highway design type and type of development. Costs are 1980 national average values, which may be changed by the user.

7. Composite Index Assignment. The composite index value is based on three components--condition, safety, and service. Each of these components is in turn based on several data items which directly affect it. This concept is similar to the sufficiency ratings used by many States.

Investment Analysis.

1. Investment Level. This process analyzes seven fixed levels of investment over a single funding period of up to 20 years. The levels range from full needs to zero capital investment. "Full needs" means that all selected improvements are funded. For the five intermediate funding levels, only a portion of the selected improvements are funded and simulated. This analysis provides identification of full needs costs, types of improvement, and the resultant system conditions for each investment level.

2. Funding Period. The model allows selection of up to four consecutive funding periods for analysis (maximum total time is 20 years). The funds available for each period are provided by the user. The results are produced separately

for each funding period. The improvements simulated for each period are taken from the top of the priority listing for the period, to the extent of available funds.

3. Improvement Prioritization. Sample sections identified as needing improvement are ranked in priority order. This ranking is based on either a cost effectiveness index, the base year composite index, a combination of these, or any one of the component indices (condition, safety, or service). When less than full needs funds are available for investment, the improvements are selected from the top of the ranking list until all funds are expended. Improvements ranked below this point are not simulated by the model. The prioritized list of sample sections may be printed for inspection.

Impact Analysis.

1. Traffic Density Distribution. The model distributes daily travel over several discrete portions of the 24-hour day, each with a different level of congestion. Each portion of the day is analyzed separately and the results are aggregated.

2. Traffic Fleet Composition. The model determines the distribution of the seven vehicle types by rural and urban functional systems. The vehicle types include two sizes of passenger cars, pickups and vans, and four sizes of trucks.

3. Vehicle Operation Simulation. Operation of each of the seven vehicle types is simulated on each sample section.

This simulation includes the effect of traffic density, pavement type and condition, curvature, and grade. The effects on vehicle operation are analyzed in terms of running speed, speed change cycles, stops, idling time, fuel consumption, and vehicle operating costs. Emissions and accidents are also considered in the analysis.

4. Estimation of User Costs. Average overall travel speeds, fuel consumption, vehicle operating costs (1980 values), and emissions are estimated for each of the seven vehicle types based on the parameters given in paragraph 3 above. Accidents are estimated collectively for all vehicle types.

Availability, Costs, and Documentation of HPMS.

The HPMS dataset is readily available since this data is furnished annually to FHWA by the States. The same sample section data is used as input to the analysis model. For use statewide, no further data manipulation should be necessary. The sample is designed to be statistically sound on a statewide basis for each functional system in either rural, small urban, or urbanized areas. The programs are designed for use with a minimum of effort or additional coding. Parameter cards are used to specify the options desired and to modify certain values or tables (e.g., minimum tolerable conditions). Other changes (e.g., construction costs) may be made by modifying only one subprogram. The actual cost of operation varies according to the computer system, number of sample sections, and types of analysis specified. In general, no more than 2 minutes CPU time and 450K core are required for a specific computer run (approximate range of $4 to $45).

Although the HPMS analytical process was originally developed for use on the national level, it has been modified for use on a statewide basis and has been tested in several States. The software is available, along with Volumes II, III, and IV of the documentation. A State may request the software by sending a computer tape to:

Federal Highway Administration
Office of Highway Planning (HHP-12)
400 Seventh Street, S.W.
Washington, D.C. 20590

The Federal Highway Administration will be available to provide technical assistance to States using the process. The HPMS documentation package consists of:

A. Volume I - Executive Summary. The Executive Summary is a brief overview of the capabilities of the HPMS analytical process.

B. Volume II - Technical Manual. The Technical Manual contains the technical aspects of the package including the types of analysis done, the formulas used, and the values of various tables included in the programs such as minimum tolerable conditions, design standards, and improvement costs.

C. Volume III - User's Guide. The User's Guide contains the instructions for using the analytical process. This includes specifying which analyses are to be run, how to override default values, and how to specify funding for analysis periods.

D. Volume IV - System Documentation. The System Documentation provides information on the structure of the software and on the logic of the analyses. It explains how certain values or features included in the process can be changed.

Highway Condition and Quality of Highway Construction Survey

Physical deterioration of pavements and bridge decks, reduction in testing and inspection manpower in construction projects, and concerns for maintaining or improving the quality of highway construction led the Federal Highway Administration to initiate the 1976 Highway Condition and Quality of Highway Construction Survey.

The basic approach of the Survey called for the conduct of the following:

1. Condition surveys of recently completed pavements and bridge decks (0-9 years of service life).
2. Construction quality surveys of on-going projects.
3. Construction staffing surveys of on-going projects.

The analytic procedures of the Survey provided for the synthesis and correlation of these three bodies of information (condition, construction quality, and project staffing), one with another, to assist in answering the following fundamental questions with respect to rigid and flexible pavements and bridge decks:

1. Are highway pavements performing in accordance with service life expectations, and if not, is there an association with construction quality?
2. What are the current quality levels of ongoing construction?
3. What are the critical quality parameters that insure good

performance?

4. What are the trends in staffing of construction projects?

5. Does project staffing affect the quality of the work?

In addition to providing insight to these basic questions, the Survey was to provide a reference datum against which subsequent quality and staffing evaluations and comparisons can be made to judge the efficacy of corrective measures.

The Condition Survey Phase consists of evaluating, on a sampling basis, the condition of completed pavements and bridge decks with 0 to 9 years of service life. The pavements and bridge decks are randomly sampled on a stratified basis for the 9-year period; thus, it was possible to draw inferences with regard to the trends of such performance criteria as pavement roughness, skid resistance, and serviceability indices.

The Construction Quality Survey Phase calls for assessing the current quality levels of materials and procedures utilized in the construction of rigid and flexible pavements and bridge decks. On-going Interstate and Federal-aid Primary projects involving the construction of one or more of these elements during the period of July 1, 1976, to October 15, 1976, were surveyed on a sample basis. Quality data were gathered for 3 production days on each project and analyzed using a statistically based estimating tool called the Quality Level Procedure. This tool uses the results of routine project tests and inspections, project specification requirements, and statistical theory to estimate the quality of work being performed or produced. The results are a measure of the Quality of Conformity to

Specifications.

The Construction Staffing Survey Phase calls for a review of project staffing relating to those activities which contribute to the quality of the pavement or bridge deck, namely inspection and testing. The staffing portion of the survey was conducted concurrently with the quality of conformity portion of the survey in order to determine if a correlation exists between staffing and quality level. In addition to staffing level information, data on personnel classifications, personnel qualifications, activities performed, and work units were collected and analyzed to provide bench marks for purposes of construction manpower planning. Due to the wide variability of staffing data collection and the difficulty in drawing conclusions, staff data are no longer collected in the Survey after 1982.

The results of the survey were published in July 1977, in the "Highway Condition and Quality of Highway Construction Survey Report." The 1976 Survey was a prototype survey and was the model for future Surveys. As a result of the experience gained in 1976, improvements were made in the survey forms and data collection techniques. The 1979, 1980, 1982, and 1984 Surveys are a continuation of the 1976 Survey and were conducted to:

1. provide current information on the condition of recently completed highways,
2. identify problem areas in the quality of highway construction,
3. provide information necessary to formulate strategies to

improve the quality,

4. provide data necessary to determine the relationship, if any, between the quality of construction and pavement distress, and

5. generate data about project staffing and productivity rates to allow identification and analysis of staffing trends.

The 1979 and 1982 Surveys covering flexible pavements and the 1980 and 1984 Surveys covering rigid pavements and bridge decks were divided into current condition, construction quality, and construction staffing phases. The projects selected for the current condition phase are limited to those that were reviewed in a previous construction quality phase. The construction quality phase consists of a review and evaluation of selected quality elements on Interstate and Federal-aid primary projects where construction is underway. Quality of construction evaluations are made on the subgrade, subbase, base course, binder and surfacing courses of both flexible and Portland cement concrete pavements. In addition, the distress, skid, and Present Serviceability Rating were determined for each project. The number of projects that have been evaluated ranged between 58 and 633 depending on which pavement element was studied. The data that were collected include the items shown in Table 3. The condition, weighted average quality level, quality level below 90 percent, and various staffing percentages were compared between 1976 and two subsequent surveys (1979 and 1980) to see whether construction quality and staffing levels are declining and whether there is a correlation between construction quality and the observed distress. Some of the

TABLE 3. Data Collected in the Highway Condition and Quality of Highway Construction Survey

<u>Project Identification</u>

Subgrade

Moisture
Density
Staffing: Testing or Inspection
Engineers or Technicians
Years of Experience
Number and Man-Hours

Subbase

Moisture or Admixture Content
Density
Grading, % Passing #200
Control Sieve, % Passing
Thickness
Staffing: (same as for subgrade)

Base

Moisture or Admixture Content
Density
Grading, % Passing #200
Control Sieve, % Passing
Thickness
Staffing: (same as for subgrade)

Binder Course

Mix Laydown Temperature
Density
Bitumen Content
Grading, % Passing #200
Control Sieve, % Passing
Thickness
Staffing: (same as for subgrade)

Bituminous Surfacing

Mix Laydown Temperature
Density
Bitumen Content
Grading, % Passing #200
Control Sieve, % Passing
Thickness
Surface Roughness, in/mi
Staffing: (same as for subgrade)

TABLE 3. Data Collected in the Highway Condition and Quality of Highway Construction Survey (Cont'd)

Project Identification (Cont'd)

Portland Cement Concrete Base or Surfacing

- Mix Temperature
- Air Content
- Slump
- Water/Cement Ratio
- Density
- Strength
- Thickness
- Surface Roughness, in/mi
- Staffing: (same as for subgrade)

Pavement Condition

- Design 18-kip Equivalent Single Axle Loads (ESAL)
- No. of 18-kip ESAL Applied to Date
- Age of Pavement
- Skid Number
- Present Serviceability Rating
- Pavement Distress Severity (10 types)
- Pavement Drainage
- Maintenance Cost/Mile

Bridge Deck Construction Quality

- Mix Temperature
- Air Content
- Slump
- Water/Cement Ratio
- Density
- Strength
- Thickness
- Surface Roughness, in/mi
- Reinforcing Bar Cover
- Staffing: (same as for subgrade)

Bridge Deck Condition

- Distress Severity
  - Cracking
  - Spalling
  - Rutting
  - Polishing
- Reinforcing Bar Cover

results of these comparisons are repeated in Tables 4 through 6. Table 4 shows the change of the percentages of projects with quality levels below 90 percent from 1976 to 1979. The average change was +10.7 percent for the binder course and +7.5 percent for the surface course, indicating a significant decline in quality. The same general trend was noted in rigid pavements and bridge decks. Table 5 shows the changes in rigid pavement quality from 1976 to 1980, indicating an average change of 11.9% of all projects being built in 1980 at lower quality than in 1976. Table 6 shows the change in construction quality for bridge decks indicating that 4.1% more projects are of lower quality in 1980 than in 1976. The changes in project inspection and testing showed that fewer and more experienced engineers and technicians are being used in these crucial areas in construction.

Quality Levels

The term "quality level" has been used without definition up to this point. A specific definition was used in this survey by basing the quality level on the degree to which construction quality control tests were within specified limits.

An upper and lower Quality Index was calculated from the average test value, x, the upper and lower specification limit, U.L. and L.L., respectively, and the range of test values, R.

The upper Quality Index is

$$Q_U = \frac{U.L. - x}{R}$$

TABLE 4. Percent of Flexible Pavement Projects With Quality Levels Less Than 90

Quality Control Factor	Percent of Projects 1976	1979	Change in Percent
Binder Course			
Laydown Temperature	10	21	+11
Density	28	42	+14
Bitumen Content	18	36	+18
% Passing No. 200	18	23	+ 5
% Passing Control Sieve	26	23	- 3
Thickness	56	75	+19
	Average change		10.7%
Surface Course			
Laydown Temperature	16	19	+ 3
Density	40	46	+ 6
Bitumen Content	30	34	+ 4
% Passing No. 200	21	27	+ 6
% Passing Contol Sieve	22	32	+10
Thickness	53	69	+16
	Average change		7.5%

TABLE 5. Percent of Rigid Pavement Projects
With Quality Levels Less Than 90

Construction Quality Element	Percent of Projects With Quality Levels Less Than 90			
	1976	1980	Change	% Change
Subgrade				
Density	27	33	+ 6	+ 22.2
Subbase				
Moisture/Admixture Content	50	38	-12	- 24.0
Density	24	33	+ 9	+ 37.5
No. 200 Sieve	10	12	+ 2	+ 20.0
Control Sieve	9	17	+ 8	+ 88.9
Thickness*	27	63	+36	+133.3
Aggregate Base				
Moisture/Admixture Content	40	54	+14	+ 35.0
Density	33	39	+ 6	+ 18.2
No. 200 Sieve	24	22	- 2	- 8.2
Control Sieve	20	18	- 2	- 10.0
Thickness*	38	48	+10	+ 26.3
Bituminous Base				
Laydown Temperature	NR	25		
Density	17	29	+12	+ 70.6
Bitumen Content	17	35	+18	+105.9
No. 200 Sieve	19	19	0	0
Control Sieve	29	31	+ 2	+ 6.9
Thickness*	60	50	-10	- 16.7
PCC Base				
Mix Temperature	NR	0**		
Air Content	NR	33		
Slump	NR	28		
W/C Ratio	NR	NR		
Density	NR	50		
Strength	NR	42		
Thickness*	NR	47		
PCC Surfacing				
Mix Temperature	10	15	+ 5	+ 50.0
Air Content	19	31	+12	+ 63.2
Slump	39	50	+11	+ 28.2
W/C Ratio	11	11	0	0
Strength	12	19	+ 7	+ 58.3
Thickness*	30	32	+ 2	+ 6.7
Density	NR	67		
Overall				
Average for all Pavement Surfacing Elements	20.2	32.1	+11.9	+ 58.9

TABLE 6. Percent of Bridge Deck Projects With Quality Levels Less Than 90

Construction Quality Element	Percent of Projects With Quality Levels Less Than 90			
	1976	1980	Change	% Change
Mix Temperature	7	14	+ 7	+100.0
Air Content	26	37	+11	+ 42.3
Slump	52	51	- 1	- 1.9
W/C Ratio	13	21	+ 8	+ 61.5
Density	20	29	+ 9	+ 45.0
Strength	5	11	+ 6	+120.0
Rebar Cover*	68	57	-11	- 16.2
Average for all Bridge Deck Surfacing Elements	27.3	31.4	+4.1	+ 15.2

*The indicated lack of conformity to specifications for thickness and rebar cover control may be due to limited construction tolerances.

The lower Quality Index is

$$Q_L = \frac{x - L.L.}{R}$$

A table for estimating the percent of the lot that is actually within tolerance was used to establish the percent within upper and lower bounds, P_U and P_L, respectively. The total percent within tolerance limits, P_T, was given by

$$P_T = (P_U + P_L) - 100$$

If this value of P_T was less than 90, the test was counted among those with a quality level less than 90.

With this definition, a quality level of "100" is an estimate that all of a product meets the specifications; a quality level of "80" is an estimate that 80 percent of the product meets the specifications.

A quality level of 90 (estimating 90 percent of the production complies with specifications) was selected as the criterion to differentiate between good quality work and that where improvements may be needed. These criteria, i.e., the estimated percent of the production in compliance with the specifications and the percent of projects with quality levels less than 90, are the basic analyses used to develop conclusions about the quality of construction.

Correlations Between Pavement Distress and Quality Level.

A simple linear regression analysis was made to determine if the severity of distress recorded in 1979 on flexible pavements was correlated with the quality levels recorded in 1976. Some correlations were found, to be significant and these are listed in Table 7.

Significance of Highway Condition and Quality of Highway Construction Survey.

The information that has been collected in 1976, 1979, and 1980 has been coded and stored in a computer-accessible form for a variety of pavement sections for which a complete set of data construction, traffic, distress, and quality control materials properties are recorded. There are over 600 flexible pavements in this data base, as well as over 400 rigid pavements and over 300 bridge decks. It is a good start for Long-Term Monitoring and may be able to be blended into an overall monitoring program.

Cost Allocation

The subject of Cost Allocation is tied ultimately to road user taxes. It is now and has been for decades a subject of intense interest by all taxpayers and has as its objective to arrive at an "equitable" means of distributing the costs of building, maintaining, rehabilitating, and reconstructing the nation's highways. As it has been practiced in the last 25 years, the cost allocation approach that has been used by the Federal government and most State governments is

TABLE 7. Correlated Distress Types and Low Construction Quality Levels

Distress	Related Quality Control Tests
Longitudinal Cracking	Binder Course Gradation Bitumen Content Surface Course Thickness Bitumen Content
Transverse Cracking	Subbase Gradation Thickness Binder Course Gradation Thickness Bitumen Content Surface Course Gradation Thickness Bitumen Content
Rutting	Subbase Moisture/Admixture Content Surface Course Density

predicted on fairness or equity, which is defined as "cost allocation on the basis of cost occasioning," that is, those vehicle groups that give rise to certain capital costs should bear the tax burden to pay for such costs. Whatever basis is adopted for allocating these costs, it must be perceived as fair or equitable by highway users and even non-users who also pay a share of the costs.

One of the primary purposes of the AASHO Road Test was to provide basic data on which to base an equitable allocation of costs for a major Federal cost allocation study conducted between 1956 and 1965 with major reports to the U.S. Congress in 1961 and 1965. The study was mandated by the Highway Revenue Act of 1956, which also established the Highway Trust Fund.

The preferred method of that early study made use of the then recently developed AASHO Road Test equations. Essentially, the method consists of a sequential design of a pavement for successive increments of axle weights and because of this is termed the "Incremental Method." Axle loads are categorized into six groups and all axle loads within a range of axle loads are assumed to weigh the same as the upper boundary of their respective weight group, except that the heaviest category is represented by an appropriate average load. Twenty-year axle passages in each weight category are estimated.

A series of pavement thicknesses is designed. The first thickness is designed for all axles at their actual weights. The next thickness is designed for all axles as though they weighed a maximum of 20,000 pounds (20 kips) for a single axle or a corresponding equivalent weight tandem axle. The difference in thickness is charged equally to each axle above 20 kips. The process is repeated until the thickness corresponding to a maximum load of 3 kips (the upper boundary of the lightest axle weight group) is designed. The cost of this final thickness is assigned equally to all axles.

Only new pavements were considered in this incremental approach. Pavement overlay and reconstruction costs were assigned in the same proportion as results from application of the approach to hypothetical new pavements. No overlaid or recycled pavements were designed or considered, as was probably appropriate for a study done when construction of the Interstate system was just beginning and when Federal funds on other highway systems were much more concentrated on new construction than they are today.

A pavement of a given thickness can withstand a certain number of ESAL applications before wearing out. According to design theory, it does not matter whether the ESAL's are provided by a large number of small axle loads or a small number of large axle loads. Further, the number of ESAL applications accommodated by the addition of 1 extra inch of pavement thickness is much less for thin pavements than for thick pavements.

The old incremental method fails to follow equitable application of design theory by charging one set of axle weights a different thickness-requirement-per-ESAL than another set of axle weights. The order of hypothetical ESAL removal, i.e., which vehicle class is removed first, has a profound effect on pavement cost assignment. According to standard design theory, it can be done in any order. An equitable removal order would not systematically give lower charges to one set of axle weights than another but would uniformly remove ESAL's from all axle weight classes during the cost assignment process.

A new study of cost allocation was mandated by the U.S. Congress in the Surface Transportation Assistance Act of 1978. There were several reasons that a new study was seen as desirable. For example, as stated in the Congressional Budget Office Guidelines:

> A new cost-allocation study now appears to be needed for several reasons. First, an increase in highway taxes appears likely in the near future as the growth in Highway Trust Fund revenues is outstripped by continued inflation in construction costs. The financial stress on the Highway Trust Fund will intensify as the effects of energy legislation start to dampen the growth in consumption of motor fuels, thereby holding back the growth in associated tax receipts.
>
> Second, a new look at cost allocation becomes timely as the federal highway program shifts emphasis away from new construction and toward repair and rehabilitation. Some of the new programs associated with this shift differ significantly from those now in effect in the ways in which costs can be traced to specific groups of users.
>
> Third, the last comprehensive federal cost-allocation study was published in 1965. Much of the information used in that study is by now out-of-date and unreliable. Estimates of travel by each class of vehicle, for example, which are essential throughout the process of cost allocation, are based on traffic counts that vary considerably in reliability.
>
> Finally, the methodology used in previous studies can be improved upon both in a number of technical aspects and in the way it reflects the new mix of federal highway programs.

It was recognized that the incremental method of cost allocation that was used in the last major Federal study did not account for pavement 4-R (resurfacing, restoration, rehabilitation, and reconstruction) costs. This is primarily because in the 1950's the emphasis was on initiating the Interstate system and the incremental method had a certain appeal.

Section 506 of the 1978 Surface Transportation Assistance Act is the portion of the Act that bears directly on the subject of Long-Term Monitoring. In Section 506, the Secretary of Transportation was authorized and directed, in cooperation with the State highway departments, to undertake a complete investigation and study of:

(1) the costs occasioned in design, construction, rehabilitation, and maintenance of Federal-aid highways by the use of vehicles of different dimensions, weights, and other specifications, and by the frequency of such vehicles in the traffic stream;

(2) the proportionate share of such design, construction, rehabilitation, and maintenance costs attributable to each class of persons and vehicles using such highways; and

(3) the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors.

Recommended Approach.

The FHWA and several contractors carried out several studies of cost allocation methods and finally arrived at a recommended one which deals with new pavements differently than rehabilitated ones. The recommended approach for assigning pavement costs follows directly from the major criticisms of the approach used 20 years ago. First of all, distinction is made between costs incurred to build new pavements and costs incurred to reconstruct or repair existing pavements. New pavement costs are assigned based on current pavement design practice. Vehicles from each class are hypothetically removed in equal proportions until further removal would not reduce pavement thickness required. Pavement repair and reconstruction costs are assigned based on each vehicle's anticipated contribution to the wearing out of the pavement. Unlike the approach of 20 years ago, the recommended approach specifically attempts to assign pavement rehabilitation costs based on the reasons these costs are incurred. Similarly, the recommended method for new pavement overcomes the major weaknesses of the application of the old approach to that category of costs.

The cost allocation approach used in the 1982 study is to consider each of the most important distresses for flexible and rigid pavements, model their occurrences as a function of traffic, and gauge the relative importance of each distress at different magnitudes in the decision to rehabilitate a pavement.

The distress models are based on both pavement performance theory and on the performance of actual pavement sections. Each distress is expressed as a function of the factors that contribute to it; traffic is one of the factors in most of the major distresses.

Together, the distress models are used to simulate the condition of pavement sections after the passage of time and traffic. At some point, the combination of distresses occurring induces a decision to rehabilitate the road. The distresses existing at the time of this decision have, therefore, caused the need to rehabilitate. A number of States use numerical ratings to determine the need for rehabilitation as a function of distresses, so the relative importance of each distress can be estimated directly.

Neither the distress models nor the distress weighting schemes are the final word in analysis of the causes of the need for pavement rehabilitation. Despite the many highway pavements built during the past 20 years, there are simply not enough monitored sections with adequate traffic data to conclusively verify the mechanistic pavement behavior theory that was relied upon in the development of the pavement distress models used in this cost allocation study.

Similarly, rationalization and quantification of the pavement rehabilitation decision are still improving and are expected to evolve rapidly in the next few years as the importance of rational pavement management gains wide recognition. Thus, the approach used in the 1982 study for rehabilitated pavement cost assignment, although judged to be better than any alternative and far better than ignoring rehabilitation costs, as was done in the 1956-1965 study, results in an improved, but much less than perfectly accurate, cost assignment.

