NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

76

COLLECTION AND USE OF PAVEMENT CONDITION DATA

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **76**

COLLECTION AND USE OF PAVEMENT CONDITION DATA

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

SUBJECT AREA
PAVEMENT AND DESIGN PERFORMANCE

MODE
HIGHWAY TRANSPORTATION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. JULY 1981

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to highway designers, researchers, and others concerned with pavement management. The report reviews current practices of collecting pavement condition data for use in making decisions on maintenance, rehabilitation, and reconstruction.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Transportation agencies systematically collect data on pavement roughness, distress, deflection, and skid resistance. This report of the Transportation Research Board includes a discussion of the methods of collection, the use of the data, and the problems encountered with various systems. The particular pavement condition data collection programs of various agencies are reviewed in the appendixes.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Harry A. Smith, Projects Engineer, and Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

COLLECTION AND USE OF PAVEMENT CONDITION DATA

SUMMARY

Pavement condition data are collected to assist in making decisions on highway maintenance, rehabilitation, and reconstruction. The data are used to establish maintenance and rehabilitation priorities, to select maintenance and rehabilitation strategies, and to project pavement performance. The pavement condition data collected by agencies can be grouped as follows: roughness (ride), surface distress, structural evaluation (deflection), and skid resistance.

Pavement roughness is defined as irregularities in the surface that affect the ride of a vehicle. Equipment used to measure roughness includes the CHLOE profilometer, car ride meter, and laser profilometer. Most of the agencies surveyed used some type of car ride meter. Advantages of the car ride meter include relatively low cost, ease of operation, ability to acquire large amounts of data, adequate repeatability, and correlation of output with the pavement serviceability index, which is a measure of a pavement's ability to serve traffic. Disadvantages include the need for frequent calibration, inability to measure pavement profile, and relationship of the data to operating characteristics of the automobile used.

Surface distress is a measure of pavement fracture, distortion, and disintegration. This information is obtained by surveying pavements and recording various defects, such as cracking and rutting. Survey methods are usually subjective; a rater uses a form to note location, extent, and severity of defects. Typically, 100 to 500 ft (30 to 150 m) are surveyed each mile (1.6 km). Variation in subjectively obtained distress data can be minimized by having raters stop at the same location each year, obtaining data every 1 or 0.5 mi (1.6 or 0.8 km), obtaining a consensus of at least two raters for each segment, and keeping procedures as simple as possible.

Structural evaluation involves determining the ability of a pavement to support traffic. Surface deflection measurements are commonly used to measure structural adequacy. The three types of deflection measurements are static deflection, steady-state dynamic deflection, and impact-load response. Because of the high costs, most agencies do not collect deflection data routinely; however, these data are collected and used in detailed design and rehabilitation selection processes.

Skid resistance data are routinely collected by most of the agencies surveyed. The data are used to identify pavements with low skid resistance; to plan pavement maintenance and rehabilitation; and to evaluate surfacing materials, designs, and construction practices. Locked-wheel or yaw-mode trailers are used to measure skid resistance.

The amount of pavement network on which data are collected each year

ranges among the agencies from 10 to 100 percent for roughness, 40 to 100 percent for surface distress, and 33 to 67 percent for skid resistance. The few agencies that routinely collect deflection data do so on between 20 and 50 percent of their pavement networks. Annual costs of collecting pavement condition data for monitoring purposes range from about $12 to $50 per center-line mile ($7 to $15/km).

Problem areas encountered during data collection and analysis include equipment (calibration and maintenance), personnel (training, motivation, and obtaining sufficient staff), seasonal variation in data collection, and data processing. To ensure effective use of the data, it is necessary to clearly define goals; document benefits; have the support of top management; provide feedback to design, construction, and maintenance to assure that data are usable; and establish a development process that involves all users of the data.

CHAPTER ONE

INTRODUCTION

NEED FOR PAVEMENT CONDITION DATA

Pavement condition data have been used in the past to develop maintenance, rehabilitation, and reconstruction programs, generally on a project-by-project basis. The data were used to determine the projects requiring maintenance and the type of maintenance or rehabilitation required to correct the observed deficiencies. These decisions were made on a year-to-year basis at a time when resources (both manpower and funds) were more plentiful than they are today.

During the 1940's and 1950's highway maintenance personnel relied heavily on visual inspections to establish type, extent, and severity of distress, and on experience or judgment to establish maintenance programs. Unfortunately, experience is difficult to transfer from one person to another, and individual decisions made from similar data are often inconsistent.

In the late 1950's and early 1960's the increased use of roughness meters and deflection and skid test equipment permitted objective data to be collected and used both alone and with visual surveys to aid in making maintenance or rehabilitation decisions.

In the 1970's highway personnel could no longer rely on the luxury of managing roadways solely on the basis of field personnel experience. Because of limited resources and increased pavement deterioration, it was essential to develop rapid, objective means to establish:

1. Projects in need of maintenance or rehabilitation.
2. Types of maintenance or rehabilitation currently required.
3. Types and schedule of maintenance or rehabilitation to be undertaken in the future to minimize life-cycle costs (construction, maintenance, and user costs) or to maximize the net benefit.

These decisions are difficult to make based on experience alone. Consistent, repeatable, and meaningful pavement data are needed as input and feedback to a well-developed framework to make the most cost-efficient decisions.

At present, three specific applications for pavement data can be identified. These applications have been grouped under the term pavement management; however, each is quite different:

1. *To Establish Priorities*. Data such as ride, distress, and deflection are used to establish the projects most in need of maintenance or rehabilitation. Often only ride and/or distress data are used; at other times ride, distress, and deflection data are combined into a single rating. Skid resistance data are often used separately. Once identified, the projects in the poorest condition (low rating) will be more closely