The assignment of pavement rehabilitation costs has a major effect on the overall cost assignments to vehicle classes. Not only are pavement expenditures the largest components of Federal highway dollars, but the relative cost responsibilities are more sensitive to changes of vehicle class than any other category of costs. Thus, the importance of improving our knowledge of pavement deterioration relationships via Long-Term Monitoring cannot be overemphasized.

Other FHWA Long-Term Monitoring Data Bases

In addition to the HPMS and Highway Condition and Quality of

Highway Construction data bases, the FHWA has developed other data bases for specific purposes. Several of these are described below.

Highway Statistics.

This data source is a general collection of a myriad of existing reporting forms which are periodically supplied to FHWA. The information gathered in this manner includes extensive mileage, motor fuel, motor vehicle, driver licensing, highway usage characteristics, and finance data. These data, however, have some features that hinder their direct use in monitoring performance. For instance, individual tables present different details that are not interrelated and data are not always presented in a consistent manner. Without these consistencies and interrelationships, performance cannot be successfully monitored.

Another problem area relates to the definition of "municipal" and "urban." The term "municipal" is not synonymous with "urban" and varies from State to State. While urban is normally defined as Federal-aid urban, there is no separation of small urban and urbanized information, and this definition is normally used only with Federal-aid system discussions.

Motor fuel, motor-vehicle taxes and revenues, vehicle registration, and driver licenses data are considerably more useful. Financial expenditure data are available in aggregate form but are not available by functional classification, improvement type, or individual urbanized area.

Table TA-1.

This table provides statewide information on mileage, vehicles per day, travel, fatalities, fatal accidents, nonfatal injuries, and nonfatal injury accidents by Federal-aid and generalized functional system--arterial, collector, and local. Rural- urban and full control of access breakdowns are provided; accident information is presented in both number and rate form.

The above data presently allows State-by-State comparisons of rate information on a Federal-aid and other State and local road basis. However, there are no property-damage-only accident rate, detailed functional system, design type, or well-defined geographic location data available.

Fatal Accident Reports System (FARS).

This National Highway Traffic Safety Administration (NHTSA) system provides data on fatal accidents for rural and urban areas within each State. However, not only does it not provide information on other types of accidents, the traffic volumes associated with the accidents, access control, and functional system, but also the accuracy of the data describing the conditions related to the accident is questionable. There is also a difference in the definition of a fatality between this source and Table TA-1.

Truck Weight Study (TWS).

This source of information provides vehicle classification data on an annual basis and truck weight data every other year with approximately half the States reporting each year. There are several difficulties in using data from this source. First, the proportion of trucks in the classified traffic stream is higher than the overall average because the stations are located on routes that have heavy truck usage. Secondly, there is a limited number of urban stations. And finally, there is significant weight information available only for the summer months. A revised TWS Guide, currently in draft form (July 1984), addresses many of these shortcomings. For additional information on this, contact Frank Jarema, HHP-44, (202) 426-0160.

Nationwide Personal Transportation Study (NPTS).

This study was conducted by the Bureau of the Census, Department of Commerce, for FHWA in 1969-70. This survey made it possible to relate household socio-economic and location characteristics to daily travel characteristics for all modes, but only for nationwide statistics.

The NPTS was merged with the National Travel Survey (NTS) in 1977 and, therefore, is part of the 1977 Census of Transportation. Resultant data are in aggregate areawide form for various levels of geographic detail. No information on functional classification is provided. These efforts will provide useful national background information but will provide no State or section specific information.

Automatic Traffic Recorder Data (ATR).

There are presently 45 States submitting hourly traffic volume data on computer tape for some 4,085 permanent ATR counter locations nationwide. Due to technical problems, particularly the collection of data in winter months, only 3,000 are supplied for more than 9 months of the year.

Each counter site reported is identified by route, location, and highway class. Until such time that the identification information can be expanded to include functional classification and other physical characteristics, these data will not be very useful in performance monitoring.

Structure Inventory and Appraisal of the Nation's Bridges. Under the National Bridge Inspection Standard (NBIS) inventory program, all bridges on the Federal-aid systems are inventoried, inspected, and appraised by the States. The first NBIS inventory was begun in July 1972 with the most recent update required as of December 1, 1977. These data now include functional classification as well as city and county codes.

National Highway-Railroad Crossing Inventory.

This inventory contains up-to-date information for each crossing. The functional classification of the highway is identified, but the Federal-aid rural, small urban, or urbanized area designation is not included.

Other Data Sources.

Four other data sources were examined and were found to be deficient to the extent that they were excluded from the monitoring process. These sources and a major deficiency for each are:

- 55 M.P.H. Speed Monitoring Studies. Collected only on those segments having a 55 m.p.h. speed limit.

- Truck Inventory and Use Survey (Bureau of the Census). Is a probability sample collected every 5 years and is not reliable at less than multi-State area levels.

- Land Area and Population (Bureau of the Census). Contains no Federal-aid urban or urbanized area statistics.

- Project Status Record (PR-37). Excludes non-Federal-aid projects.

DEVELOPMENT OF STATE AND NATIONAL LONG-TERM MONITORING DATA BASES

In addition to the data resources that have been compiled by the FHWA in the Highway Performance Monitoring System (HPMS), the Highway Condition and Quality of Highway Construction Survey, the Cost Allocation studies, and the Vehicle Size and Weight studies, other data bases have been assembled primarily for research purposes by the States, the National Cooperative Highway Research Program (NCHRP), and by the FHWA. Primarily in response to the need for Satellite Road Test information at the conclusion of the AASHO Road Test, a number of States began systematically to collect detailed inventory and monitoring data on a collection of pavements. An assessment of the quality and quantity of that data was made recently in NCHRP Project 20-7, Task 17, by Texas A&M University, and the results of that study will be summarized below. In addition, the NCHRP funded the development of the Concrete Pavement Evaluation System (COPES) at the University of Illinois. A separate section of this background materials will be devoted to a description of COPES because of its close relation to the ongoing Long-Term Monitoring pilot studies. One other data base is in the process of being assembled under contract to the FHWA, this one being concerned with projects on which various forms of asphalt recycling have been used. The Asphalt Recycling Data Base contains approximately 316 projects, was initiated by Iowa State University, and is being carried on at present by the Asphalt Institute. All of these data sources may play an important role in the future Long-Term Monitoring program.

The title of NCHRP Project 20-7, Task 17, was "Evaluation of AASHO Road Test Satellite and Environmental Studies" and was conducted in two phases by the Texas Transportation Institute. In the first phase, a questionnaire was sent to all 50 States and replies were received from 47. The replies were studied systematically to determine both the quality and quantity of data that were available and an assessment was made of the likelihood that such data could be used in the development of pavement design equations. The questionnaire also revealed how accessible the data were: whether they were stored in centralized or decentralized manual files, or in a computer accessible form. The second phase investigated some of the data in detail to determine how good of an overlay design equation could be constructed from the data that were available in Texas and Minnesota, and what kind of data are needed to develop different levels of such equations. The results of this study will be discussed in more detail in a later section of this report.

IMPACT OF THE 1982 SURFACE TRANSPORTATION ASSISTANCE ACT

In the Surface Transportation Assistance Act (STAA) of 1982, the U.S. Congress added several more tasks to those that had been mandated in the STAA of 1978. The 1978 Act called for a study of the costs, benefits, and the effects of State regulations on truck sizes and weights, a study of cost allocation, and a pilot long-term monitoring effort to assess the costs of collecting long-term performance data. In the 1982 Act, further truck size and weight studies were called for, as well as a study of the effect of climate on the rate of pavement deterioration to determine whether climate factors should be included in cost apportionment formulas. The two Acts taken together showed a clear recognition by Congress, and firm support by AASHTO, industry, and the FHWA of the need to have more detailed and accurate data and models to permit careful and comprehensive studies of:

1. Cost responsibility, allocation, and apportionment.
2. Effects of truck sizes and weights on pavement deterioration, transportation benefits, and revenues.
3. Effects of weather on pavement deterioration.
4. Quality of highway construction and development of realistic statistical specifications which are based upon actual performance.
5. Cost effective preventive maintenance and rehabilitation strategies.

The data for all of these studies must come from a Long-Term Monitoring program which involves the testing of pavements in the field, and the patient collection of inventory and monitoring data for the full life cycle of selected types of pavements. All of this, and other considerations as well, has led to the adoption of the Federal pavement initiatives.

NATIONAL INITIATIVES ON PAVEMENT REHABILITATION AND DESIGN

The shift of emphasis from new construction to rehabilitation raises many questions that can only be answered by judgement and intuition at present. In addition to the need for the studies mentioned in the previous section, the following questions have been raised:

1. Which rehabilitation strategies are more suitable under given conditions?
2. What are the costs of deferred maintenance?
3. What maintenance costs are associated with various types of rehabilitation?
4. What are the long range (life cycle) performances and costs of rehabilitation strategies?
5. What are the future long term impacts of increased truck loadings?

Securing information to provide needed answers to current and future pavement rehabilitation and design issues is extremely complex, and at present, fragmented. In order to address short term and long term needs and at the same time mesh with ongoing activities, FHWA has embarked on the following overall program:

1. Working with AASHTO, FHWA will compile and disseminate all presently used pavement rehabilitation design methods and techniques that have proven to be successful and are cost effective. This is a near term solution to make the most of what we now have while waiting for the results of longer range efforts outlined below.
2. The FHWA will survey and identify the national pavement management information needs (both policy and technical) of FHWA in the areas of planning, design, construction, and maintenance, as required by Congress to manage the national highway program. The effort will be an internal FHWA activity and will be related directly to Long Term Pavement Monitoring (LTM). The identified needs will be used in evaluating ongoing information-gathering efforts and in assessing new initiatives.
3. Working with AASHTO and industry, FHWA will develop a coordinated program of demonstration and experimental projects on pavement rehabilitation techniques and materials. The effort will be meshed with the ongoing research program.
4. The FHWA will work with AASHTO and TRB to complete the update of the interim pavement design guide in the shortest possible time frame.
5. Working with AASHTO and TRB, FHWA will evaluate the need for

future full-scale road testing of some form and the feasibility of accelerated testing systems to allow more rapid evaluation of new pavement rehabilitation techniques and materials.

6. The FHWA will issue a quarterly newsletter to highlight pavement management state-of-the-art, technology transfer activities, research, training, and other pertinent information of interest to pavement engineers.

More detailed descriptions of the six FHWA initiatives are given below.

Initiative No. 1. Pavement Rehabilitation Design and Techniques Study

There are no road tests or other significant work upon which to base our rehabilitation design and construction procedures or to address the ever increasing questions concerning rehabilitation techniques. With the current level of expenditures for pavement rehabilitation, and the increased level expected, there exists a definite need for guidance on rehabilitation techniques and design and construction methods. Securing information to provide needed answers to current rehabilitation issues are extremely complex and at present fragmented. With the current emphasis on rehabilitation, the state-of-the practice needs to be evaluated. It is important to know which techniques have been tried and how they have performed. It is equally important to have a system to ensure that rehabilitation data will be collected and analyzed in the future.

Objective of Initiative No. 1.

To compile and disseminate all presently used pavement rehabilitation design methods and techniques used and to evaluate their performance. To develop a system to collect rehabilitation information on a continuing basis.

Scope of Initiative No. 1.

The FHWA will investigate the presently used pavement rehabilitation design methods and techniques throughout the United States. A rehabilitation technique is considered to be any procedure or method used to extend the useful life of a flexible or rigid pavement. An evaluation will be made to determine the performance of various techniques. Information gathered will be compiled and disseminated in a summary report and manual. A system will also be developed to collect rehabilitation information on a continuing basis.

Work Plan.

The proposed study will include a three-phase approach. Under the initial phase, a general questionnaire will be completed by the regions, or division offices if necessary. The questionnaire will identify the pavement rehabilitation techniques that have been used and are being used, and what information is available. Under the second phase, review guidelines will be developed and enough selected divisions will be visited and reviewed to compile detailed information for a manual of available rehabilitation techniques. The final phase will involve developing a system to collect project specific rehabilitation information on a continuing basis.

Tasks.

A. Present study concept to the AASHTO Standing Committee on Highways for its information and comments.

B. Conduct a literature review of rehabilitation design methods and techniques currently used for flexible and rigid pavements.

C. Develop a general questionnaire to be used in a nationwide evaluation of the state-of-the-practice in rehabilitation design and construction techniques for both flexible and rigid pavements.

D. The questionnaire developed under Task C will be completed for each State by the regional office. This may require reviews in or assistance by the respective division offices, depending upon information available at each regional office.

E. Develop a summary report from information obtained in Task D.

F. Using information from Task D, identify the rehabilitation techniques that will be evaluated in depth. Develop review guidelines and data collection plan, i.e., sample size, frequency, etc. for use in the selected states. Conduct a pilot review of one State to evaluate the effectiveness of the guidelines.

G. Using the above guidelines, conduct a field review in one State of each region with region and division staff. Following these reviews, the regions will conduct reviews in selected States. States will be identified depending upon difference in techniques, geographical areas, and climatic conditions.

H. Prepare a reference manual on rehabilitation techniques based on existing literature and data gathered during the survey in Task E.

I. Develop a system to collect, store, retrieve, and analyze pavement rehabilitation information. The system will include rehabilitation data collected under Task D and G. The system is to be expanded to include data from future rehabilitation projects. Prior NEEP, experimental projects, demonstration projects, research and development work will be coordinated. It is anticipated that the system will be coordinated with the proposed revision of the Highway Condition and Quality of Highway Construction Survey.

J. Develop a plan to periodically update the summary report, manual, and survey.

K. Continue field reviews by regions.

The following items will be considered within this initiative:

1. In addition to preparing a manual, technical assistance may be prepared on special topics or techniques that are not in the manual or that warrant extra attention.

2. Contact will be made with industry and leading universities to keep them advised of the initiative and to solicit their input.

3. This initiative will be paralleling the update of the AASHTO Interim Guide. The update will also address rehabilitation design. The Joint Task force on Pavements will be advised of this initiative and the results will be closely monitored.

4. This work plan will be submitted to the Pavement Management Coordinating Group (PMCG). The Office of Engineering will

keep the PMCG advised of progress.

5. The possibility of securing the service of an outside consultant for assistance under Tasks C, F, and I will be evaluated and pursued.

Initiative No. 2. Pavement Management Information Needs Study

This internal study by the FHWA calls for coordination with all the various pavement management activities that might have data collection implications, and, in particular with the Long-Term Monitoring Workshops and Initiative Number 5 dealing with accelerated laboratory testing and road testing.

Background.

It has been recognized by the Federal Highway Administration (FHWA) that a higher level of effort is justified to secure better information upon which to base cost-effective decisions relating to pavements. In order to satisfy one aspect of the recognized need for more definitive information, this initiative was approved in May that would survey and identify national pavement information that is needed by the FHWA in the areas of planning, design, construction, and maintenance to manage the National Highway Program.

Objectives of Initiative No. 2.

a. To identify, categorize, and prioritize FHWA pavement management information uses and needs

b. To survey available and required resources necessary to satisfy the high priority needs

c. To develop a coordinated plan (including a coordinated set of data elements) for obtaining and maintaining an adequate information system

Scope of Initiative No. 2.

The FHWA is examining national pavement management information needed by the various FHWA Headquarters offices for proper stewardship of the Federal-Aid Highway Program. The end product of such examination will be a coordinated plan aimed at the collection and analysis of pavement data and relationships in a more cost-effective and comprehensive fashion. Distinctions will be made between recurring monitoring types of information needs and one-time or infrequent special analyses or data collection efforts.

Description of Tasks.

Task A. Literature Review: Perform literature search to become familiar with organizations, functions, and procedures of various program offices that are involved in pavements.

Task B. Inventory Needs and Resources: Develop classification parameters and initial summary of pavement information needs (data and relationships) and resources as perceived by various offices.

Task C. In-Depth Interviews on Uses, Needs, and Resources: Conduct in-depth interviews of various program offices to:

1. Verify information uses and needs contained in initial summary and add or delete as necessary.

2. Determine data that is currently being collected and relationships currently available, including their use, mode of collection, and collection costs (FHWA and States).

Task D. Analysis of Interviews: Analyze results of interviews to arrive at final list of pavement information uses and needs. Develop inventory of data currently being collected and extant relationships.

Task E. Needs versus Resources: Translate information needs into data elements. Compare data element list (derived from the information needs) with inventory of data currently being collected and extant relationships.

Task F. Prioritization of Needs: Present needs list and current resources to FHWA top management for approval and prioritization. This would be accomplished by each program office. Interim Report 1 (April 1984) was distributed to program offices involved in the project.

Task G. Coordination with Other Efforts: Participate in an advisory capacity in the Long-Term Monitoring and Evaluation of Road Testing and Accelerated Testing (Initiative #5) efforts. Ensure that the results of these efforts are considered in this study.

Task H. Criteria Development: Develop criteria to assess and rank information uses and needs (cost of collection of data to satisfy needs, relative importance, etc.).

April-May 1984 — Prepare a concept paper defining the criteria, including possible ways to measure them. Potential criteria include:

Immediacy of need is the information requirement pressing and current or long-term, etc.

Void of current information are there surrogate or substitute measures that could satisfy the information need at no or low additional cost.

Importance to the agency's mission is the information needed for a required project, e.g., project approval, report to Congress, etc., and how important is the particular mission.

Importance of the information to the States

Dollar savings from better information -for example, a reduction in required future capital/maintenance outlays resulting from better designs; user cost savings from better investment/maintenance practices resulting from more informed decisions based on better information, etc.

Cost of improved information -this subtask is the major tie-in with Task 9. The costs of gathering better data (mechanical, LTM, etc.) will be estimated in a crude fashion at first to be used as one of the screening criterion. A more refined cost estimate will be made as part of Task 9 on the screened or reduced set of priority information requirements.

April-May 1984 — Reexamine the Task F results by putting the information needs into a suitable form for priority assessment; consolidate the information needs into a smaller number of categories where feasible.

June-August 1984 — Define the data elements required to meet the information data available, possible surrogates, and current voids.

June-December 1984 — Quantify the various criteria

Apply the criteria to the information needs from Task F.

September 1984: Finish a draft Task 8 report (Interim Report Number 2) for use in the LTM conference the first of October 1984.

December 1984: Refine the criteria quantification in conjunction with the Task 9 alternative development effort.

Task I. Alternative Development: Develop coordinated plan for satisfying all data needs.

June 1984-March 1985 — Determine method of collection of increased data requirements--LTM, laboratory mechanical testing, on-site accelerated mechanical testing, etc.

Determine sample size, frequency, etc., and how to coordinate the sampling and data collection efforts.

Estimate the cost of additional data collection efforts.

Task J. Alternative Selection: Present various alternatives for a coordinated pavement management information system to top management for decision (March 31, 1985).

Task K. AASHTO Involvement: Brief AASHTO on selected alternative. Work on plans for changes to existing data collection efforts and on new efforts.

Task L. Implementation Plan: Develop implementation plan.

January- September 1985	Prepare multi-year program budget for plan. Suggest revisions to existing plans/budgets. Define responsibility for collection, storage, and analysis of data (i.e., Headquarters, field, States, etc.). Determine data storage/retrieval system.

Task M. Implementation Decisions: Present implementation plan for top management decision (Milestone 3 - September 30, 1985).

Initiative No. 3. Coordinated Demonstration and Experimental Projects Program

Because the complete replacement of the deteriorating pavements is, in many instances, undesirable because of excessive cost and traffic disruption, a definite need exists for direction on proper pavement rehabilitation techniques. The pavement rehabilitation techniques currently in use need to be evaluated to identify those which are the most efficient and cost-effective.

Objective of Initiative No. 3.

The objective of this initiative is to work with AASHTO and private industry to develop and implement a continuing major coordinated demonstration/experimental projects program on pavement rehabilitation and mesh this effort with other FHWA pavement rehabilitation programs.

Ongoing Activities of Initiative No. 3.

Both the Demonstration and Experimental Projects Programs currently have underway activities relating to pavement rehabilitation. The following is a listing of those activities.

1. NEEP No. 27 - Portland Cement Concrete Pavement (PCCP) Joint Restoration and Rehabilitation: The objective of this project is to obtain experience with a variety of joint rehabilitation techniques to restore load transfer between slabs, prevent the intrusion of material and water into and through the joint, reduce resultant cracking, and restore the existing PCCP to high service condition without use of an overlay.

2. NEEP No. 28 - Highway Pavement Subdrain Systems: The objective of this project is to obtain experience and data on the various types of drainage systems, both for new construction and for 4-R type projects.

3. Experimental Project No. 2 - Concrete Overlays: The purpose of this project is to gather data needed to determine the potential of thin bonded concrete overlays as a rehabilitation procedure. The work will require monitoring performance of selected thin bonded concrete overlay projects to establish the feasibility of this technique. Data will be gathered regarding the initial construction costs and problems. Long-term performance studies will attempt to document maintenance costs and pavement life to establish cost-effectiveness.

4. Experimental Project No. 3 - Asphalt Additives: The objective of this project is to promote the systematic gathering and reporting of information on the design, construction, cost, and performance of different asphalt additives. The different additives eligible for evaluation under this project can include rubber, chemical, or natural products that are added to the asphalt.

5. Experimental Project (proposed) - Joint Sealants: Significant contract use of improved joint materials for concrete pavements is limited. Most States have experience with one or more of these materials, but because of the abundant types and brands available, it is difficult for a State to obtain adequate experience with them all. To expedite evaluation and dissemination of information on the use of the various joint sealants, it is proposed to select a representative sample of interested States having contract

experience with a particular sealant to participate in a controlled evaluation of their projects. Utilizing information derived from the State evaluations of the various sealant products, information on costs and performance will be compiled and disseminated.

6. Experimental Project (proposed) - Pavement Rehabilitation Techniques: This project is still in the development stage. It will be part of a coordinated effort between the Demonstration Projects Division, the Construction and Maintenance Division, and the Pavement Design Branch to collect data on quality control, materials, specifications, and adequacy of design for various pavement rehabilitation techniques and to equate these variables to the overall performance of the pavement.

7. Demonstration Project No. 17 - Prestressed Concrete Pavement Construction: The objective of this project is to demonstrate the technological and economical feasibility of prestressed concrete pavements. Evaluation of the various projects constructed to date has demonstrated that prestressed concrete pavements can be built using currently available prestressing technology and that it represents a competitive alternative to other conventionally used pavements. The application of prestress allows a significant reduction in the thickness and reinforcement requirements of concrete pavements. Also, this method is expected to result in faster paving rates, energy

conservation, and by reducing the number of joints and cracks, reduce maintenance requirements.

8. Demonstration Project No. 47 - Recycling Portlant Cement Concrete Pavements: The objective of this project is to construct and evaluate recycled portland cement concrete pavements. Crushed concrete is obtained from any satisfactory source and used in the new portland cement concrete pavement.

9. Demonstration Project No. 50 - Sprinkle Treatment: The objective of this project is to construct and evaluate projects involving the application of nonpolishing aggregates to the surface of newly placed hot-mix asphalt concrete pavements. Addition of skid-resistant aggregate prior to compaction of the asphaltic concrete enables embedment and retention of the skid-resistant material. As a result, the less expensive and more readily available polishing aggregates can be used for structural requirements of the pavement while reserving the high-quality nonpolishing aggregates for the wearing surface. The result is a roadway with improved skid resistance qualities and a savings in cost and valuable aggregate resources.

10. Demonstration Project No. 54 - Sulfur Extended Asphalt (SEA): The objective of this project is to encourage the construction and evaluation of pavements using SEA as a binder. The projects are being evaluated to determine the performance and durability of pavements incorporating

sulfur, the cost effectiveness of using sulfur, and the quantities of energy and resources that are conserved.

11. Demonstration Project No. 55 - Asphalt Emulsions: The objective of this project is construction and evaluation of projects using asphalt emulsions. A mix design method for emulsified asphalt aggregate pavements has not been universally accepted. Currently, at least 11 different procedures are being used. This demonstration project encompasses projects in which asphalt emulsions are used as surface treatments, including seal coats, slurry seals, tack coats, and prime coats.

12. Demonstration Project No. 59 - The Use of Fly Ash in Highway Construction: The objectives of this project are to use fly ash in construction and evaluate its use in highway construction. One major use is in lime-fly ash-aggregates (LFA) mixtures. LFA mixtures are blends of mineral aggregate, lime, fly ash, and water combined in proper proportions and compacted to high densities. When properly cured, these mixtures harden to produce high quality paving materials that are suitable for use as road base and subbase courses. For faster curing and accelerated strength gains, portland cement has been partially or wholly substituted for lime. Another use of fly ash is the partial replacement of portland cement in PCC mixes. When used in this manner, it has the potential to reduce costs, reduce heat of hydration, and increase the mix workability. Fly

ash can also be used as a stabilized fill and embankment material, and as a partial replacement for the binder material in various grouts.

13. Demonstration Project (proposed) - Portland Cement Concrete Pavement (PCCP) Restoration: It is anticipated that this project will be announced in the near future. This project has been developed to highlight certain proven rehabilitation techniques to restore PCC roadways which can be used as an alternatives to currently employed methods such as PCC or bituminous concrete overlays or total reconstruction of the pavement structure. This demonstration project will incorporate many proven methods of PCC pavement restoration such as diamond grinding, joint sealing, and slab replacement. The widespread use of these method can provide an economical cost effective means of improving the rideability and extending the service life of many deteriorating PCC pavements.

Proposed Activities of Initiative No. 3.

1. Work with the Office of Research, Development, and Technology and the Pavement Management Coordinating Group (PMCG) working group to identify items of new technology to be incorporated in either the experimental or demonstration project. This will be accomplished prior to the annual budgeting process.
2. Solicit input from the field on items of new technology and

potential rehabilitation techniques and materials on an annual basis. This will be proposed as a continuing agenda item at the annual national technology transfer meeting. Research, Development, and Technology is currently developing a new process for solicitation of research problems. This solicitation could also provide input into the experimental projects program.

3. Use the input from the Task Force for Initiative No. 1 to assist in identifying items of new technology and potential rehabilitation techniques and materials.

4. Continue solicitation of new technology on potential rehabilitation techniques and materials from industry and AASHTO through representation on the following committees or task forces:

   a. ACPA Committee on Pavement Rehabilitation

   b. AASHTO/AGC/ARTBA Subcommittee on New Highway Materials

   c. Task Force No. 20, Development of Generic Specification for Patching Materials Used in Rapid Repair of PCC

   d. Task Force No. 22, Cross Reference of Materials Specifications for Waterways, Airports, Transit, and Highway Projects

   e. Task Force No. 23, Materials, Specifications, and Processes for Rehabilitation of PCC Pavements

   f. Task Force No. 25, Development of Generic Specifications and Laboratory Test Procedures for Geotextiles Used in Civil Engineering Applications

5. Solicit representation from all involved program offices on the technical advisory committee of all experimental and demonstration projects.

6. Assist the Construction and Maintenance Division with the development of an automated information collection analysis and retrieval system.

7. Work with the region and division office technology transfer coordinators and State representatives to improve the reporting and dissemination procedures for new and innovative technology.

Initiative No. 3. Demonstration/Experimental Projects Program

Time Schedule:

The schedule for the various projects listed previously are on the following page.

Initiative No. 4. Updating the AASHTO Pavement Design Guide

The AASHO Road Test, when completed in 1960, was the most significant of a number of road tests conducted since the beginning of the highway program. It provided information that has been used internationally for cost allocation and pavement design purposes. No road test work of similar significance has been done since that time. While research has continued in the pavement area, the limitations of the AASHO Road Test (one climate, locally available materials used, short duration, limited load applications, etc.) continue to be monumental problems that must be dealt with in a much greater effort.

Task	Year: 83 84 85 86 87 88
*1. NEEP No. 27	--------
*2. NEEP No. 28	--------
3. EP No. 2	------------------------ - - - - - - - - - - -
4. EP No. 3	------------------------ - - - - - - - - - - -
5. EP-Joint Sealants	----------------
6. EP-Pvt.Rehab.Tech.	------------------------ - - - - - - - - - - -
7. DP No. 17	------------------------
8. DP No. 47	---------------- - - - -
9. DP No. 50	---------------- - - - -
10. DP No. 54	------------------------ - - - - - - - - - - -
11. DP No. 55	---------------- - - - -
12. DP No. 59	------------------------ - - - - - - - - - - -
13. DP-PCCP Restoration	------------------------ - - - - - - - - - - -

*After 1984, results from these NEEP's will be included in the Experimental Project on Pavement Rehabilitation Techniques.

Issues such as: the effects of climate, the effects of various configurations of truck sizes and weights, the cost responsibility, and the need for performance and life cycle cost information remain as issues that call for solutions. This lack of information for pavement purposes has been recognized by the Congress, industry, AASHTO, and FHWA.

The AASHTO recognized these problems when it recently approved $500,000 to update and expand (to include rehabilitation) the AAHSTO Interim Guide using currently available information.

Objective of Initiative No. 4.

Encourage and assist AASHTO and TRB in completing the update of the Interim Pavement Design Guide in the shortest possible time.

Scope of Initiative No. 4.

The Chief of the FHWA Pavement Branch serves as secretary to the AASHTO Joint Task Force on Pavements. Using this position, the Pavement Branch will assist AASHTO and TRB in updating the guide in the shortest possible time while ensuring a high quality product.

Work Plan.

The Pavement Branch, Office of Engineering, will closely monitor the progress of Phase I and Phase II of the AASHTO Design Guide Update. Phase I includes performing a literature review and survey, securing public input from industry and others, and developing an outline and format for the new guide. Phase I was completed in

December 1983. Phase II is the development of technical input for the guide, and is scheduled for completion in December 1984. The Pavement Branch will work with AASHTO and TRB to ensure adequate funding and completion in the shortest time.

Technical assistance and review will be provided by the Pavement Branch with the assistance from other offices in the PMCG. The Pavement Branch will keep the PMCG advised of the progress on the update and involve the other offices in the review of the update. The Pavement Branch will provide representation at all public meetings held on the update and of all AASHTO Joint Task Force meetings concerning the update where possible.

Initiative No. 5. Pavement Testing

The AASHO Road Test completed in 1960 was the most significant of a number of road tests conducted since the beginning of the highway program. It provided information that has been used internationally for cost allocation and pavement design purposes. No road test work of similar significance has been done since that time. While research has continued in the pavement area, the limitations of the AASHO Road Test (one climate, locally available materials used, short duration, limited load applications, etc.) continue to be monumental problems that must be dealt with in a much greater effort. Issues such as: the effects of climate, the effects of various configurations of truck sizes and weights, the cost responsibility, and the need for performance and life cycle cost information remain as issues that call for solutions. This lack of information for pavement purposes has been recognized by the Congress, industry, AASHTO, and FHWA.

The FHWA Office of Research recognized the need for a pavement testing program when it proposed an accelerated testing system to perform more rapid evaluations of pavement designs and performance.

As we now enter an era of 4R or rehabilitation, the questions are more complex and there has been no road test or other significant work done with respect to the rehabilitation questions. With the current level of expenditure for pavement rehabilitation, and the increased level expected, a higher level of effort is justified to secure better information upon which to base cost effective decisions in the use of those funds.

Objective of Initiative No. 5.

To evaluate the need for future full-scale road testing of some form and the feasibility of accelerated pavement testing to perform more rapid evaluation of new pavement rehabilitation techniques and materials.

Scope of Initiative No. 5.

The FHWA convened a national workshop in March 1984 with international representation of experts in the field of pavements. The end product of this workshop was an evaluation report discussing how these tools can be used in an overall approach to evaluating and testing pavements. The results and recommendations that came from that Workshop will be discussed more in detail in Chapter 3.

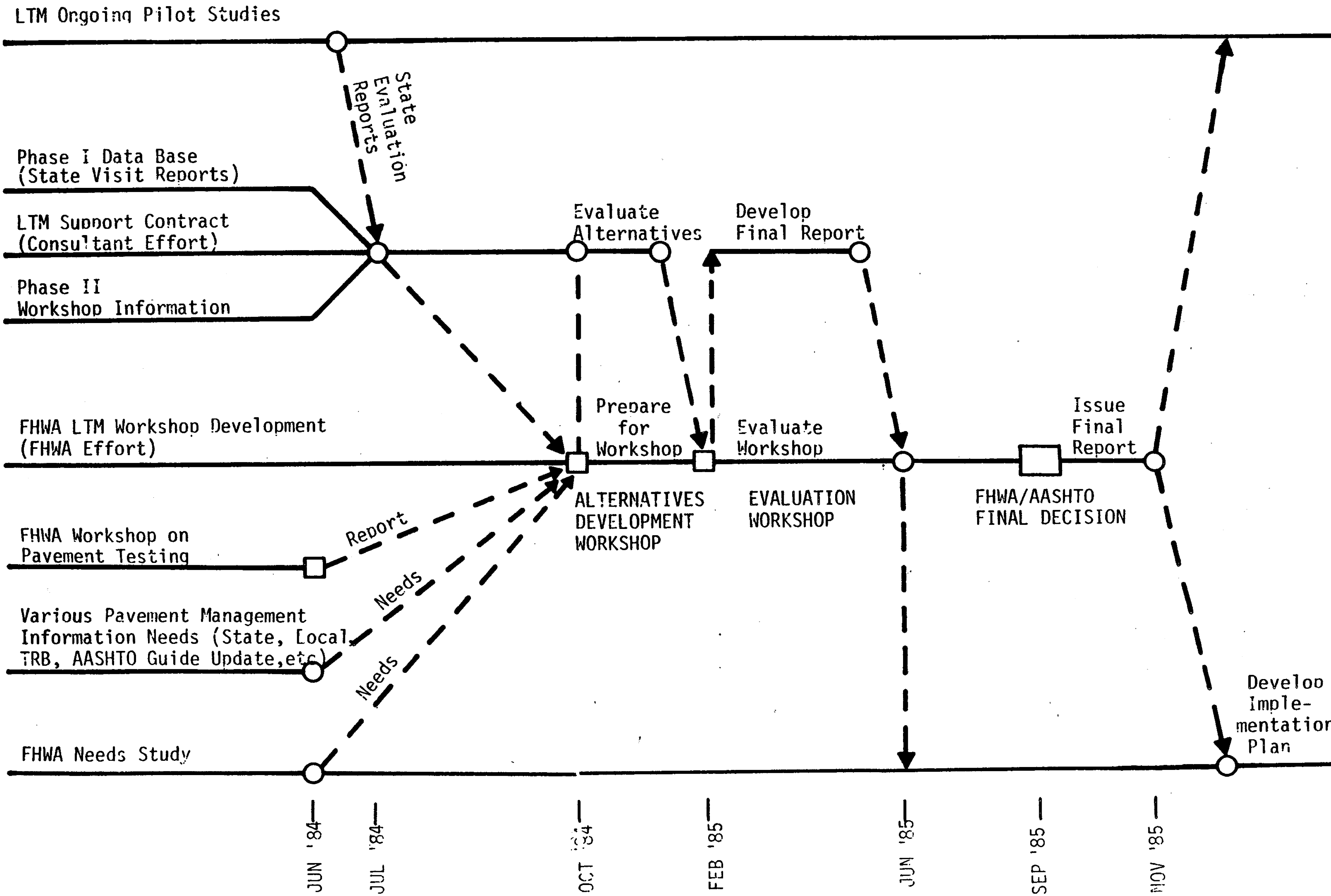
Initiative No. 6. Quarterly Pavement Newsletter

New developments in 3R and 4R projects, methods, and techniques and progress on the national pavement initiatives suggests that there is an urgent need to get new pavement state-of-the-art information out to the pavement community: FHWA, State, and local officials. Much of this information is not widely available or used. New information is presently being developed, and will be available in the future. It is important to develop a process to collect and disseminate such pavement information. The Pavement Newsletter was designed to provide this needed service, and the second edition has now been distributed.

Coordination of Initiatives

The overall coordination of the results of the National Initiatives is expected to result in an overall plan for a coordinated Long-Term Monitoring program, a national Pavement Testing program, the revised AASHTO pavement design guide, and for an efficient cooperative program for satisfying State and local pavement management information needs.

Much of the information that has been assembed will be presented to the participants in the two Long-Term Monitoring workshops, the first of which will develop alternative methods of creating a national Long-Term Monitoring program including possibly the coordinated use of available data bases. The second workshop will evaluate the alternatives and arrive at a final recommendation for an overall coordinated plan. The importance of these two workshops is illustrated in Figure 2, which shows the approximate time scale



ure __. Re...ionship o... Pavement In...ati... Eff...

according to which these workshops are proceeding.

LONG TERM MONITORING PROGRAM

As discussed in Chapter 1, the FHWA and AASHTO took the lead in developing concepts for a program of ongoing monitoring of in-service pavements to develop a national data bank. This national data bank is intended to serve a number of information needs, and to especially support the development of badly needed relationships for predicting performance of pavements and designing repair or rehabilitation projects. This work effort to date has included:

1. Initial identification of data items to be collected and development of a data collection guide and data bank schema for use in collection and management of the data.
2. Establishment of LTM pilot studies in eight states and including 144 test sections. The distribution of these test sections by state, type of pavement, and environmental zone appears in Table 8.

   The initial program was accomplished by having each of the eight participating States identify their pavement monitoring data needs for statewide program analysis, project analysis, and deterioration case studies. States were provided with input on pavement data needs by the AASHTO Joint Task Force on Pavement FHWA staff, and several noted experts in special aspects of pavement monitoring systems. These State pavement monitoring programs were

TABLE 8. Pavement Sections for the Long-Term Monitoring Pilot Study

State	Environmental Zone	Type of Pavement Flexible	Composite	Rigid
Arkansas	Wet - No Freeze	4	10	6
California	Dry - No Freeze	6	2	16
	Wet - Freeze	3	4	3
	Wet - No Freeze	4		
Colorado	Dry - Freeze	7		2
	Wet - Freeze	2		
Idaho	Dry - Freeze	7		7
Iowa	Wet - Freeze	3	4	9
New Mexico	Dry - Freeze	4		
	Dry - No Freeze	8	1	
Pennsylvania	Wet - Freeze			22
Washington	Dry - Freeze	3		
	Dry - No Freeze			1
	Wet - Freeze	2		1
	Wet - No Freeze	3		
	TOTAL	56	21	67

reviewed by the AASHTO Joint Task Force on Pavement advisory panel of experts and comments given as to how each State could improve their pavement monitoring program. Each participating State operated their pavement monitoring program. At the end of each year, the participating State reports on their pavement monitoring program to the FHWA contract manager.

The major portion of resources in this effort were placed on the deterioration case studies which call for the establishment of a minimum of ten sites per State to be studied in detail to develop improved relationships between pavement design, axle-load, maintenance, and environment. At the end of each year the participating State prepares a report that details the information obtained, analysis performed, cost to obtain the data, and makes recommendations concerning the techniques used for long-term pavement monitoring. Each participating State is expected to continue to monitor pavement performance on the case study sites and provide annual reports.

3. A contract for technical support to assist in evaluating the pilot studies, creating a data bank for managing the data, developing an annual plan for continued collection and management of the data, preparing background documents for use in the two LTM workshops, developing alternatives to be considered by the workshop in selecting a tentative plan for the future expanded LTM effort, and documenting the results

of the pilot studies, workshops, and other studies included.

4. Planned and hosted the Pavement Testing Conference discussed previously and in the next chapter.
5. Participated with AASHTO and the Transportation Research Board in planning a national pavement testing program.

CHAPTER 3

PAVEMENT TESTING CONFERENCE

The purpose of the Pavement Testing Conference sponsored by the Federal Highway Administration (FHWA) was to develop a National Pavement Testing (NPT) Program which would yield data to serve the following needs:

1. Evaluating and developing alternative pavement rehabilitation and construction techniques.
2. Evaluating and developing predictive design equations for pavement design and rehabilitations.
3. Conducting special studies, such as cost allocations, heavy vehicle weight effects, and environmental effects, required by the Congress or others.
4. Supporting project and network pavement management activities at the State and national level.

To fulfill its purpose, the conference was divided into two broad categories and four workshops within each category as follows:

Category 1 - Testing Methods

Workshop A - Road Test and Test Track

Workshop B - Mechanical Testing

Workshop C - Inservice Testing

Workshop D - Combination of A, B, and C

Category 2 - Data Needs and Uses

Workshop E - Rehabilitation Techniques

Workshop F - Equations and Materials

Workshop G - Special Studies

Workshop H - Network Pavement Management

The primary task addressed in the first of each workshop session was the assessment of the state-of-the-art in the workshop subject area and the identification of future data needs or listing of methods required to upgrade the subject for future pavement management. In the second workshop session, participants evaluated the FHWA proposed NPT program, based upon the identified future needs, and developed recommended changes to the proposed program.

In order to assure a broad consultation and a comprehensive viewpoint to the conclusions reached, the 88 participants in the Workshop were invited from the variety of categories shown in Table 9.

TABLE 9. Pavement Testing Conference Participants

State Agencies	15
Universities	7
Private Consultants	8
Foreign Countries	9
International Road Federation	1
World Bank	1
Transportation Research Board	2
Industry Groups	5
U.S. Army Corps of Engineers	2
Federal Aviation Administration	1
Department of Transportation	1
Consulting Firms	3
FHWA	33
TOTAL PARTICIPANTS	88

FHWA PROPOSED NATIONAL PAVEMENT TESTING PROGRAM

The FHWA identified four work categories that will generate the major pavement testing and data needs for the future:

1. Evaluating alternative rehabilitation and construction techniques was considered an immediate need, requiring test methods which can rapidly evaluate rehabilitation strategies and generate required data needs.
2. Evaluating and developing predictive design equations was considered strategically important to developing mechanistic pavement analysis models essential to overall pavement management. Data, particularly that related to pavement performance, and test methods applicable to verification of prediction models will be required.
3. Special studies, including technical problems or Congressional mandates, generally require solutions to very specific issues such as cost apportionment, cost allocation, effect of axles or wheel configurations, effect of tire pressure, dynamic impacts and similar items.
4. Pavement management activity--project and network pavement management at the State and national levels--will require predictive models for many of the factors affecting pavement performance. A vast amount of pavement data will be required.

Following a brief description and analysis of the current pavement testing programs and data bases, the FHWA evaluated the advantages and disadvantages of testing systems and proposed the following NPT program:

1. <u>Inservice testing</u> - Inservice testing would consist of two

major parts: (1) Long-Term Pavement Monitoring (LTM) in which each State would collect data on carefully selected sections of existing pavements, and (2) Design Highway Sections (DHS) which would be located either parallel to or in the main traffic lanes and data collected by LTM along with additional measurements as necessary. There are many advantages and disadvantages to inservice testing. A major advantage is the realism and credibility of the data collected, while the major disadvantage is the time required to collect the data.

2. Mechanical testing - For the proposed NPT program, mechanical testing is considered to be the application of simulated rolling-wheel loads on either inservice or laboratory pavement sections and under either controlled or ambient climatic conditions. The FHWA program proposed conducting mechanical testing in two phases. Phase I would consist of developing and using a mechanical testing system at the Turner-Fairbank Highway Research Center to test simulated highway sections. Phase II would be to build four mechanical testers to be located in each of four environmental zones and used primarily to test inservice pavement sections. Among its several advantages is the speed at which data can be generated. The main disadvantage is the need to translate the data to represent real-world conditions.

3. Test Track - Test tracks are considered to be full-scale

pavement sections constructed by normal construction equipment and subjected to planned combinations of real traffic in an accelerated manner. The AASHO Road Test is an example of this type of testing. The FHWA program considered three options: (1) Update the AASHO Road Test section designs, track configurations, and other factors, (2) Construct four regional test tracks, and (3) Use a single test track equipped with an automated guidance system for the application of traffic. Of these three options, the FHWA program recommended using the automated test track. Test tracks have the advantage of full-scale pavement sections subjected to actual traffic which can generate realistic data much more rapidly than inservice testing. The major disadvantage is the lack of credibility of results because environmental effects cannot be evaluated.

Estimated startup, annual operating, and total costs for the NPT program were included in the proposal, as was an implementation plan. The implementation plan proposed starting with mechanical testing and inservice testing over the first 2-5 years and introducing test-track testing in approximately 5-10 years. A total of 20 years was selected as reasonable for the program, with significant data being generated within the first 5 years.

Proposed Testing Methods

Although all three testing methods proposed by the FHWA were perceived as yielding needed pavement data, inservice testing and mechanical testing were given the highest priority in the program. In addition, the need for continued laboratory testing was stressed.

Inservice Testing.

The inservice testing program as proposed was defined as the collection of pavement performance data through long-term monitoring of selected sections of pavement which are a part of the operating highway network. Two categories of highway sections are proposed as a part of the inservice testing--existing on-line pavement sections and specially designed, newly constructed pavement sections built either on-line or parallel to existing on-line pavements.

It was proposed that a long-term monitoring program on existing inservice pavements should be initiated as soon as possible, and that the program include all States, with an average of 40 test sections per State, or a total of around 2,000 sections.

A program of testing and monitoring designed highway sections averaging 2 miles per State, or 100 miles, also should be undertaken. Specifically, it was decided that designed highway sections on parallel sites should be constructed as a part of this program, in at least each of the four AASHTO regions, to permit some special testing to be done on them in lieu of regional test tracks.

Mechanical Testing.

The proposed mechanical testing program was defined as the loading and testing of pavements using mechanical devices to simulate vehicle loads and to accelerate application of those loads to test pavement strips, inservice existing pavements, and new design sections of inservice pavements. Recommended is a linear mobile testing system similar to the unit developed in Australia (ALF) or the unit developed in South Africa (HVS). It was suggested that consideration also be given to the use of existing mechanical testing devices (i.e., at the U.S. Army Waterways Experiment Station, University of Washington, University of Illinois) to fulfill immediate testing needs. Although the inservice testing program was considered the most valid and cost-effective method for studying rehabilitation, it was recognized that mechanical testing on specially designed test sections or newly constructed highway sections would permit initial test results to be expedited.

Acquisition and assignment of mobile linear mechanical testing systems were recommended on a phased basis. The conference recommended the initial acquisition of one mechanical testing unit to be used in a national laboratory at the FHWA Turner-Fairbank Highway Research Center. The unit should provide national testing capability in an environmentally controlled laboratory setting and with mobility for field tests as well.

When the initial operating experience in the laboratory has substantiated the desirability of the selected linear mobile testing system (or suggested modifications), two additional units should be acquired and stationed in two AASHTO regions for testing inservice pavement sections. Following sufficient regional operating experience to support the continuation of the plan (or its modification), the final two units should be acquired and stationed in the remaining

AASHTO regions. Because the mechanical tests are key factors in the short-term results needed from the program, the phasing sequence was proposed on a relatively rapid schedule so that the laboratory and regional mechanical testing systems all would be in place and operating within a 5-year period.

Test Roads or Test Tracks.

Consideration was given to the need for full-scale test tracks capable of using actual vehicles for loading and testing. There was no support for a major national test road on the AASHTO scale. The conference participants expressed some interest in smaller regional test tracks to accommodate alternative environmental factors. Special studies such as evaluating the effect of new axle configurations and suspension systems on pavement performance may require test track experiments. However, it was concluded that no test road or test track should be considered until the feasibility of utilizing existing test tracks, such as the one in Pennsylvania, is fully explored. Because of the limitations on environmental variability and the costs of construction and operation, it was recommended that test tracks not be included in the program unless it is impractical to contract for studies at existing tracks.

Data Needs

All of the data needs outlined in the test program proposed by FHWA were strongly endorsed by the conference participants.

Rehabilitation.

The evaluation of rehabilitation techniques and the improvement of rehabilitation technology was ranked as the single most important data need to be satisfied by the NPT program. In recognition of this need, the conference participants proposed that a majority of the long-term monitoring inservice sections and the designed highway sections be rehabilitated pavement sections. The inservice testing program was considered the most valid and cost- effective method for studying rehabilitation. Mechanical testing on designed highway sections would permit initial test findings to be expedited by accelerating the loadings.

Network Pavement Management.

The data needed to serve pavement management systems is to be provided primarily through inservice testing. Many performance questions critical to effective pavement management can be satisfied through the inservice testing program.

At the national level, pavement management systems require data on:

- physical characteristics (design, age, etc.)
- operations characteristics (traffic, loads)
- performance characteristics (roughness, distress)

At the State network level, pavement management system data should include:

- physical characteristics
- operations characteristics

- maintenance performed (activity, data, costs)
- rehabilitation performed (design, construction, dates, costs)
- performance (roughness, distress, skid resistance, accident record, structural capacity [deflections])

The conference participants recommended that both national and State-level network pavement management systems be established and operated in close coordination with the NPT program.

Equations.

Pavement system performance models can take the form of mechanistic, probabilistic (statistical), or empirical equations. The inservice tests using designed highway sections were ranked as offering the greatest value for developing improved pavement performance models. Such models need to be developed in terms of distress phenomena such as deformation, cracking, disintegration, and surface friction.

Three levels of response need to be considered in developing models and in planning the data collection program for the national pavement tests:

- the primary response of pavements to loading through stress, strain, and deformation;
- a secondary response through the development of distress phenomena such as cracking, spalling, and disintegration; and
- a tertiary response through changes in riding quality (PSI).

Materials.

Mechanical and chemical tests of materials in the laboratory need to be verified and correlated with field performance in the pavement system. The inservice testing method using designed highway sections was considered the best source of data needed for materials studies.

Special Studies.

Two types of special studies were considered by the conference in assessing data needs:

- policy studies, such as cost allocation and apportionment formulas;
- technical studies, such as evaluation of tire pressure or axle configurations; and load equivalency factors.

All testing methods may be needed to satisfy special study requirements, but the inservice tests were ranked as most valuable, with test tracks as an important supplemental data source. Mechanical tests were considered the least likely to serve special needs. The conference recommended that the NPT program be structured to provide special undesignated funds for special studies rather than attempt to provide for unknown needs in the ongoing program.

Program Characteristics

As an important part of its deliberations, the conference considered not only the experimental design for the NPT program, but also the institutional and operational characteristics which will influence its success. The conference committee felt strongly that a significant effort would be required to assemble representatives of the participating agencies, create advisory groups at the policy and technical levels, establish an organizational plan, arrange funding, institute standards for program performance, and design the experiment. Criteria that should guide those involved in this process were proposed in each of the workshops and endorsed by the conference committee. The criteria that pertain to Long-Term Monitoring and data collection are discussed below.

Data.

An important, complex, and difficult requirement that must be addressed is the establishment of data collection and data processing procedures which provide the required uniformity and quality necessary for reliable applicable analyses and results. Standards need to be set for the data collected (i.e, what is measured, how it is measured, where it is measured, when it is measured, what it is measured with). Sample selection procedures, frequency, and quality controls need to be set. Where possible, equipment should be standardized (i.e., roughness-measuring equipment) or a reliable correlation established between acceptable alternative types of equipment. Also, a process and program for equipment calibration will be needed to ensure continuing accuracy of some types of measuring devices.

Data management techniques must be employed for the following:

1. The variety and quantity of data collected should be carefully controlled. Data collection decisions must be based upon established needs for the data, not upon its

availability.

2. Data bases should be designed to ensure that the retained data be in content and form suitable for the broadest possible use in the NPT program and in other programs such as pavement management, maintenance management, maintenance budgeting, and safety studies.

Supplemental Research.

A peripheral research need that should be considered in the NPT program is the need either to develop new technology or to improve existing technology and equipment so that mechanized, efficient, low-cost data collection processes can be employed where possible. The use of infrared, radar, sonar, lasers, photography, television, radio, fiber optics, and other technologies may permit automated sensing, recording, and transmission of data at high speeds and low costs with great benefits to the national program.

The development of computer-based "expert systems" in which computer programs emulate the problem-solving behavior of human experts by interrogation, interpretation, inference, diagnosis, prescription, and recommendation hold much promise. The magnitude of the data base and the scope of the expertise involved in the NPT program offer significant resources for developing expert systems in pavement performance and should be considered as a component of this program.

Costs.

The deliberations of the conference committee were concentrated on the conceptual design and characteristics of the program rather than costs. The cost estimates prepared by the FHWA as part of its proposed plan were reviewed and broad-based assessments made of the levels of research effort and hardware and construction requirements. The resulting estimates developed or modified by the conference and reflecting the recommended program configuration are shown in Table 10. While these values are unrefined and derived from early conceptual plans, they do support a national program with likely startup costs in excess of $100 million and an annual operating cost of approximately $20 million in 1984 dollars.

These expenditures represent a major new investment in pavement research, but a very modest expenditure when put in perspective with the need to rehabilitate and protect the multibillion dollar national pavement network toward which the new technology will be directed.

QUESTIONS THAT NEED ANSWERS

The questions that have been raised are all important and Long-Term Monitoring will play an important role in how well they are answered. As in all of these matters, the way that the Long-Term Monitoring program is organized will be determined primarily by those answers which are regarded as most important. There are data needs on every level: national highway network, State and district highway network, and project level. As many questions as there are and as

TABLE 10. National Pavement Testing Program
Preliminary Estimates of Costs

	Start Up Costs $Millions	Annual Costs $Millions	Total Costs (20 years) $Millions
Inservice Testing			
Existing Pavement Section ±2000 sites	14	10	214
Designed Highway Sections ±2 miles per State on-line sections and parallel sections	100	2 ($20,000 per mile)	140
Mechanical Testing, Linear Mobile Testing Unit			
Phase I: Laboratory and one testing unit	3	1	23
Phase II: Regional testing units	8	4	88
Initially: 2 testing units Final: 2 additional testing units			
Test Roads and Tracks			
Study of Existing Tracks	1		1
Contract Studies (with existing test tracks)		4	80
TOTAL:	126	21	546

many data needs as have been identified, it is highly probable that the most cost-effective organization of the Long-Term Monitoring Program should be such as to make data as transportable and as usable for multiple purposes as is possible. If this is so, it is also highly desirable to have the data measured, recorded, and stored in as uniform a way as possible to make it as retrievable as possible and useful to as many agencies as may have a need for it. The more specialized or local a particular item of data is, the less need there is for it to be measured in a uniform way. Data uses can be characterized by the scope within which they will be shared among organizations according to the following scheme:

Data Uniformity Category	Scope of Shared Data Use	Required Degree of Uniformity
A	National	Highest
B	Regional	High
C	State	Moderate
D	District	Fair
E	Project	Low

Data may also be categorized by the object of its use; whether it is intended for research or special studies or for calibrating mechanistic models or whether it is intended as a broad-scale statistical measure of the pavement function, condition or performance. Four data categories have been defined on the basis of its intended use.

Data Use Category	Date Use
A	Simple broad scale measurements, statistical relations between data items
B	Network level pavement management
C	Project level pavement management and design
D	Research, special studies, calibrating mechanistic models

As the list of questions is given below, it is well to reflect upon the type and amount of data that is needed to answer each question and how uniform the data should be.

Questions

1. What are the most suitable rehabilitation strategies and under what conditions?
2. What is the expected pavement life and life cycle costs of different rehabilitation strategies?
3. What are the appropriate decision criteria and costs for preventive maintenance?
4. What are the costs of deferred maintenance?
5. What are the costs of routine maintenance?
6. What are the impacts of increased truck loadings, increased tire pressures, and changing tire construction?
7. What should be the factors that are considered in cost apportionment formulas?
8. What effects of traffic, pavement design, tire pressure and design, climate, volumetrically active subgrades (frost and

expansive clay) should be considered in cost allocation?

9. What portion of user costs should be considered in arriving at decisions on optimum pavement designs?
10. What specifications that are currently used for construction quality control should become statistically-based and be correlated with actual pavement performance?
11. How should constructor's pay quantities be changed based upon the quality control that is achieved? Should the pay item deduction be tied to the expected increase in life cycle costs?
12. What are the effects of new materials, construction techniques, additives, reinforcing and strain-relieving layers on the life of rehabilitation and its life cycle costs?
13. What new design and analysis methods for pavements and overlays need to be developed and evaluated?
14. What are the appropriate decision criteria to use to establish priority lists and to distribute rehabilitation and construction funds for different candidate projects?
15. What data should be collected in order to be prepared to respond to future studies that are required by Congress?

Obviously, a wide variety of data will be required to answer these questions. In order to keep the quantity of data collected and the cost of collecting and storing to a minimum, it is essential to plan the data collection effort carefully to attain the maximum use from it. This consideration naturally brings up the subjects of experimental design and statistical sampling which will be considered in subsequent chapters.

CHAPTER 4

AASHO ROAD TEST

In this section, several aspects of the AASHO Road Test will be discussed:

1. Its experimental design for both rigid and flexible pavements
2. What was monitored
3. What relationships were found
4. What types of analysis were used; the form of the equation selected and the selection criteria that were used.

This will be instructive in showing how to determine what types of data are required and how much of it is needed.

The AASHO Road Test was composed of two fairly simple experiments one with flexible and one with rigid pavements, each with four variables. These variables for flexible pavements were load level and the thicknesses of surface, base, and subbase. For rigid pavements, the variables were load level, thicknesses of slab and subbase, and whether the slab was reinforced or not. Despite its simplicity, there were a total of 468 sections of flexible pavement and 368 sections of rigid pavement, for a total of 836 sections of pavement.

FLEXIBLE PAVEMENT EXPERIMENT

So many pavement sections were required because of the number of levels that were used. For example, there were 6 single-axle and 4 tandem-axle loads that were applied to these pavements. Table 11 shows the levels of the different variables that were used in the flexible pavement experiment. When the number of levels of the variables are multiplied together, i.e. load, 11; surface thickness, 6; base thickness, 4; and subbase thickness, 5, the product is 1320, which is the total number of sections that would have been required to fill out a "full factorial" experimental design. However, by arranging the pavement sections so that only the stronger pavements were loaded with the heavier loads, the total number of "main experiment" pavement sections was reduced to 288 with another 44 "replicate sections," which were built in order to give an idea of how much experimental error occurs between pavement sections that are built and loaded in an identical way. By recognizing the simple engineering fact that strong pavements are used with heavy loads, the number of required sections was reduced to 22% (i.e. 288 divided by 1320).

There were special studies that were also conducted on the effects of the subsurface layers, surface treated pavements, paved shoulders, and base type. Table 12 shows how the main experimental design of the AASHO Road Test on flexible pavements was set up. As shown in the table, the experiment was broken down into sub-experiments in which, typically, there were <u>two</u> load levels and three levels of thickness of surface, base, and subbase. Three levels are usually put into an experiment when it is suspected that what is measured will vary in a nonlinear way with one of the variables in the experiment. It is worth while noting that in the layout of the

TABLE 11. Flexible Pavement Experiment Variables at the AASHO Road Test

Variables	Number of Levels	Size of Variables
Load Level	11	see below
No Load	1	0 kips
Single-Axle	6	2, 6, 12, 18, 22.4, 30 kips
Tandem-Axle	4	24, 32, 40, 48 kips
Surface Course Thickness	6	1, 2, 3, 4, 5, 6 inches
Base Course Thickness	4	0, 3, 6, 9 inches
Subbase Thickness	5	0, 4, 8, 12, 16 inches

TABLE 12. Actual Number of Variables and Pavement Sections in the AASHO Road Test Flexible Pavement Experiments

A. MAIN EXPERIMENT

	Loop No.	Load Levels* 0	S	T	Thickness Levels Surface	Base	Subbase	Total in Main Experiment	Replicates
Increasingly Heavier Loads ↓	1	2	0	0	3	2	3	36	12
	2	0	2	0	3	3	2	36	8
	3	0	1	1	3	3	3	54	6
	4	0	1	1	3	3	3	54	6
	5	0	1	1	3	3	3	54	6
	6	0	1	1	3	3	3	54	6
						TOTALS:		288	44

* 0 - Zero Load; S - Single-Axles; T - Tandem-Axles

B. SPECIAL STUDIES

	Loop No.	Subsurface	Surface Treatment	Paved Shoulders	Base Type	Total in Primary Experiments	Replicates
Increasingly Heavier Loads ↓	1	12	--	--	--	12	4
	2	--	12	--	--	12	12
	3	--	--	6	6	12	12
	4	--	--	6	6	12	12
	5	--	--	6	6	12	12
	6	--	--	6	6	12	12
				TOTALS:		72	64

experiment, the Road Test staff considered that between 36 and 54 pavement sections were a sufficient number of pavement sections for any of the sub-experiments that were conducted on each Loop of the Road Test.

RIGID PAVEMENT EXPERIMENT

Table 13 shows the levels of the variables in the main rigid pavement experiment. If the number of levels are multiplied together, the total number of pavement sections is 704. Using the same engineering knowledge that the heavier loads are placed on the heavier pavements, the experiment was broken into sub-experiments, and the total number of pavement sections was reduced to 260 or 37 percent of the full factorial. Another 52 pavement sections were built as replicates to determine the size of experimental error, and still other pavement sections were placed as special studies of the effect of the subsurface and of paved shoulders. Table 14 shows how all of the sub-experiments and special studies on rigid pavements were set up. It is worth noting that here again in the main sub-experiments the total number of pavement sections that was judged to be sufficient was between 32 and 48.

OVERLAY EXPERIMENTS

A total of 99 flexible pavement sections were overlaid when they reached a Serviceability Index that was generally below 1.5. Overlay

TABLE 13. Rigid Pavement Experiment Variables at the AASHO Road Test

Variables	Number of Levels	Size of Variables
Load Level	11	see below
No Load	1	0 kips
Single-Axle	6	2, 6, 12, 18, 22.4, 30 kips
Tandem-Axle	4	24, 32, 40, 48 kips
Reinforcing	2	None, Reinforced
Slab Thickness	8	2.5, 3.5, 5, 6.5, 8, 9.5, 11, 12.5 inches
Subbase	4	0, 3, 6, 9 inches

TABLE 14. Actual Number of Variables and Pavement Sections in the AASHO Road Test Rigid Pavement Experiments

A. MAIN EXPERIMENT

	Loop No.	Load Levels* 0	Load Levels* S	Load Levels* T	Rein-forcing+ 0	Rein-forcing+ R	Thickness Levels Slab	Thickness Levels Subbase	Total in Main Experiment	Replicates
Increasingly Heavier Loads ↓	1	2	0	0	1	1	4	2	32	16
	2	0	2	0	1	1	3	3	36	4
	3	0	1	1	1	1	4	3	48	8
	4	0	1	1	1	1	4	3	48	8
	5	0	1	1	1	1	4	3	48	8
	6	0	1	1	1	1	4	3	48	8
							TOTALS:		260	52

* 0 - Zero Load; S - Single-Axles; T - Tandem-Axles
\+ 0 - no reinforcing; R - Reinforced

B. SPECIAL STUDIES

	Loop No.	Subsurface	Paved Shoulders	Total in Main Experiment	Replicates
Increasingly Heavier Loads ↓	1	4	--	4	4
	2	--	--	--	--
	3	--	12	12	--
	4	--	12	12	--
	5	--	12	12	--
	6	--	12	12	--
			TOTALS:	52	4

thicknesses ranged between 2 and 3.5 inches. A total of 18 overlays were placed on the rigid pavements with thicknesses of 2 and 3 inches.

INVENTORY OF THE AASHO ROAD TEST

The identification of all of the thicknesses and the material properties of each layer, the dimensions and cross-section of each pavement section, as well as all of the statistical properties of weather such as annual rainfall, maximum and minimum mean monthly temperatures are all part of the inventory data for the AASHO Road Test. The sections of pavement in Loop 1 were left without traffic in order to observe the effects of the weather on the rate of deterioration of the pavements.

MONITORING OF THE AASHO ROAD TEST

The data that were monitored at the AASHO Road Test included traffic, environmental variables, some materials properties, and three types of response of the pavement: primary, secondary, and tertiary. Each of these will be summarized below.

1. Traffic

   The daily number of passes of the vehicles in each lane in each Loop were counted.

2. Environmental Variables

   Daily air and pavement temperature and rainfall, seasonal subgrade water content, seasonal changes in the vertical elevation of the pavement surface in the untrafficked Loop, and curling and joint opening in the rigid pavement sections were monitored.

3. Material Properties

Subgrade water content, density, CBR, and plate load tests to determine the coefficient of subgrade reaction, Marshall stability as a function of temperature, and moisture and temperature coefficients of expansion of concrete were either monitored or measured in special lab tests at the AASHO Road Test.

4. Primary Responses

The primary responses that were monitored at the Road Test included deflections, strains, and stresses.

5. Secondary Responses

The secondary responses at the Road Test included roughness, various forms of distress and pumping, and rutting and distortion of the layers with time and traffic. Patching was recorded as it was required.

6. Tertiary Responses

The tertiary response at the Road Test was the Serviceability Index, which was inferred from other physical measurements such as roughness, cracking, patching, and rutting.

It is from the inventory and monitoring data that were collected at the Road Test that several relationships between the variables were developed.

ANALYSIS OF MONITORING DATA

The monitoring data (primary, secondary, and tertiary) was assumed to depend primarily upon the load applied to the pavement and to the "structural" thickness of the pavement section, which will be called the "design" of the pavement. A form of equation that was assumed to give the proper relationship between the variables was used in a linear regression analysis to give the "constants" that related the variables.

Four types of relationships were analyzed:

1. The relations between performance as a dependent variable and load and design as the independent variables. These relations became the well known AASHO pavement design equations.

2. The relations between structural deterioration (various forms of distress) as dependent variables and load and design as independent variables.

   In flexible pavements, the measures of structural deterioration for which equations were developed included rut depth and Class 2 cracking. In rigid pavements, the structural deterioration for which equations were developed included a cracking index although faulting and pumping were also measured and recorded. Each of these equations can be used as a pavement design equation and also can be used to develop equivalent axle loads.

3. The relations between deflection or strain as a

dependent variable and load, design, traveling speed, and temperature as independent variables.

In flexible pavements, equations were developed for normal and rebound deflections in the spring and fall, and total deflections at different vehicle speeds. In rigid pavements, equations were developed for both deflection and strain and it was found that they both depend upon the temperature differential across the depth of the concrete slab.

4. The relations between performance as a dependent variable and deflection or strain and temperature differential as independent variables.

The equations that were developed for flexible pavements related the number of equivalent axle loads to reach a set value of serviceability index to the spring and fall normal deflections. The equations developed for rigid pavement related equivalent axle applications to dynamic edge strain and to static edge deflections, the latter being corrected for temperature differential.

Regression Analysis Used

Linear regression analysis was used at the AASHO Road Test. The familiar design equations with exponents in them were developed by linear relations between the logarithms of the dependent and independent variables. Because we now have larger and faster computers than were available in 1960 when the analysis of AASHO Road

Test data was done and because we now have standard analysis methods that permit routine nonlinear regression analysis, we have many more options in the analysis of pavement data than were available to the staff of the AASHO Road Test. It is, in fact, possible to select the form of equation which is known from engineering principles and from theory to represent correctly the relations among the variables and allow the computer to find the constants for the equation automatically.

Form of Equation Selected

The form of equation that was used at the AASHO Road Test was limited by what could be analyzed using linear regression. The form of equation that was finally selected was

$$g = \left(\frac{w}{\rho}\right)^{\beta} \tag{1}$$

where

- g = the damage ratio, a number varying from 0 to 1.
- w = the number of equivalent axle loads.
- ρ = a constant representing the number of equivalent axle loads required to take a pavement to a damage ratio of 1.
- β = a power representing the rate at which damage accumulates.

The logarithm of the equation gives

$$\log g = -\beta \log \rho + \beta \log W \quad (2)$$

which is of a linear form such as

$$y = a + bx \quad (3)$$

where

$$y = \log g \quad (4)$$

$$x = \log W \quad (5)$$

$$a = -\beta \log \rho \quad (6)$$

$$b = \beta \quad (7)$$

Although other forms of equation were tried that were reducible to the linear form shown above in Equation 3, this equation was finally selected because the sum of squared errors between the observations and the predictions were as small as any and smaller than most.

However, as in the original experimental design of the Road Test, in which engineering knowledge was able to reduce the number of required pavement sections to 22 and 37 percent of the full factorial, the same kind of engineering knowledge could have eliminated a number of forms of equation from consideration, including the form of equation that was originally chosen.

The serviceability index is defined on a scale between 0 and 5 and cannot become negative no matter how many axle equivalents pass over a pavement. This fact, which is a "boundary condition," requires a form of equation that remains between 0 and 5, a requirement that is violated by the form of equation that was selected at the AASHO Road Test. The form of equation that is required by the boundary conditions on serviceability index must approach a horizontal asymptote at large values of equivalent axle load applications. This requirement can be satisfied by exponential and S-shaped curves.

Because we no longer have the hardware and software constraints that were faced by the staff of the AASHO Road Test, we can and should spend the extra time it takes to make sure that the correct form of equation is selected based upon "boundary conditions" and the principles of mechanics. Just as it was used in the design of the Road Test experiment, engineering knowledge should be used in the selection of the form of equation used for the analysis.

Why is the <u>form</u> of equation important? A statement from the AASHO Road Test Report 5 (HRB Special Report 61E) states the reason as well as any:

> "Attempts at mathematical analysis designed to establish specific relationships between performance and overlay design were unsuccessful, because the outcome of each analysis proved to be <u>highly dependent</u> (emphasis mine) on the assumptions made concerning the mathematical model for the analysis." (pg. 112)

The same can be said for all assumed forms of equation, and especially as is related to overlay design. This statement emphasizes the need for selecting the form of the equation carefully based upon engineering principles rather than upon mere statistical or computational convenience.

CHAPTER 5

AASHO ROAD TEST SATELLITE STUDIES

At the conclusion of the AASHO Road Test, it was recognized that there were two major "variables" that affect the performance of pavements which had remained constant during the Road Test: the effects of the subgrade and of the local climate. It was apparent that these variables and others needed to be incorporated into the AASHO design equations in order for them to have widespread applicability. Further data collection in locations other than Ottawa, Illinois, the site of the AASHO Road Test, was required and this initiated the satellite studies program, guidelines for which were provided in NCHRP Report 2A, "Guidelines for Satellite Studies of Pavement Performance." The following is a review of the recommendations contained in NCHRP Report 2, "An Introduction to Guidelines for Satellite Studies of Pavement Performance."

Any variable in a satellite study is considered to be either a load variable, a climatic or regional variable, a structural variable, or a performance variable. The general objective for a study might be, for example, to learn how a particular structural variable is affected by a climatic variable, or how some performance variable is affected by combined changes in load, climatic, and structural variables.

Four interrelated activities are required to produce this kind of information. Appropriate experiment designs need to be developed, test sections selected or constructed, and appropriate measurements made, processed, and analyzed.

One of the basic proposals in the guidelines in NCHRP Report 2A is that measurement teams be equipped and trained to obtain "common denominator" measurements on all satellite test sections, or at least on those which are part of a nationwide design. These teams would be supplemental to the sponsor's measurement programs and would visit each satellite project on a regular basis throughout the life of the project.

It is assumed in the guidelines that a manual specifying in detail how "common denominator" measurements are to be obtained will be developed for use by the measurement teams.

Whether undertaken by the measurement team, project sponsor, or both, the following measurement program is considered to be minimal for any satellite test section:

1. Structural Variables. Thicknesses of surfacing, base, and/or subbase courses; strength characteristics of each structural component, by at least one and preferably two test procedures; measurements for classification of structural components (wherever appropriate); and at least one measure of composite strength.

2. Load Variables. At least one loadometer study which applies directly to the test sections in the study. Load studies will ordinarily be supplemented by vehicle count studies and applicable trends of traffic composition.

3. Climatic and Regional Variables. Measurements to describe year-round test section climate and environment, as well as seasonal variations in composite strength, for example, "highs and lows" for

deflections.

4. Performance Variables. Yearly evaluations of surface deformation and deterioration, present serviceability index and performance index. The guidelines give details for several alternative methods of obtaining present serviceability and performance index values.

DEVELOPMENT OF EXPERIMENTAL DESIGNS

The controlling activity in any satellite study is the development of an experimental design which shows how selected structural, load, and climatic or regional factors will be varied in combination with one another.

Test Site Factors.

Certain variables will not vary appreciably within test sites, but will have different levels from one test site to another. Such variables are called test site factors, and will generally involve differences in roadbed material, climatic conditions, or rate of equivalent 18-kip axle-load accumulation.

A simple example is shown in Figure 3. Rainfall and freeze-thaw conditions, for instance, have been used to describe three levels of climatic severity: low, medium, and high. The vertical scale shows three levels of as-constructed roadbed strength, perhaps in terms of subgrade modulus of reaction. Thus there are nine combinations of test site factors in the illustrative experiment design. It will be

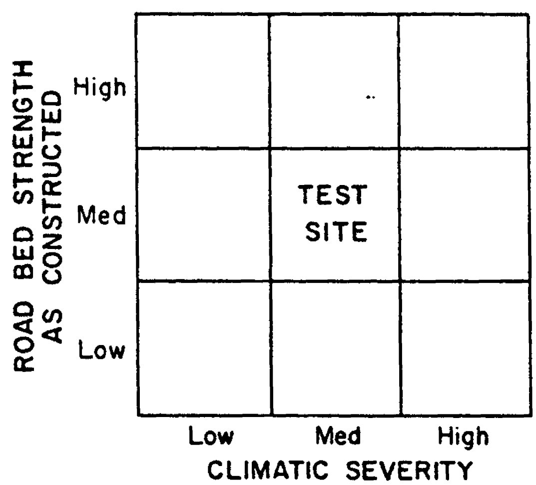


Figure 3. Experiment design for test site factors

supposed in this example that all nine test site conditions will have the same number of equivalent 18-kip axle loads per day, so that they are not an experimental factor.

Pavement Structure Factors.

The next question is whether any pavement structure factors will be included in the experiment design. If not, the example will be a two-factor study which has either the same pavement design at all nine test sites, or perhaps the same range of designs at every site.

It will be supposed that this example is a rigid pavement study and that two pavement structure factors will be varied at each test site. The first factor will be thickness of surfacing at two levels, seven and nine inches. It is assumed that the surfacing material, reinforcement, and jointing is similar to that of the reinforced AASHO Road Test sections. The second pavement factor will be the strength of subbase material which is six inches thick for all test sections. The low-level strength is assumed to be equivalent to that of AASHO Road Test subbase, and a high-level strength will be obtained by cement stabilization. As shown in Figure 4, the illustrative experiment design provides for four different pavement designs at any test site, 7L, 7H, 9L, and 9H.

Complete Factorial Experiments for Individual Satellite Studies.

If the experiment design contains all possible combinations of selected factor levels, the study is a complete factorial experiment. For the example, Figure 5 shows 36 test sections in the complete

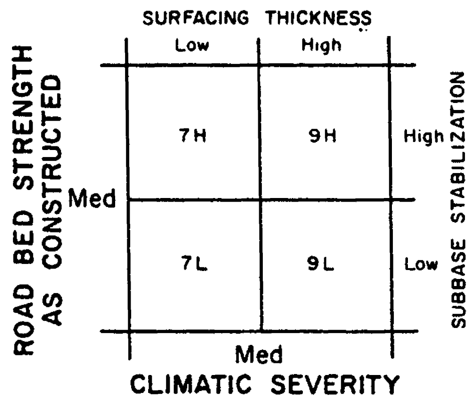


Figure 4. Experiment design for pavement structure factors

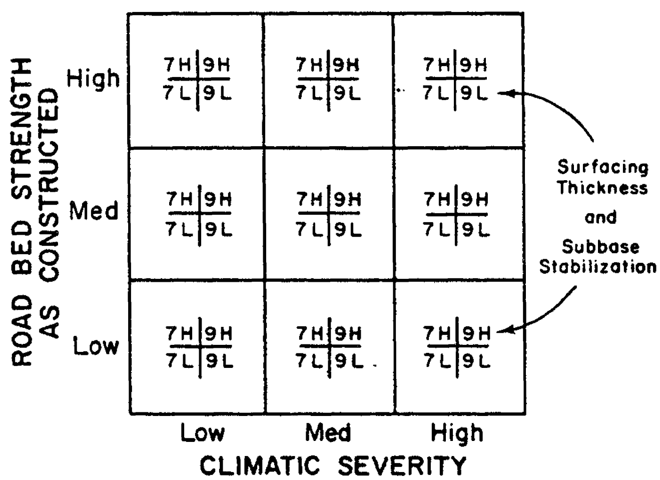


Figure 5. Complete factorial experiment - 36 test sections

factorial, nine test sites in all combinations with four pavement structures. The guidelines recommend this type of experiment design for any individual satellite study, using either two, three, or four factors and either two or three levels for any factor. It is also recommended that at least one factor be similar to a Road Test factor and that one or more new factors be included. Furthermore, it is proposed that at least one level of any factor should correspond to a level that was used in the Road Test. Of the four factors in the example, only the surfacing thickness factor was varied at the AASHO Road Test, so this study will provide information on three new factors.

Experiment Designs with Factors Confounded.

In existing pavement studies, particularly, it may not be possible to fill all cells in a proposed experiment design. As an extreme case, perhaps only the seven sections shown in Figure 6 can be found in the existing highway system. It can be seen that the stronger pavement designs are associated with more adverse roadbed and climatic conditions and that weaker designs are found in more favorable roadbed-climatic conditions. This situation is to be expected in existing pavement studies since the basic principles of pavement design imply that such compensations be made. As the example now stands, a few direct comparisons can be made, but for the most part surfacing and subbase effects are confused or confounded with each other and with the effects of test site factors. Still further confusion would occur if the 18-kip ESAL's were to vary from one site

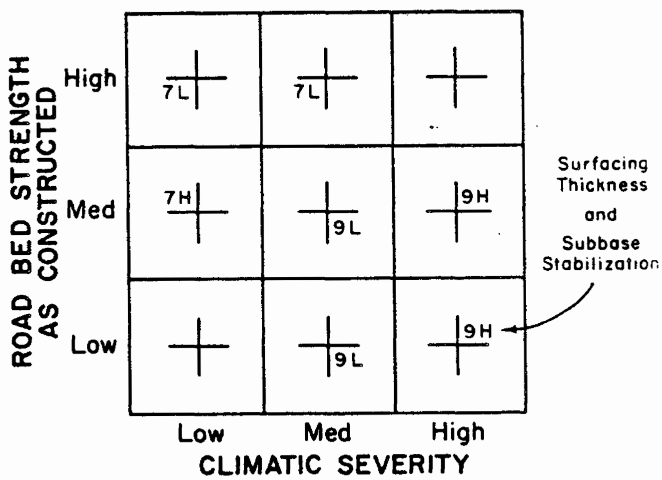


Figure 6. Design with factors confounded - 7 test sections

to another. In this example, it is virtually impossible to analyze the separate effects of the four factors selected for study. If the research objectives definitely include the study of all four variables, then consideration will have to be given to the construction of new experimental sections to give a complete factorial experiment.

Composite Experiment Designs for Nationwide Satellite Studies.

In addition to experiment design guides for individual satellite studies, the guidelines include composite experiment designs that can be used for nationwide cooperative studies of pavement performance. The present illustration shows the nature of the proposed nationwide designs. Three types of test sites are shown in Figure 7: four factorial sites involving the high and low levels of roadbed strength and climatic severity, one centroid site with medium levels, and four extension sites which introduce very high and very low levels of one factor when at the medium level of the other factor. In the nationwide composite design, five test site factors are used: two for roadbed strength, two for climatic conditions, and one for daily load rate, with a total of 32 factorial sites, one centroid site, and ten extension sites. Thus a nationwide composite experiment would involve 43 test sites encompassing a wide range of roadbed and climatic conditions.

As shown in Figure 8, several additional combinations of surfacing thickness and subbase stabilizations are introduced for the composite experiment design. One of these is for a centroid structure

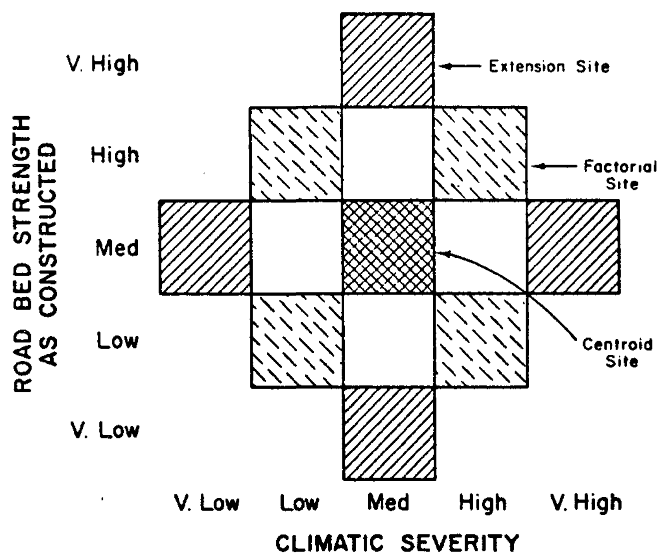


Figure 7. Composite experiment design - test sites

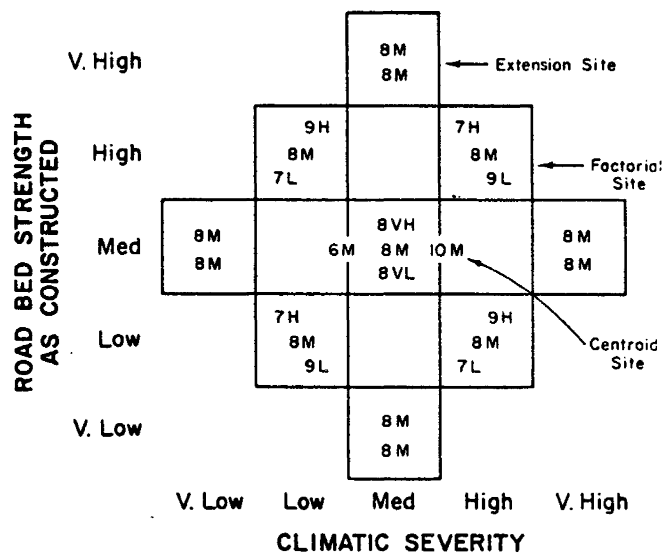


Figure 8. Composite experiment design - 25 test sections

which has eight-inch surfacing thickness and medium stabilization level. This 8M section occurs once at the centroid site, once at every factorial site, and in duplicate at all extension sites. Thus the centroid structure is common to all test sites and serves as a control or standard section. Factorial sites now include only two of the four pavement designs which were in the complete factorial experiment of Figure 5, but these have been selected according to certain mathematical principles.

At the centroid site extra low and extra high levels of surfacing thickness (six and ten inches) are used with medium stabilization, and extra low and extra high levels of subbase stabilization (VL and VH) are used with medium surface thickness. Thus the centroid site now has five test sections for the study of wide variations in pavement structure factors.

In the illustrative composite experiment design, only 25 test sections are used to study the same factors, and over wider ranges, as for the 36-section complete factorial experiment. The nationwide designs given in the guidelines involve six structural factors in addition to the five test site factors previously described. Each of the ten extension sites has two centroid sections, each of the 32 factorial sites has five sections, and the centroid site has 13 sections, totaling 193 test sections for any pavement type under study. To study eleven factors in a complete factorial experiment would require over 2,000 test sections. The composite experiment design is believed to be near optimum for nationwide cooperative studies. Any cooperating state might have two, five, or more sections in the overall pattern, provided that appropriate test site conditions are available.

In some cases, test sections representing a part of a nationwide experiment design might also be part of an individual study.

SELECTION OR CONSTRUCTION OF TEST SECTIONS

After an experiment design has been developed for selected factors, specifications are needed for all structural, load, and climatic or regional variables not covered by the experiment design. Such specifications relate to test section dimensions, provision for destructive testing, ground rules for the immediate environment of test sections, and values or permissible variations for materials and construction procedures. Many of these items are discussed in the guidelines, but all details are left to the sponsors of individual or nationwide satellite projects.

Preliminary data on sections selected for existing pavement studies may reveal the need for revisions in the experiment design. As a general rule, it is suggested that if suitable test sections, including sufficiently precise load histories, cannot be found for at least 90 percent of the planned experiment design cells, then the design should be reduced through the deletion of factors and factor levels. It is important in existing pavement studies to select sections in such a way that variables occurring in the experiment design are not correlated with other variables.

NCHRP Reports 2 and 2A gave explicit guidelines for the organization and conduct of a nationwide Satellite Study program. Nearly two decades later, a study was made of the data that are available in the various States as a result of Satellite and environmental studies in NCHRP Project 20-7, Task 17. The results of that study are summarized below.

STUDY OF DATA AVAILABLE FROM SATELLITE ROAD TESTS

In 1980, the NCHRP circulated a questionnaire to all 50 States to assess the quantity, quality, and accessibility of the data that are available from Satellite Studies that were conducted by the States. A total of 47 States replied. The total number of test sections that were found were 3167 flexible pavement and 1192 rigid pavement test sections, distributed as shown in Table 15.

A careful assessment of the available data were made to determine the likelihood of being able to successfully develop a design equation for a pavement. The data were classified into five categories:

1. Design
2. Soil Support
3. Environment
4. Traffic
5. Performance

The list added "Soil Support" to the four that were specified in NCHRP Report 2A. Finding that it was impossible with the available data to construct a "universal" pavement design equation that would be applicable in all climatic zones, the study broke pavements down into

TABLE 15. Number of Test Sections

States	Number of Test Sections
Arizona	50
California	100
Colorado	20
Connecticut	17
Florida	137
Georgia	12
Illinois	127
Louisiana	120
Maine	60
Minnesota	82
Missouri	239
Nebraska	24
New Jersey	9
New York	228
North Carolina	36
Pennsylvania	38
Texas	511
Virginia	65
Washington	2,596

11 different types and divided the United States into 6 different climatic zones, giving a total of 66 possible regional pavement design equations that could be developed. In order to qualify as a likely equation, between 30 and 50 separate pavement sections were required and high quality data in each of the five categories was necessary. It was found that a total of 38 regional pavement design equations could very likely be assembled from the available data, as shown in Table 16.

VERIFICATION OF FINDINGS OF THE STUDY OF AVAILABLE SATELLITE DATA

The second phase of NCHRP Report 20-7, Task 17, attempted to verify the conclusions reached in the study of the questionnaires in the first phase of the project by performing a pilot study. Data from Minnesota and Texas were used to develop regional overlay design equations. Three levels of design equations were identified in the study, characterized by increasing similarity to a mechanistic design equation, which is the third level. A Level 1 equation can be assembled with presumed, rather than measured, material properties. A Level 2 equation makes use of measured material properties. Level 1 equations were successfully developed from both the Minnesota and Texas data, with coefficients of determination (R^2) around 0.20 to 0.60, which is about as good a fit as can be expected from a Level 1 equation. An unusually successful Level 2 overlay design equation was developed from the Texas data with an R^2 of 0.94.

The second phase of the study showed that the assessment that was

TABLE 16. Most Likely Regional Equations

Pavement Type	Climatic Regions 1	2	3	4	5	6
Flexible						
1. Asphalt on flexible base	California Florida Washington	California Missouri Washington	Minnesota Missouri New York	Cali- fornia	California Washington	Washington
2. Asphalt on stabilized base	Louisiana Washington	Louisiana Washington			Washington	Washington
3. Asphalt on bituminous base	Florida Texas	Missouri Texas	Missouri	Texas	Texas	
4. Full depth asphalt						
5. Surface treated pavement	Texas	Texas		Texas	Texas	
6. Overlaid flexible pavement	Texas Washington	Texas Washington		Texas	Texas Washington	Washington
Rigid						
1. Contin-uously reinforced concrete	Texas	Texas		Texas	Texas	
2. Jointed plain concrete	Washington	Washington			Washington	Washington
3. Jointed reinforced concrete	Louisiana	Illinois Louisiana	Illinois			
Composite						
1. Asphalt overlays on jointed concrete	California Washington	California Washington		Cali- fornia	California Washington	Washington
2. Concrete overlays on jointed concrete						

made of the data that are available from the States is very likely to be accurate at least for Level 1 pavement design equations. It is unlikely that more than a dozen Level 2 equations can be composed of the available data.

NUMBER OF PAVEMENT SECTIONS NEEDED FOR REGIONAL PAVEMENT DESIGN EQUATIONS

Rather than attempting to develop a "universal" equation for each of 11 or 12 types of pavement that will be valid in all climatic areas, the "regional" approach was adopted. In this approach, it is necessary to identify those climatic areas which can be considered reasonably homogeneous as far as pavement performance is concerned, and attempt to develop models using only those variables which vary significantly within that region. It will be remembered that a procedure such as this was used at the AASHO Road Test to break it down into sub-experiments with a reduced number of variables. Within each area, all of the design factors not included in the blocking scheme would be allowed to change within reasonable ranges. This proposed approach has the attractive feature that it allows the development and implementation of a factorial design with a number of experimental conditions that is far less than that required by the "universal" equation approach.

Essentially, the "regional" approach is computationally equivalent to the "universal" approach. The conceptual difference lies in the fact that in the geographical approach several regions are defined based on soil support and climatic conditions. Within each of these (possibly) five or six regions, a fractional factorial design with blocks should be run to estimate the main effects and interactions.

Within a particular region the following is a likely list of factors to be investigated:

- Surface thickness
- Surface modulus
- Base thickness
- Traffic intensity
- Traffic distribution
- Drainage
- Geometry (shoulder, no shoulder, cross-slope)
- Pavement type

As can be seen, the reduction in the number of factors would be from (approximately) 15 to (approximately) 8. Since 2^8 designs are easier to handle than 2^{15} designs, the computational improvement would be significant. Table 17 summarizes a comparison between the "universal" and "regional" approaches.

The regionalization of the performance equation is very attractive from a computational point of view. In practice, a true attempt at optimizing the pavement experimental design conditions is plausible by using so-called "Response Surface Exploration." This approach consists of sequentially adjusting the levels of the factors using a "steepest descent methodology," which has the purpose of minimizing the squared error between observed and predicted

TABLE 17. Number of Sections Required for Universal and Regional Design Equations

	Universal	Regional
Factors, n	15	8
Experimental Conditions, Full, 2^n	32768	256
Recommended Fraction	1/128	1/8
Experimental Conditions Fractional, 2^{n-p}	256	32
Recommended Number of Blocks	8	4 (*)
Experimental Conditions per Block	32	8

*As an example

performance of pavements. The adjustments are based on results from the runs of a 2^{n-p} fractional factorial design. In the neighborhood of the optimum, 3-level designs are used instead of 2-level designs in order to investigate the curvature of the performance function.

As a result of these considerations of the design of experiments and of the distribution of good data within the United States, it appears to be more feasible to construct regional equations for each major pavement type than to try to modify or revise single equations for flexible and rigid pavements to take into account all of the possible variables. In addition, the regional equations for each pavement type are more likely to be reliable representations of pavement performance than a single universal equation.

FACTORS AFFECTING THE QUALITY OF AVAILABLE DATA

The quality of the available data will be affected by two major factors: (1) the accessibility of the data and (2) the lack of an experimental design as a basis for selecting the pavement sections.

The accessibility of the data includes the way in which they are stored as well as the familiarity of the personnel of the State agency with these data. For example, it was found that Minnesota, which reported that its pavement data files are manual and decentralized, had excellent data which were very accessible because of the familiarity the State's personnel had with the data. In such a State, it is possible to construct a reasonably well represented experimental design from the available data with the assistance of the State's personnel in the selection process.

An experimental design of the data collected is important primarily as a factor to reduce bias in the data. It is to be expected that the pavement sections on which data have been kept were normally not built with the careful construction control exercised at the AASHO Road Test so that a larger degree of scatter of the data points may be expected. Estimates of the sizes and distribution of error sources in the data may be made with an analysis of variance if the data are gathered according to an experimental design and as such, it is valuable information. However, even if pavement sections are not available which fit into a predetermined experimental design, performance and distress equations can still be found. These equations should be used with the understanding that there may be bias in the data and thus in the predicted results.

REQUIRED NUMBER OF PAVEMENT TEST SECTIONS

Taking 32 pavement sections as a minimum number of sections that are required to develop an equation, and approximately 60 different regional pavement design equations to be developed, a minimum number of pavement sections that are required is 1920. Taking 50 pavement sections as an upper limit, the number of required pavement sections is around 3000. The type of data that should be collected on these sections should be sufficient to develop Level 2 equations. In order to see the quantity and type of data that are needed to construct reliable design equations, as well as the kind of detail that is necessary for this purpose, it is worthwhile to consider the COncrete Pavement Evaluation System (COPES), which was developed on NCHRP Project 1-19 by the University of Illinois.

CHAPTER 6

CONCRETE PAVEMENT EVALUATION SYSTEM (COPES)

COPES includes jointed plain, jointed reinforced, and continuously reinforced concrete pavements. The COPES data bank provides extensive information for the development of predictive models that can be used for pavement management purposes, including prediction of remaining life and future rehabilitation needs.

The system consists of three major components: data collection, storage and retrieval, and evaluation. These three components and several uses of the data are illustrated in Figure 9. Both historical and field data are obtained for each pavement section included in COPES. The data processing is computerized for maximum efficiency. The user can retrieve pavement information and perform many analyses and evaluations of the data almost instantaneously using a remote computer terminal.

The sample of data included in the COPES data bank (1297 miles) represents approximately 6 percent of the total mileage of the Interstate concrete pavement network.

State level demonstrations of COPES have been conducted in six states: Illinois, Georgia, Utah, Minnesota, Louisiana, and California. A number of demonstration analyses and evaluations were made in these States including the following:

- Network inventory data summary
- Network condition data summary
- Prediction of future pavement deterioration (cracking, joint

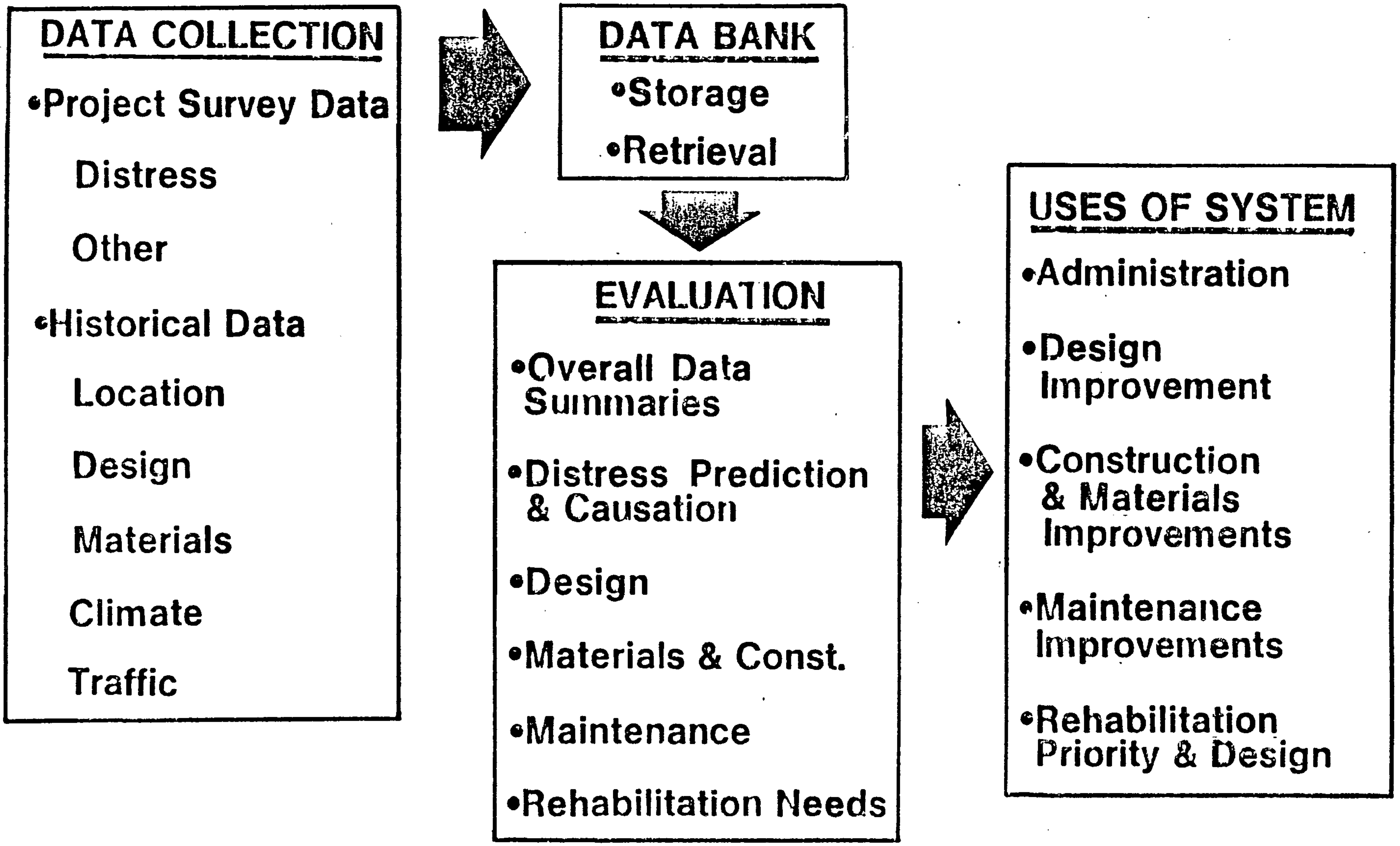


Figure 9. Concrete Pavement Evaluation System - COPES

deterioration, faulting, PSR, pumping)

- Design evaluation and improvements
- Construction and materials evaluation
- Maintenance evaluation
- Determination of causes of pavement deterioration
- Determination of rehabilitation needs
- Determination of research needs and special studies

COPES relies heavily on the use of existing pavement distress to conduct the many analyses and evaluations subsequently described. Because of this, a comprehensive distress identification manual was developed to provide for standardized uniform data collection. The manual describes each distress type, what causes it, and how to measure it; defines levels of severity; and provides photographs of many typical distresses. The manual lists approximately 17 types of distress for flexible, jointed concrete pavement, and continuously reinforced concrete pavement.

COPES or its various components are already being used by several agencies. The Distress Identification Manual is being used by several states, and two states (Minnesota and Virginia) are implementing COPES presently. The data collection forms and procedures developed for COPES were used as the pattern for the data collection guides for the ongoing FHWA Long Term Monitoring Pilot Program. One state has also extended COPES to include asphalt pavements (Illinois).

In summary, the development and field demonstration of COPES show that state and national pavement monitoring efforts can produce results that can be used to great advantage by AASHTO, the FHWA, and individual states involved in developing improved management, design, construction and maintenance procedures for concrete pavements.

In the following, a brief description will be given of each of the three elements of COPES: data collection, storage and retrieval, and evaluation and use.

DATA COLLECTION

The concrete pavement network is divided into "uniform sections." A uniform section has uniform characteristics along its length including structural design, joint design and spacing, reinforcement, truck traffic, subgrade conditions, distress, etc. Uniform sections are frequently defined by original construction section boundaries.

The number of uniform sections from which data are collected depends upon the purpose of the pavement evaluation. If the data in COPES is to be used for network level pavement management programming, then all sections on a given highway system should be included. The COPES data can then be utilized to prioritize projects for maintenance or rehabilitation and to develop rehabilitation strategies.

If COPES is to be utilized basically for research purposes (e.g., design evaluation, etc.) then only a "sample" of the entire network is required. The uniform sections must be stratified into groups based upon similar climate, design, and any other major factors that are believed to influence performance. A sample of sections can then be selected from each of these stratified groups. Because of the highly variable performance of pavements, at least 20 sections of a given pavement type should be selected from each climatic zone to provide a data base capable of adequately assessing climatic effects. For nationwide evaluations, data for each pavement type and design will be required from each broad climatic zone. Pavements of similar design built on similar subgrades should generally give similar performance in each of these zones.

The collection of historical (design) and field data is next. The historical or inventory data can include over 325 variables covering project identification, location, environment, structural design, joint design, reinforcing steel, concrete mix design and properties, base and subgrade properties, shoulder design, drainage, previous traffic, and previous maintenance and rehabilitation activities. The historical data are recorded on 13 data collection sheets that are designed to facilitate direct data entry onto computer cards or other input media. The historical data can normally be obtained directly from State Department of Transportation as-built construction plans, standards, specifications, construction and materials reports, traffic studies, W-4 tables, climatic records, and other sources.

The field data collection procedures describe how to obtain all needed data from a given highway construction project during a single visit to the project. These procedures are outlined below:

1. A trained two-to-three person survey crew makes one pass over each lane of the entire project at the posted speed limit in a mid- to full-sized automobile. Present

serviceability ratings and certain distress types are recorded at this time.

2. The automobile is then driven slowly (10-15 mph) along the outside shoulder of the entire project to allow the collection of additional distress data.

3. The survey team stops once within each mile (1.6 km) and conducts a detailed survey of a randomly selected 0.1 mile (0.16 km) sample unit.

This survey procedure provides for the efficient collection of all existing distress data on 7 field data collection sheets. No expensive equipment is needed to conduct the field survey. Only items such as a hand-held odometer, measuring tape, scale or pocket ruler, and faultmeter are required.

Field data collection times are highly dependent on the amount of distress present and the volume and characteristics of traffic present. The following survey time estimates for two lane-miles show that the field data can be collected quickly by a trained survey team:

Good Pavement Condition - Rural (10-15 min.), Urban (15-25 min.)

Fair Pavement Condition - Rural (15-25 min.), Urban (25-35 min.)

Poor Pavement Condition - Rural (25-45 min.), Urban (35-50 min.)

COPES was designed to be able to accommodate the many unique pavement designs, material properties, construction procedures, distress types, etc. that might be encountered in nationwide uses. Considerable data collection and storage savings can be realized by eliminating the collection of any variables that are of constant value or of little use to the user-agency.

DATA STORAGE AND RETRIEVAL

Large amounts of data must be collected and processed by COPES for a typical state highway network, and especially for nationwide or regional evaluations over many states. Thus, the use of automatic data processing (ADP) is essential for successful system operation. The data management system used in COPES is the Scientific Information Retrieval (or SIR). SIR is a data base management system with the following major capabilities:

1. efficient storage, retrieval, and manipulation of large amounts of data (input, modifications, deletions, and other means of controlling the data bank contents);
2. simple and complex data retrievals in a straight-forward manner;
3. report-generating procedures for the production of simple or complex reports;
4. direct interface with other computer programs to perform statistical and other analyses on the data; and
5. many other capabilities.

The statistical analyses of the data can be performed using the SPSS (Statistical Package for the Social Sciences) or the Bio-Med Computer Package, P-Series (BMDP). These are widely used statistical systems.

Data retrieval and analyses are easily accomplished using SIR in either batch mode or interactive mode from a remote computer terminal. The terminal can be located in the user's office and connected to the computer by means of telephone lines. This allows the user to input and execute a set of SIR commands, retrieve data files in any desired format, and conduct many kinds of analyses of the data, without leaving the office.

It should be noted that the data collected on the historical and field data collection sheets can be entered into other computerized data management and statistical analysis systems (e.g., SPSS, SAS, BMDP, etc.). If the selected systems do not have the capabilities of SIR, some difficulties might be expected because of the large size of the data base, and the cost of data storage, retrieval, and analysis may be greater. However, COPES can be used even if the SIR system is not available.

The data processing procedure used in COPES is as follows. The first set of field and inventory raw data are collected using standard data collection sheets that are then stored in a manual filing system. The raw data are then extracted from these sheets and keypunched directly onto computer cards or other input media for automatic data processing. The cards are read into a digital computer and the data are entered into the SIR data base. At this point, the raw data are edited, cleaned, etc., to prepare them for analysis. The data may then be retrieved and analyzed using the many statistical procedures contained in the SPSS or BMDP. The resulting summary tables, reports, predictive equations, plots, etc., may then be evaluated to produce recommendations for design, construction, and materials improvements.

Additional data are collected at periodic intervals (e.g., at 1, 2, or 3 year intervals). These data are input in the same way as the initial data and are simply added to the existing data base. Both the manual storage files and the computerized SIR data bank are easily updated with new data. Data analyses can then be repeated, making time sequence analyses possible, since condition data are available at more than one point in time.

The development of automated reports is desirable for specific agency uses. The SIR data base management system provides the user-agency with flexible report generation facilities.

DATA ANALYSIS AND EVALUATION

The information contained in the COPES data bank can be analyzed in many ways. Examples of these are given below.

1. Network Inventory Data Summary. Network inventory information addresses the need to know the extent and design of pavement facilities. Overall summaries of pavement age, slab/base design, subgrade soil types, climate/drainage characteristics, traffic volumes, and 18-kip equivalent single-axle loadings (ESAL) can be developed. This information can be sorted and summarized by highway district, highway route, county, and pavement type.

2. Pavement Condition Summary. Brief or comprehensive summaries of an agency's pavement condition can be generated. These can be sorted statewide by district, county, route, etc. A complete summary of pavement condition includes distress, roughness, and PSR or PSI.

3. Future Pavement Condition Prediction. Regression models can be developed using the data collected to predict slab cracking,

pumping, joint deterioration, joint faulting, and PSR. These models can be used for predicting remaining life, selecting rehabilitation strategies, and determining causes of pavement deterioration.

Regression models were developed for PSR and for the four major types of distress identified for either JRCP or JPCP in each of the six demonstration states (5 x 6 = 30 models). Regression models were also developed for the national data base for each of these distress types and PSR for JRCP and for JPCP (5 x 2 = 10 models). These models provide a valuable source of information for determining which variables affect serviceability and distress occurrence the most.

4. Design Evaluation and Improvements. The COPES data provides an excellent source of information to continually monitor the performance of past designs. The adequacy of the design procedures can be evaluated by comparing field performance with predicted performance. The demonstrations in six states and the national demonstration showed that it is possible to develop many recommendations to improve pavement design, construction and maintenance practices.

5. Construction and Materials Evaluation. The detailed information in COPES provides information to determine if construction procedures or materials used are contributing to pavement deterioration. For example, in the demonstration project, inadequate or improper sawing of joints was observed in three of the participating states. This resulted in considerable random slab cracking and can be expected to significantly reduce pavement life.

6. Maintenance Evaluation. Several aspects of pavement

maintenance and rehabilitation can be evaluated, including full depth patching, joint sealing, subdrainage, etc. For example, it was found that the extent of joint deterioration for effectively sealed joints was 2 to 3 times less than that for joints that were poorly sealed and contained incompressibles.

7. Rehabilitation Needs. The data in COPES provides an excellent source of information to assist in determining rehabilitation needs for individual projects, and for determining general rehabilitation strategies for an overall network of pavement sections.

8. Research Needs and Special Studies. COPES provides an excellent source of distress data for determining research needs. For example, if the data shows that joint deterioration is excessive, research studies could be initiated to develop improved joint spacing, load transfer methods, joint sealants, and forming methods, etc.

COPES can also be a valuable tool in conducting a number of special studies. For example, field data collected in the six participant states were used to develop regression models to estimate the lane distribution of trucks. Truck counts (129 in six states) were made in each lane of controlled access highway with two to five lanes in each direction. Regression analysis of the data provided two models for estimating the percentage of trucks driving in the different lanes. The only significant variables in these models are one-way ADT and the number of lanes in the direction of travel.

SUMMARY OF COPES POTENTIAL FOR PAVEMENT MANAGEMENT

The experience with COPES thus far strongly supports the need for long-term monitoring. Valuable information can be obtained through the evaluation of in-service concrete pavements to improve design, construction, material quality, and maintenance procedures. The information is also very useful in pavement management for determining the condition of an overall pavement network and its existing and future rehabilitation needs.

A summary of expectations of how COPES will be utilized by the Minnesota DOT is as follows:

> "Minnesota constantly needs answers to questions regarding the performance of their pavements. It is difficult to tell in advance what questions, to what detail, and what the far reaching implications might be.
>
> "Considering the cost of our existing capital investment, the rate at which it is wearing out, and the even higher costs of major rehabilitation or removal and replacement, we simply cannot afford to repeat design and construction techniques which will result in below optimum performance.
>
> "Therefore, we believe that COPES, with its vast amount of detailed information, coupled with SIR as a highly efficient data base manager and suitable statistical packages, will through simple and multiple regression analysis enable us to rapidly:
>
> 1. evaluate past pavement designs in detail;
> 2. evaluate past construction practices;
> 3. evaluate the effects of traffic on these pavements;
> 4. make predictions of remaining pavement life in existing pavements;
> 5. indicate the value of timely and appropriate rehabilitation techniques;
> 6. weed out elements in our concrete pavement philosophy which result in poorer performance;
> 7. emphasize elements in our concrete pavement philosophy which result in better performance;
> 8. support concept development which lowers annual road user costs; and
> 9. store this information in a readily retrievable format which through high tech equipment will make detailed information regarding a pavement available to our design, materials, and maintenance engineers."

CHAPTER 7

LONG-TERM MONITORING PILOT STUDIES

Although a separate, more detailed report will be furnished to the participants in the Long-Term Monitoring Workshop, a brief summary of the pilot Long-Term Monitoring Studies will be presented here.

Although the pilot study began with a total number of pavement sections of 102, some States voluntarily added more to their total and in other States, it was found that the pavement cross-section changed so much that the original pavement section had to be classified as two sections. As a result, the final count of pavement sections in the Pilot Study became 144, distributed among the climatic zones as shown in Table 18.

As can be seen from the Table, 3 of the 12 cells in the table have 16 or more pavement sections in them. If the data from each of these pavement sections were collected uniformly, it would be possible to develop preliminary pavement design equations for each of the three. If there were at least 30 pavement sections in each cell of the table, making 360 total pavement sections in all, it would be possible to develop pavement design equations for all 12 combinations in the table. But this requires the ability to combine data across State boundaries, a condition that can be met only if the data are collected in a reasonably uniform way.

In the following sections, the LTM plan that was adopted by each State is summarized.

TABLE 18. Distribution of Pavement Types in Different Climatic Zones

	Flexible	Composite	Rigid	Totals
Wet - Freeze	10	8	35	53
Wet - No Freeze	11	10	6	27
Dry - Freeze	21	--	9	30
Dry - No Freeze	14	3	17	34
Totals	56	21	67	144

SUMMARY OF ARKANSAS' WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

The pavement management program (May 1980) has developed pavement condition ratings for all sections of pavement on Arkansas' 16,000 mile system. These ratings are used to justify project needs and priorities. Pavement management's goal is to be able to compare different types of pavement sections to determine the most economical section to construct. In addition, it should be able to address the effect of various weight limitation revisions that are being considered. (Current 73,280 lbs. weight limit.)

Improvements to Existing Pavement Management (Task C)

- Automation of Mays Ride Meter with PCR 2000 digital recorder.
- Purchase of portable weighing device to facilitate weighing of trucks at temporary weigh station sites.
- Development of a portable (bridge) weight-in-motion system.*
- Development of design procedures for ACHM overlays on PCC pavements.*
- Stresses and strains in ACHM overlays on PCC pavements.*
- Development of computerized procedures for retrieval and analysis of pavement monitoring data.
- Development of a calibration procedure for Mays Ride Meter using GM profilometer or calibration track.

* Note direct result of LTM Program.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible				4
Composite				10
Rigid				6

SUMMARY OF CALIFORNIA'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

Existing Pavement Management System (PMS) - "The system contains a biennial pavement conditions inventory of all 47,000 lane-miles of State highways, an engineering logic system which analyzes the extent and severity of pavement problems to determine and report approximate rehabilitation strategies and their costs, and a prioritizing system which reflects top-level management policy direction on the rehabilitation of pavements." "In essence, Caltran's PMS provides much of the input needed to answer most of the above with the exception of predictive capability."

Improvements to Existing Pavement Management (Task C)

- More systematic communication is being developed between all concerned Caltrans Headquarters functional areas.
- More systematic performance reviews will be made of experimental pavement construction and rehabilitation project

segments.

- Methods are being sought, at least over the long term, to predict pavement deterioration rates.
- Development of a "master plan" to implement a weigh-in-motion (WIM) system that will address the potential benefits and cost of such a system.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible		6	3	4
Composite		2	4	
Rigid		16	3	

Start monitoring of case study sites, Fall 1982.

SUMMARY OF COLORADO'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

Colorado's pavement project decisionmakers have three tools to assist them in the prioritization process:

1. sufficiency ratings
2. dynaflect or Benkelman beam measurement of pavement structural integrity
3. results and findings of research studies

The sufficiency rating is an evaluation of the existing condition of the State highway system and its ability to handle present traffic demands. The sufficiency rating study provides a general overall view of the pavement performance. When the overall sufficiency rating for a particular roadway section dips below the acceptable limit, a field inspection is essential to assess the extent of the deficiency. At this point, the decisionmaker has to investigate the structural integrity of the pavement unless deficiency is due to safety of capacity. The final decision rests with the district engineer as to the recommended treatment to be used. It is not envisioned Colorado will make any sweeping changes in the current pavement monitoring system. However, there is room for improvement both in the data gathering techniques as well as the quality of the measurements obtained with the present equipment.

Improvements to Existing Pavement Management (Task C)

- Installation of a microprocessor and tape recorder in the profilometer and skid testing vehicle to improve efficiency of data collection.
- Develop an improved calibration procedure for roughness measurement.
- Coordination of network level monitoring and the pavement management system currently being developed.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible	7		2	
Composite				
Rigid	2			

SUMMARY OF IDAHO'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

Each of the six operating districts of the Highway Division submits a list of proposed projects based on a needs evaluation conducted within the district. The Headquarters staff reviews the proposed projects and develops the statewide program of projects. A number of factors influence this process, including available funds, district distribution equity input from the Idaho Transportation Board, and others. In the near future, Idaho plans to begin developing the pavement monitoring system into a complete pavement management system. This will be accomplished by applying Idaho's modified HWYNEEDS/HIAP package, which is operational, and upgrading it to treat pavement rehabilitation projects. The final development phase of Idaho's pavement management system will include treatment strategies for both nonpavement deficiencies (HWYNEEDS/HIAP) and pavement problems (pavement management system)--this process will then be utilized to develop its overall program.

Improvements to Existing Pavement Management (Task C)

Idaho's pavement management system will be improved by developing a cost analysis and optimization package for prioritizing the overall program of improvements and for estimating network serviceability trends under various budget constraints. The major effort will be to develop a pavement performance prediction and user cost estimating models for its pavement management system.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible	7			
Composite				
Rigid	7			

SUMMARY OF IOWA'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

Currently improvement projects are the result of the combined efforts of Highway Division, the Offices of Construction, Materials, Maintenance, Bridge, Design, and Road Design, and six district offices. Physical inventories of the primary system are conducted every 3 years. Inventory data are then entered into a computerized database record system. Updating of pavement features based on as-built plans is done continuously. Municipal and secondary road systems are inventoried at 6- and 10-year intervals, respectively. The present goal is to develop ways to utilize all data elements currently being collected that will result in reduced costs in programming and project development.

Improvements to Existing Pavement Management (Task C)

- Develop a common reference system for all data records.
- Develop cost-effective rehabilitation procedures.
- Develop a mechanism for predicting remaining pavement life.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible			3	
Composite			4	
Rigid			9	

SUMMARY OF NEW MEXICO'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

The goal of New Mexico's pavement management system is to provide enough information to enable selection of optimum strategies for providing a serviceable roadway system. To do this, it is necessary to establish a definition of serviceability and then decide what information must be gathered to monitor serviceability. The New

Mexico method of road condition rating provides information to determine the sections of highway that are deficient, the reasons for the deficiencies, and to indicate needed corrective measures. The New Mexico State Highway Department is involved in a concerted effort to upgrade its pavement monitoring program.

Improvements to Existing Pavement Management (Task C)

- Calibration of a response-type road roughness measuring device (second-generation photolog equipment).
- Development of objective distress data using photolog equipment.
- Put the road rater in operation to measure pavement deflection.
- Revise the existing maintenance management system so that maintenance activities are reported by milepost.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible	4	8		
Composite		1		
Rigid				

SUMMARY OF PENNSYLVANIA'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

Existing data collection efforts form a good foundation for a pavement management system. Necessary data exists but it is scattered in various locations and formats and it is difficult or impossible to use the data effectively to generate the information needed to meet the needs of decisionmakers. Plans to improve the data monitoring system are being made and have been described (in the workplan). These improvements should bring together the scattered roadway information and improve the quality of that information.

Improvements to Existing Pavement Management (Task C)

- The Trained Observer Survey will be expanded to provide information at the project as well as the network level (sample rate from 4 percent to 17 percent). Additionally, changes will be made in the reportable condition, particularly cracking categories, to distinguish among different pavement distresses.
- A paired-lane study will be performed to compare conditions in the two lanes (all truck traffic in the right lane) to determine the relative effects of loading with all other conditions equal.
- Development of a comprehensive data collection and storage system which will result in a computerized, comprehensive road inventory.

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible				
Composite				
Rigid			22	

SUMMARY OF WASHINGTON'S WORKPLAN

Existing Pavement Monitoring System (Tasks A and B)

The Washington State Department of Transportation (WSDOT) has been developing a pavement management system since 1972. The major uses of the WSDOT pavement management system is for priority programming. The system is applied in three major areas:

1. providing pavement analysis data for the priority array
2. providing assistance to each district in assembling its legislative plan
3. providing assistance to each district in assembling its operating program.

The pavement management system has the ability to match projects (a program) to levels of funding. Corresponding systemwide average pavement condition values are also produced. This process permits exploration of a host of alternatives quickly at low costs.

Improvements to Existing Pavement Management (Task C)

- Development of a project specific maintenance cost model.
- Determine climatological influences on pavement performance.
- Determine trends in material and soil properties that are relatable to pavement performance purchase.
- A falling weight deflectometer to determine stress-dependent resilient E moduli for pavement base and subgrade and determine changes in the E modulus over time to measure fatigue.
- Develop relationships between axle loads and pavement performance

Case Study Sites (Task D)

	DRY		WET	
	FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
Flexible	3		2	3
Composite				
Rigid		1	1	

DATA THAT ARE INCLUDED ON THE LONG-TERM MONITORING FORMS

As a matter of interest, Tables 19 and 20 summarize the type of data that are provided on the Long-Term Monitoring forms which each of the pilot-study States filled out. Table 19 includes all of the inventory data and Table 20 has all of the monitoring data. The actual Data Collection Guide for Long-Term Monitoring will be provided to the Workshop participants as a separate document.

TABLE 19. Items of Inventory Data Recommended for Collection for Long-Term Pavement Monitoring

1. Test Section Identification:

Highway Number	Functional Class
Urban or Rural	Location of Test Section
Lanes Included	

2. Geometric Details and General Information:

Width of Highway	Width of Shoulders
Number of Lanes	Year Originally Constructed
Thickness of Layers	Identification of Layer Materials
Years When Overlays or Reconstruction Occurred	Thicknesses of Overlays or Final Layer Thicknesses After Reconstruction
Identification of Materials Used in Overlay or Reconstruction	Year and Details if Roadway Widened
Adequacy of Drainage	Joint Spacing
Underdrains Provided	Dowel Bar Diameter
Extent and Severity of Rigid Slab Cracking Prior to Overlay	Type of Load Transfer (Aggregate Interlock or Dowels)
	Dowel Bar Spacing

3. Environmental Data:

General Type of Environment (Dry-Freeze, Wet-No Freeze, etc.)	Lowest Mean Monthly Temperature
Number of Freeze-Thaw Cycles Per Year	Thornthwaite Index
Highest Mean Monthly Temperature	Lowest Mean Solar Radiation
	Highest Mean Solar Radiation
	Annual Precipitation
	Freeze Index

4. Accumulated Traffic and Axle-Load Data Prior to Long-Term Monitoring Effort:

Mean of AADT for Prior Years	Accumulated Tandem Axles by Load Class
Accumulated 18-kip ESAL (AASHO Equivalencies)	Accumulated Single Axles by Load Class
Weighted Mean of % Trucks for Prior Years	

TABLE 19. Items of Inventory Data Recommended for Collection for Long-Term Pavement Monitoring (Cont'd)

5. Material Properties

a. Subgrade Soil:

Soil Type and Classification	Dry Density
% Passing No. 200 Sieve	CBR (Estimate from other data if not available)
Plasticity Index	

b. Base and Subbase Layers (unbound):

Soil Type and Classification	Percent Modified AASHO Compaction
Dry Density	Percent Binder (Passing No. 40 Sieve)

c. Base and Subbase Layers (stabilized):

Type of Treatment (Cement, Lime, etc.)	Dry Density
	Percent of Stabilizing Agent
Untreated Soil Type and Classification	Percent Modified AASHO Compaction

d. Asphalt Concrete Layers:

Asphalt Grade	Penetration of Asphalt*
Asphalt Content	Initial Air Voids
Viscosity of Asphalt*	Type of Coarse Aggregate
Original Stability	Dynamic Modulus

e. Rigid Layers:

Percent of Steel in Longitudinal Direction	Modulus of Rupture**
	Type of Coarse Aggregate

6. Construction Costs Prior to Long-Term Monitoring Effort:

Cost of Initial Construction	Accumulated Pavement Maintenance Costs (If Available Separated From Routine Maintenance)
Cost of Each Past Overlay	
Cost for Each Restoration or Rehabilitation Project	

* Viscosity and penetration of asphalt cement at time of basic inventory data collection.

** Compute from compressive strength if not available.

*** Table from "Data Requirement for Long-Term Monitoring of Pavement as a Basis for Development of Improved Damage Function."

TABLE 20. Items of Monitoring Data Having Statistical Significance for Multiple Regression Relationships

1. Distress and Performance Measurements:

a. Flexible Pavements (With or Without Overlays):

Alligator Cracking (Fatigue)	Low-Temperature Transverse or Longitudinal Cracking
Longitudinal Cracking in Wheel Path (Fatigue)	Low-Temperature Block Cracking
Rut Depth	Skid-Resistance (To Monitor Reductions)
Roughness	Flushing
Raveling	

b. Rigid Pavements:

Slab Cracking	Skid Resistance (To Monitor Reductions)
D-Cracking	Roughness
Joint Faulting	Blow-ups
Pumping	Deterioration of Transverse Joints
Joint Spalling	

c. Rigid Pavements With Flexible Overlays:

Reflection Cracking	Skid Resistance (To Monitor Reductions)
Rut Depth	Roughness
Pot Holes in Overlays	Flushing
Raveling	

2. Traffic and Axle Loads:

AADT	18-kip ESAL for Year
Number and Distribution of Single Axle Loads	Accumulated 18-kip ESAL
Number and Distribution of Tandem Axle Loads	Weighted Mean of Percent Trucks
	Truck Lane Distribution

3. Deflection Testing Results:

Mean Maximum Deflection Under Load	Coefficient of Variation of Maximum Deflection
Basin Parameters	

4. Pavement Maintenance Costs Per Square Yard of Test Section (Exclusive of Routine Maintenance Such as Mowing, Salting, Snow Removal, etc.)

* Table from "Data Requirements for Long-Term Monitoring of Pavements as a Basis for Development of Improved Damage Functions"

CHAPTER 8

DESIGN OF DATA COLLECTION EFFORT

In a previous section of this report on the AASHO Road Test and its Satellite studies, there was a discussion of the experimental design that was used at the Road Test and a procedure for experimental design that was recommended for Satellite studies in NCHRP Report 2A. Subsequently, in considering the NCHRP Project 20-7, Task 17, suggestion that regional pavement design equations should be developed, an estimate was made of the minimum number of pavement sections that would be required, assuming that only high and low values of any variable would be represented in the experimental design of the regional equations approach.

In this section of the report, the subject of experimental design will be addressed again, this time giving an example of the way to set up a small, partial factorial experimental design taking into account four factors as was done in the sub-experiments at the AASHO Road Test. The techniques for setting up such a design are simple and are important to consider because of the extra information that the analysis of the data can give and the lack of bias that may result in the equations that are developed.

In addition to developing equations for design and for making network level projections, there is another important feature of long-term network monitoring and that is to determine how effectively the funds are being spent and what are the current needs for funding. This type of monitoring is carried out by sampling surveys of the condition of the pavement network. Two methods of statistical sampling will be discussed: the Highway Performance Monitoring System (HPMS) method and the Texas Transportation Institute method.

THE HPMS METHOD OF STATISTICAL SAMPLING

The sample of sections selected for the HPMS is the basis of the continuing monitoring effort. The data reported for the sampled sections serves as the source of system condition, usage, and operational characteristics and is used in the calculation of performance measures and impacts--the changes in performance over time. These data will also serve as the data base for various analytical models.

The HPMS method uses "cluster" sampling: as defined by the HPMS manual, a cluster is a county, a small urban area, or an urbanized area which contains sub-areas (or sub-clusters) having randomly selected sections of pavement. The sample design is based upon a random selection of a fixed number of pavement sections within randomly selected geographic sub-areas which are, themselves, contained within randomly selected counties or urban subdivisions of a State. Thus, there are three levels at which random sampling is done:

1. at State level, there is a random selection of counties or urban subdivisions,
2. at county or urban subdivision level, there is a random selection of sub-areas,

3. with each sub-area, there is a random selection of a specific number of pavement sections.

The number of pavement sections that is chosen within each sub-area is chosen based upon how small of a change in the mean value it is desired to be able to detect and the desirable level of confidence in the result.

While it is assumed that there is a "technically best" way to collect sample data, it was necessary that the sample design be simple and cost efficient because of manpower and cost considerations. The required number of samples are derived empirically by formula from the normal dispersion characteristics of AADT values within the framework of preselected AADT groups (strata). The sample size requirements relate to the critical data element, AADT, whose values can be conveniently stratified.

In order to obtain cost-effective, valid comparisons of system performance over time, the sample was designed to minimize both sampling error and sample size. This was accomplished by stratifying the sample and keeping it fixed over time. Hence, the same sections that are inventoried now will be updated in future years on a cyclical basis. This means of obtaining data is efficient because: 1) the need for the periodic drawing of a new sample is eliminated, 2) the need to update or reinventory all data elements every cycle is eliminated, and 3) only those data elements that change over time need be updated on a cyclical basis, the length of the cycle being determined by the known statistical characteristics of individual elements, the intended use and accuracy needed, and the time and cost required to collect and report such data. However, the use of fixed panel sections is not without disadvantages. These include: the possible loss of the sample's representativeness as the highway networks and traffic patterns change and the inability to assess the correctness of the estimates by comparing them with those of a different sample.

Scope of HPMS Sampling

Data needs will vary for the rural, small urban, and urbanized areas. This variation was reflected in the sample design. The design is capable of producing valid estimates of the condition of the highway plant and its operating and performance characteristics on a State-by-State basis. Rural and small urban functional systems are sampled on a statewide basis. The original HPMS design required that functional systems in urbanized areas be sampled individually. In order to reduce the data collection burden and to increase flexibility, that requirement was modified. Urbanized areas can now be sampled individually, collectively on a statewide basis, or as a combination of both at the State's option.

Stratification and Precision Levels

The sample consists of the randomly selected panel of road sections within predetermined AADT volume groups (strata) for each functional highway system in the rural, small urban, and urbanized areas of the State. The stratification of sections (sampling units) into relatively homogeneous AADT groups produces estimates of greater accuracy with respect to VMT for a smaller number of samples at the functional class (summation) levels. Although stratification is based on the critical data element AADT, tests have shown that AADT stratification is compatible with the sampling of nonvolume-related data elements.

Stratification by AADT also has other advantages: 1) most of the impacts discussed are very sensitive to VMT, 2) it serves as a weighting device for quantitative data element values sampled from sections of nonuniform length, 3) the effect of volume on volume-sensitive data element values may be measured, and 4) it is useful in the application of specific formulas for data element estimates.

Sample size requirements per functional class vary by State according to the total number of road sections, the number of predetermined volume groups, and the design precision level. The term "precision level" is defined as the degree of confidence that the sampling error of a produced estimate will fall within a desired fixed range. Thus, for a precision level of 80-percent confidence with 10-percent allowable error (80-10), there is the probability that 80 times out of 100 the error of a data element estimate will be no greater or less than 10 percent of its true value. The precision levels determined for this sample design apply specifically to the individual volume strata. Aggregation of the estimated stratum values of volume-related data elements results in an upgrading of the precision level for functional system estimates. The precision levels specified for HPMS represent minimum requirements for rural, small urban, and urbanized area functional class volume groups.

The HPMS sample size requirements are more stringent for the arterials, where a higher level of precision is needed because of the high level of Federal interest in them. In rural, small urban, and collective urbanized areas, the sample sizes are based on a 90-5 precision level for the volume groups of the principal arterial system, 90-10 for the minor arterial system, and 80-10 for the collector system(s). For individual urbanized areas, the design precision levels for individual volume strata are 80-10 or 70-15, depending upon the number of urbanized areas designated as individual at the States' option. Those States with less than three designated individual urbanized areas use a precision level of 80-10 for all functional systems, while those with three or more may use the lower precision level of 70-15 for minor arterials and collectors and 80-10 for principal arterials thereby requiring a smaller number of samples. The statewide summation of individual urbanized functional system data element estimates will result in an overall precision level of at least 80-10 at the State level. These higher precision levels at the State level are necessary for two important reasons--to obtain comparable urban and rural precision levels and to obtain precision levels that can adequately accommodate desired levels of accuracy for estimates of proportionate values.

The precision levels established above and the associated sample sizes relate solely to the measurement of data such as AADT. The same samples will be used to estimate the proportionate values of data such as pavement condition. Given the same desired precision levels, larger sample sizes are required for estimates of proportionate values. Since the level of accuracy for estimated proportions is closely related to sample size, care was taken to set the above precision levels sufficiently high to produce reasonable proportionate estimates at the functional class level.

Calculation of HPMS Sample Size

The sample size estimates for each stratum are derived from the following formula:

$$n = \frac{Z_\alpha^2 C^2 / d^2}{1 + 1/N\left(\frac{Z_\alpha^2 C^2}{d^2} - 1\right)}$$

where

n = required sample size

Z_α = value of the standard normal statistic for an α confidence level (two-sided),

C = AADT coefficient of variation,

d = desired precision rate, and

N = universe or population stratum size

For example, the sample size for a stratum with a coefficient of variation of 0.61 and with a desired precision of $\pm$ 5 percent with 90-percent confidence is estimated by:

$$n = \frac{(1.645)^2(.61)^2/(.05)^2}{1 + 1/N\left(\frac{(1.645)^2(.61)^2}{(.05)^2} - 1\right)}$$

$$= \frac{402.76}{1 + \frac{401.76}{N}}$$

If N = 3000, the estimated sample size is 356.

Values of the standard normal variable Z_α for different level of confidence are as follows:

Level of Confidence	Z_α
50	0.00
70	1.04
80	1.29
90	1.65
95	1.96

The critical point in this process is the value designation of C, the AADT coefficient of variation. The original HPMS design was based on empirical estimates using data from a small number of States. The procedures presented here require the estimation of AADT coefficients of variation based on the latest available State data. The results are then always up-to-date, based on the latest information, and are tailored to the specific State. Table 21 presents the original (1978) HPMS design values of the coefficient of variation of AADT.

The volume groups 1 through 8 that are shown in Table 21 are AADT traffic ranges that vary with the functional class of the highway and the precision levels that are required of the surveys. Typically, Group 1 will have between 0 and 5000 AADT and Group 8 will have between 35,000 and 45,000 AADT.

Table 21. AADT Coefficients of Variation, C

Functional Class	Volume Group 1	2	3	4	5	6	7	8
Interstate								
Rural	.61	.24	.16	.13	.10	.10	--	--
Small Urban	.61	.24	.16	.13	.10	.10	--	--
Individual Urbanized Areas	.61	.24	--	--	--	--	--	--
Collective Urbanized Areas	.61	.24	.16	.13	.10	.10	--	--
Other Freeways & Expressways								
Small Urban	.61	.24	.16	.13	.10	.10	--	--
Individual Urbanized Areas	.61	.24	--	--	--	--	--	--
Collective Urbanized Areas	.61	.24	.16	.13	.10	.10	--	--
Other Principal Arterials								
Rural	.64	.24	.17	.15	.14	.12	.10	.10
Small Urban	.64	.24	.17	.15	.14	.12	.10	.10
Individual Urbanized Areas	.53	.27	.27	.17	--	--	--	--
Collective Urbanized Areas	.64	.24	.17	.15	.14	.12	.10	.10
Minor Arterials								
Rural	.67	.27	.25	.25	.17	--	--	--
Small Urban	.67	.27	.25	.25	.17	--	--	--
Individual Urbanized Areas	.53	.27	.27	.17	--	--	--	--
Collective Urbanized Areas	.67	.27	.25	.25	.17	--	--	--
Collectors								
(Major) Rural	.67	.25	.25	.25	--	--	--	--
(Minor) Rural	.96	.33	.25	.25	.25	.25	--	--
Small Urban	.96	.33	.33	.25	.17	.17	--	--
Individual Urbanized Areas	.96	.33	.33	.25	.17	--	--	--
Collective Urbanized Areas	.96	.33	.33	.25	.17	--	--	--

Figure 10 can be used to estimate the minimum functional system sample size to detect a 10 percent change in performance with 80 percent confidence.

If the total sample size for a functional class is less than 80, it may need to be adjusted upward to permit the desired accuracy in estimating the size of the change in the performance measure.

THE TEXAS TRANSPORTATION INSTITUTE METHOD

The Texas Transportation Institute had several objectives in devising its empirical sampling rules:

1. To determine by sampling, the mean condition of a pavement network, by functional class, for deflections, skid measurements, visual condition, and riding quality. The size of sample is to be chosen based on a tradeoff between the cost of the survey and the accuracy of the estimated mean.
2. To determine by sampling the distribution of pavement conditions in a network, by functional class for visual condition and riding quality measurements.
3. To determine by sampling an estimated cost of maintaining and rehabilitating a pavement network, separated into functional classes.

The mean is a good way to compare one district with another and to determine where the critical needs are for major funding. The distribution of pavement condition is useful in determining the

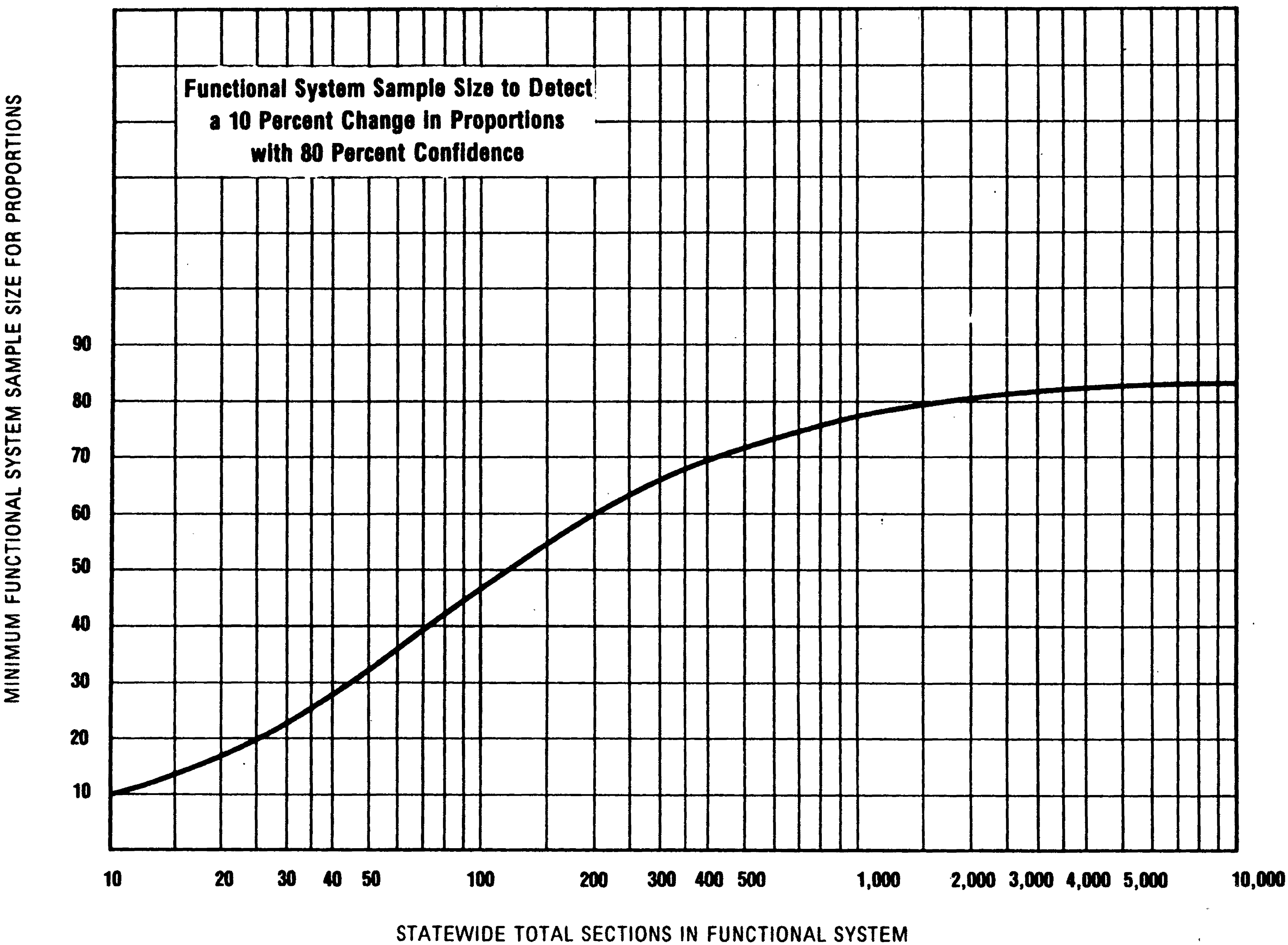


Figure 10. HPMS Sample Size to Detect a 10 Percent Change With 80 Percent Confidence

major problems in a district, and the best rehabilitation strategies to use, and in setting up a rehab program and a future inspection schedule. The cost estimates are needed to determine a reasonable idea of the funding needs.

Estimating the Means

The sampling plan that was set up to determine the mean was a two-stage random sampling procedure which was found by experimentation to give the smallest error of the estimated mean. Within each District, a county was chosen at random, and a fixed number of pavement sections was selected at random within the county. The error in the mean divided by the mean itself that came from this study is shown in Figure 11. The best sample size can be estimated by eye to be where the curves begin to get so flat that it doesn't pay to gather more data. The optimum sample sizes when costs and accuracy are weighted equally are as shown below.

Sample Size for Estimating Mean Condition, in Percent

	Class of Highway	
Measurement	U.S. or State	Farm-to-Market
Visual Condition	3.0%	2.0%
Deflections	2.0	2.0
Skid Number	3.0	2.0
Riding Quality (PSI)	2.0	3.0

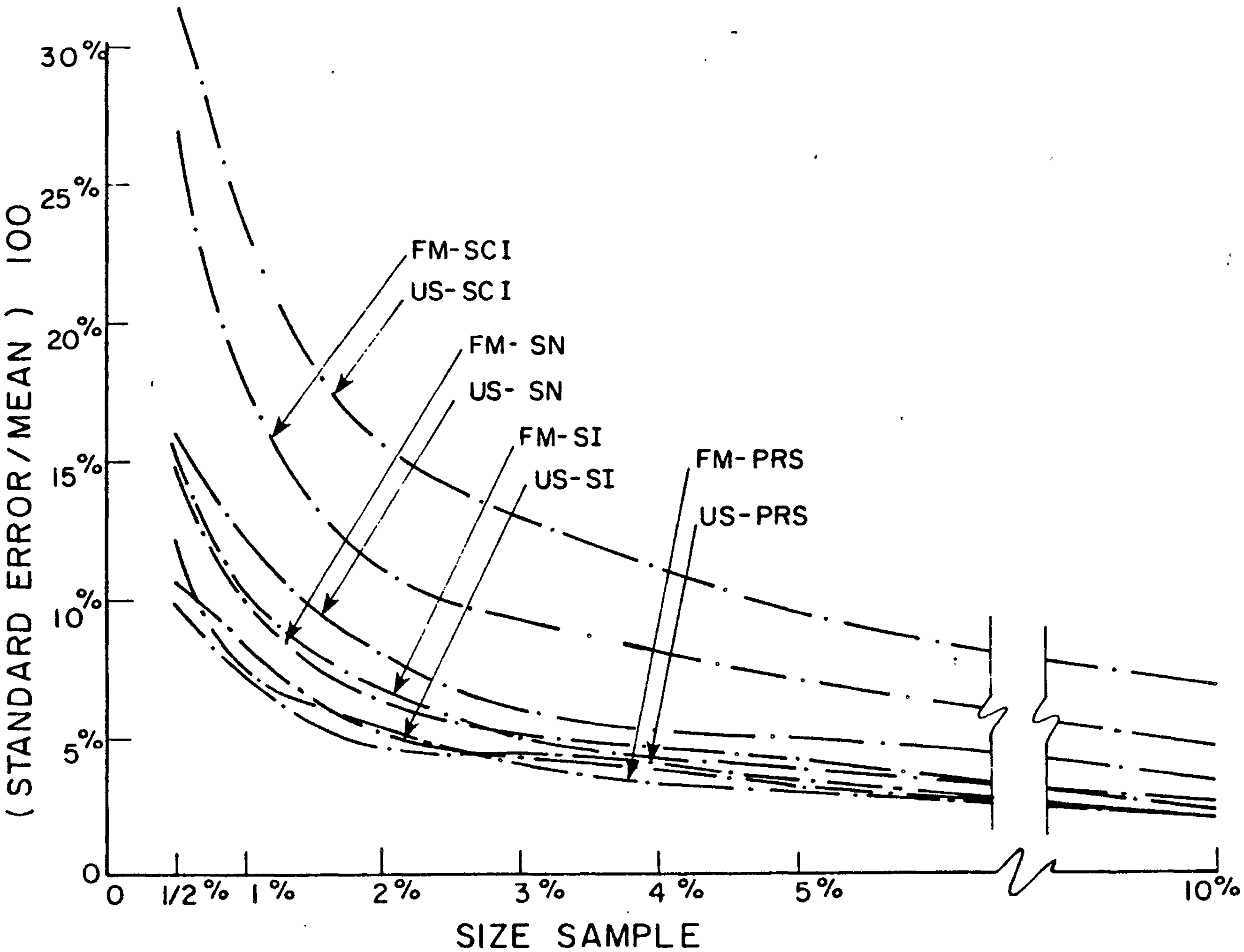


Figure 11. District 21 - Coefficient of Sample Variation vs. Sample Size (1975 Data)

Estimating the Distribution of Pavement Condition

After some experimentation, it was found that selecting a fixed number of pavement sections at random within each county of a District produced the most accurate estimate of the distribution of visual pavement condition scores. There were three Districts in which 100 percent of the pavement network was observed and this permitted a study of the size of sample that is required to produce a cumulative distribution of pavement scores that is reasonably close to the actual distribution. An illustration of this is shown in Figure 12, in which the distribution of Farm-to-Market pavement scores, labeled F(x), is the true cumulative distribution and the confidence bands were generated using a 5 percent sample empirical distribution, labeled $S_n(x)$.

The size of sample that is required to make sure that the sampled cumulative distribution is always within 10% of the actual distribution is shown in Table 22. The size of the sample varies with the total number of pavement sections and with the variance of pavement scores. Consequently, the size of the sample varies from district to district, as shown in the table.

Estimating the Mean Cost Per Square Yard

Not all pavement sections need to have maintenance or rehabilitation efforts applied and thus it is necessary to sample enough sections of pavement that need work to be done on them so as to reach a reliable estimate of the average costs in a district. The better condition the pavement network is in, the larger the sample

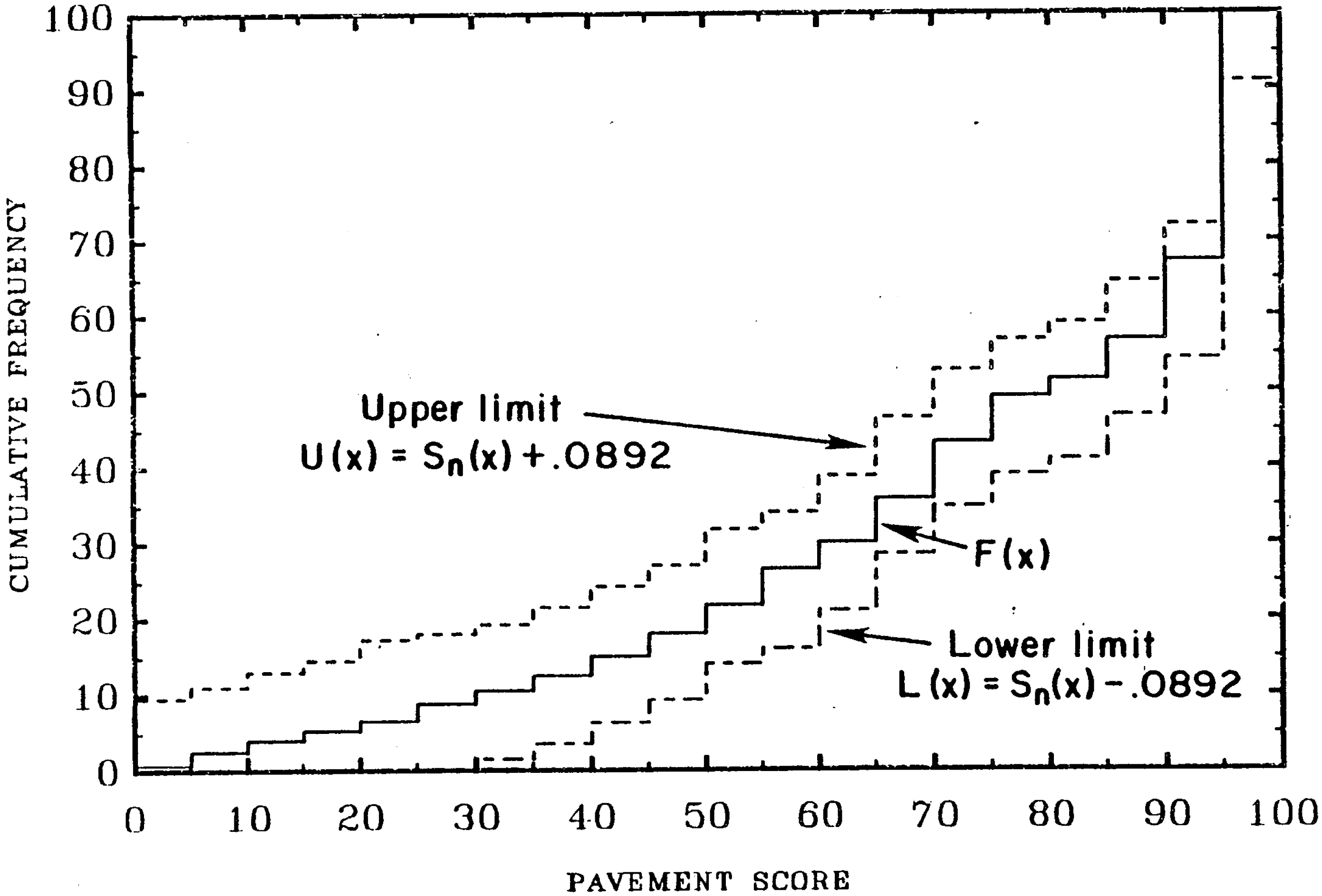


Figure 12. Confidence band for cumulative distribution function of Pavement Scores F(X), Districts 8, 11, 15, System FM

TABLE 22. Sample Sizes to Assure a Cumulative Pavement Score Distribution Within 10 Percent of the True Distribution

District	Interstate	U.S. Highways	State Highways	Farm-to-Market
8	21	10	17	5
11	--	17	12	5
15	7	9	7	5
Overall Weighted	15	12	12	5

must be.

The best method of sampling to determine a mean cost proved to be a random selection of a fixed number of pavement sections within each county. Table 23 shows the sizes of sample that are required to assure that the estimated mean cost per square yard in a district is within 25 percent of the true mean cost. Another way of looking at the same data is to take note of the expected mean error for each highway system that may be expected with a 25 and 40 percent sample as shown in Table 24.

These sample sizes and sampling plans are needed to estimate mean costs and needed rehabilitation work on an annual basis.

EXPERIMENTAL DESIGN FOR PAVEMENT DATA COLLECTION FOR DESIGN EQUATIONS

In determining the number of pavement sections that are needed to develop a good pavement design equation, three steps are necessary:

1. Decide upon the variables using theory and engineering mechanics
2. Select the level of factorial that is practical
3. Design the experiment using the appropriate high, low, and medium level values of the selected variables

Steps 2 and 3 are usually worked together iteratively.

Selection of Variables

It will be recalled that in the AASHO Road Test, simple variables were used such as thickness of surface course, thickness of base course, thickness of sub-base, and load level. Because of the results

TABLE 23. Sample Sizes to Assure a Mean Error of Estimated Mean Cost Within 25 Percent of the True Mean Cost

District	Interstate	U.S. Highways	State Highways	Farm-to-Market
8	13	22	17	12
11	--	8	11	6
15	48	27	>50	35
Overall Weighted	34	25	13	17

TABLE 24. Percent Mean Error in Mean Costs Per Square Yard

Percent Sample	Interstate	U.S. Highways	State Highways	Farm-to-Market
25%	29	21	25	19
40%	24	15	22	15

of the AASHO Road Test and the explosive development of analytical methods, computerized techniques, and nonlinear regression analysis, it is possible to build upon what has been learned in the selection of the variables. For example, as pointed out in the Final Report of NCHRP Project 20-7, Task 17, Phase II, the AASHO Road Test proved that the damage to a pavement is proportional to its deflections, and thus to a whole collection of variables that are related to one another in predicting deflections. As a result of what was found at the AASHO Road Test, it is possible to choose as a single variable a term like

$$\delta = \frac{L_1 + L_2}{E_s \left[\sum_{i=1}^{n} h_i \left(\frac{E_i}{E_o}\right)^{1/3} \right]}$$

where

δ = the deflection of the pavement

L_1 = the axle load

L_2 = the axle index; it is 1 for a single axle, 2 for a tandem axle, and so on

E_s = the modulus of the subgrade

h_i, E_i = the thickness and modulus of all layers above the subgrade

E_o = the "datum" modulus, which appears to be the modulus of concrete for the AASHO Road Test materials.

The use of engineering mechanics or of theory can provide as single variables these clusters of variables which are known to be related to one another and which, by themselves, predict a primary or secondary response of the pavement. An example of this was given in the Final Report of NCHRP Project 20-7, Task 17, Phase II in which expressions were derived for the number of stress cycles that would cause the fracture of an overlay due to bending, shear, and thermal stress. The following variables were included as parts of the expressions for the number of stress cycles to failure:

1. Bending Stress Cycles to Failure.

   Tire pressure and radius, depth of overlay, fracture properties of the overlay, maximum size of the aggregate, asphalt content, viscosity of the asphalt, volumetric concentration of the aggregate, moment transfer efficiency factor across a crack in the old pavement as determined by non-destructive testing, stiffness of pavement underlying the old surface layer.

2. Shearing Stress Cycles to Failure.

   All of the variables listed above were included except that the shear transfer efficiency factor across a crack in the old pavement replaced the moment transfer efficiency factor. Also, the relations among the variables were different than in the expression for bending stress cycles to failure.

3. Thermal Stress Cycles to Failure.

   Thickness of overlay, maximum size of aggregate, asphalt content and viscosity, volumetric concentration of the aggregate, thermal fracture properties of the overlay, shear stiffness of the interface between the overlay and the underlying old cracked surface, temperature change in the old surface layer.

By using the principles of mechanics in this way, all of these variables are combined in a known, mechanistic way to form single variables which can be used as single variables in experimental design. It can be done now and it is a waste of time and money to do otherwise.

For the purpose of illustrating experimental design, we shall select these mechanistically predictable variables:

Variable	Type of Variable
A	Percent trucks in traffic stream
B	Bending Stress Cycles to Failure
C	Shearing Stress Cycles to Failure
D	Thermal Stress Cycles to Failure

Because it is impossible to have only a single load level on a pavement that is in service, it is well to use the percent trucks in the traffic stream as a load variable. The dependent variable will be the actual number of load cycles to reach failure.

Selection of a Factorial Level

If a linear relation between the dependent and independent variable is expected, then two levels of the independent variable are sufficient. If a nonlinear relation is expected, three levels of the independent variable, high, low, and medium are needed. A full factorial experiment will require a total number of pavement sections equal to

$(\text{no. of levels})^{\text{no. of variables}}$

In our example, this would be 3^4 or 81 pavement sections, unless a special experimental design were used to reduce the total number of sections to within 30 to 50 sections as was done at the AASHO Road Test. This can be done in several ways. One is to use only two levels, high and low, in which a full factorial will require only 2^4 or 16 sections. But this may lose the advantage of having some sections with the variables in the medium range to give some idea of the degree of "curvature" the design equation may have between the two extremes. Table 25 shows the combinations that may be used to set up an experiment that avoids this difficulty while providing some observations of the curvature. In general, this experimental design has 2^n+2n+1 sections where n is the number of variables. It is noted that this design uses only 25 pavement sections instead of the 81 required by a full factorial design with three levels.

If it is desired to cut the number of sections still more, it is noted that the first 16 pavement sections in Table 25 form a full factorial design for two levels, high and low. This could be changed to a half factorial composed of 2^3 or 8 pavement sections by referring to a standard reference book "Fractional Factorial Experiment Designs for Factors at Two Levels," Applied Mathematics Series 48 by the Statistical Engineering Laboratory of the National Bureau of Standards. In this case, two "blocks" can be set up with 4 pavement sections to each as shown in Table 26.

This exercise will reduce the total number of pavement sections

TABLE 25. Experimental Design for Four Variables

Section Number	Level of Variables High	Medium	Low
1	ABCD		
2	ABC		D
3	ABD		C
4	ACD		B
5	BCD		A
6	AB		CD
7	AC		BD
8	AD		BC
9	BC		AD
10	BD		AC
11	CD		AB
12	A		BCD
13	B		ACD
14	C		ABD
15	D		ABC
16			ABCD
17		ABCD	
18		ABC	D
19	D	ABC	
20		ABD	C
21	C	ABD	
22		ACD	B
23	B	ACD	
24		BCD	A
25	A	BCD	

TABLE 26. Partial Factorial Design for Four Variables

Section Number	Level of Variables: High	Level of Variables: Low
1	ABCD	
2	BC	AD
3	AC	BD
4	CD	AB
5	AB	CD
6	BD	AC
7	AD	BC
8		ABCD

Bending Stress	Shear Stress	Load: High, Thermal Stress: High	Load: High, Thermal Stress: Low	Load: Low, Thermal Stress: High	Load: Low, Thermal Stress: Low
High	High	X			X
	Low		X	X	
Low	High		X	X	
	Low	X			X

to 17. From this point, once the experiment has been run, regression analysis and analysis of variance can be made to see how good of an equation has been developed. By using a knowledge of the engineering mechanics of pavements at the outset of the experimental design, it was possible to include a large number of material property and layer thickness variables in the experiment which otherwise would have required a very large factorial design.

There is obviously more to the discipline of experimental design than has been presented here, but the same basic principles can be applied to the design of any experiment.

CHAPTER 9

SUMMARY AND CONCLUSIONS

The subject of Long-Term Monitoring is complex and can be expected to play a vital and even crucial role in the future management and financing of the nation's highway system. It is apparent that Long-Term Monitoring data is needed to provide answers at several levels:

1. Federal Highway Administration Mandated Studies
2. Network level management at District, State, and national levels
3. Control of the quality of construction, rehabilitation, and reconstruction
4. Project design for both rehabilitation and new construction.

The type and quantity of data that is collected, the uniformity with which it is collected, the types of analyses that are made of the data, and the management uses to which it is put vary considerably from one level to the next. There is a wide degree of overlap in the types of data that are needed on each level so that no strict choice has to be made between collecting data for one level or another. The number of pavement sections that must be monitored increases and the number of data items that are collected on each section diminishes at increasingly higher levels of Long-Term Monitoring. Because of the multiple uses and objectives of LTM and the benefits to be gained through cooperation and coordination, a list of priorities needs to be drawn up for the Long-Term Monitoring effort to establish the overall emphasis of the LTM program and the most important alternative uses of it.

The matrix of Uses and Requirements for Long-Term Monitoring as shown in Table 27, illustrates the tasks for this workshop. As a better understanding of the Long-Term Monitoring process emerges, decisions can be made to establish priorities among the Uses and Requirements that are summarized in that table.

This report has described much that has occurred during the evolution process toward Long-Term monitoring and has outlined both the uses and the requirements for Long-Term Monitoring. It is a principal objective of the first Long-Term Monitoring Workshop to arrive at recommended priorities for the alternative uses of LTM.

The FHWA Mandated Studies include

1. Highway Cost Allocation
2. Highway Cost Apportionment
3. Truck size and weight benefits and costs
4. Quality of construction survey
5. Effects of weather on cost apportionment formulas
6. Cost effectiveness of highway funding and quality control programs
7. Life expectancy of pavements
8. Others

Network management uses at District, State, and national level include

1. Predictive equations to project the expected life of different classes of pavements

TABLE 27. Uses and Requirements of Long-Term Monitoring

Requirements / Uses	Data Needs	Data Elements	Data Analysis	Uniformity Requirements
FHWA Mandated Studies				
Network Management				
Construction Quality Control				
Project Design				

2. Survivor curves, probability models, Markov transition matrices, decision criteria
3. Fund distribution studies
4. Funding needs estimates
5. Budget projections
6. Pavement condition sampling
7. Pavement maintenance and rehabilitation cost sampling
8. Network costs of deferred maintenance
9. Rehabilitation strategy studies
10. Network priorities and optimization
11. Others

Uses of Long-Term Monitoring data for Highway Construction Quality Control include

1. Correlations between quality control tests, pavement condition, and service life
2. Data to establish statistical performance-based specifications
3. Trends in quality of construction with time
4. Distribution of staff effort and its effect on construction quality
5. Studies to determine the quality standards that insure good performance
6. Trends in project staffing and productivity rates
7. Effect of inspection and of different specification standards on construction quality
8. Staff work units for construction manpower planning

9. Information to formulate strategies to improve construction quality
10. Others

Project design uses of Long-Term Monitoring include

1. Data to evaluate and to calibrate mechanistic design computer programs
2. Design equations for rehabilitated and new construction
3. Predictive equations for the effects of environmental effects on pavement performance: frost heave, expansive clays, thermal cracking, and thermal fatigue
4. Data to provide a means of estimating the reliability of different pavement designs
5. Maintenance costs
6. Predictive equations for various types of distress for use in cost allocation studies, pavement design, and network optimization
7. Effects of increased truck loadings and tire pressures
8. Effects of new materials, additives, and construction techniques on pavement life and life cycle costs
9. Pavement life and life cycle costs of rehabilitation methods
10. Design studies to retard deterioration rates and take advantage of changes in materials or traffic characteristics
11. Others

The numerous uses of Long-Term Monitoring data at all levels of pavement management and financing show its importance to the entire process at project, District, State, and national levels. It is only through monitoring that the basic data can be acquired to permit the rational and equitable management of the nation's highway network and to provide measures of the cost effectiveness of the overall management process policy. Technical questions can only be answered objectively, in the final analysis, by referring to data that have been carefully and consistently collected on our nation's highways.

REQUIREMENTS FOR LONG-TERM MONITORING

The matrix in Table 27 shows four requirements for each level of Long-Term Monitoring:

1. Data needs
2. Data elements
3. Uniformity Requirements
4. Data analysis

The topic of "Data Needs" refers to the size of the sample and the way it is selected in order to meet the objectives of a specific use. For most of the FHWA Mandated Studies, the data needs to be sampled in a random, stratified manner following the pattern used by the Highway Performance Monitoring System. For network level management purposes, the data needs to be sampled randomly again. In order to determine the mean condition of a network, a 2 to 5 percent sample is required whereas if a distribution of the condition is needed (and it usually is), a 15 to 25 percent sample is needed. If a cost estimate is required, a 25 to 35 percent sample is needed. There are some network level needs for predictive equations, survivor curves, and other similar items which assist in making projections of the future condition of the network. These projections must be developed from data collected in accordance with a designed experimental plan and in a very detailed and uniform manner on a much smaller sample of the network. The data needed for Highway Construction Quality Control must also be sampled randomly from ongoing construction projects of known age and traffic, and for which the initial quality control was monitored. Project design needs design equations developed from carefully and uniformly collected data on a small sample of the pavements selected to fill out an experimental design.

The "Data Elements" for each level of use will vary. The data elements can be broken into inventory and monitoring items. In general, the need for inventory data increases at the lower levels. For example, for FHWA Mandated Studies, almost all of the inventory data that is needed is the functional class and surface type of each highway section in the sample. For Network level management, specific sections must be identified, urban or rural setting determined, climatic zone and weather characteristics, geological or geographical zones established, and previous and future traffic estimated. For Highway Construction Quality Control, the inventory will include the results of many of the tests that are made and of the characteristic staffing that was used on each project. In project design, the inventory requirements are numerous, calling for material properties, layer thickness, previous traffic, environmental data, as well as precise location, project number, county, district, and so on.

The monitoring data that is required differs with level as well, since much more detail is required at the lower levels. For FHWA Mandated Studies, a single item of monitoring data may be sufficient for the purpose intended, such as a present serviceability index or rating. Network level management usually will call for more of a breakdown of distress, riding quality, skid measurements, maintenance costs, and so on. Highway Construction Quality Control is concerned with tying subsequent distress, riding quality, and maintenance costs to the initial quality of construction and will usually want to have a detailed distress survey with area and severity of each type of distress noted at several ages of each project. Project design requires the same level of detail in recording distress, riding quality, skid, and maintenance costs but usually must add vehicle weights, deflections, laboratory tests on cores, and so on.

"Uniformity Requirements" for the data that are collected become increasingly stringent as the need to share the data among agencies increases. The major difficulties in this regard are with truck weights recorded by weigh-in-motion devices, deflection tests, measured roughness, methods of recording distress survey information, laboratory test methods, and the details of the way that maintenance cost and staffing data are recorded. Once again, the detail that is required and thus the need for more detailed uniformity requirements increases with the lower levels of LTM data usage.

"Data Analysis" methods become more complex at the lower levels of data usage, as well. At the level of FHWA Mandated Studies, simple means and standard deviations are generally all that are required. There are notable exceptions to this in the case of Cost Allocation Studies that require detailed project design types of equations. The HPMS analysis uses linear regression to obtain relations among dependent and independent variables. Network level management requirements for data analysis contain a wide variety of statistical techniques and projection methods, including the occasional use of project design equations. It is at this level that survivor curves are developed using "maximum likelihood estimators;" that "Markov transition matrices" are constructed which show how the condition of a network changes from one time period to the next; and that "decision criteria" are determined by statistical techniques such as discriminant analysis or logistic regression. In the process of decision making at Network level, various operations research methods are used including linear programming, dynamic programming, integer programming, and other specialized techniques intended to maximize the effectiveness of the use of highway funds. Highway Construction Quality Control studies have used simple means and standard deviations and linear regression in the past to establish relations and correlations, but it is very likely that the future will see the use of nonlinear regression methods to establish equations that will tie pavement service life to quality control levels. Project design equations require the use of various forms of linear and nonlinear regression analysis, and uses the types of analyses that can be made with mechanistic analysis computer programs. Project level optimization techniques are used to select the best alternative design from among numerous alternatives. All of the analysis methods that are mentioned above are now available in "off-the-shelf" packages, many of which have been developed specifically for use in pavement management processes.

It is the objective of the first Long-Term Monitoring Workshop to consider these alternative Uses and Requirements for Long-Term Monitoring data; to arrive at priorities on each of the uses; and to decide which are the best ways of satisfying the LTM requirements for those uses. What should emerge from this Workshop is a better understanding of the entire Long-Term Monitoring process and a set of decisions which will determine the future direction of Long-Term Monitoring in the States and in the nation.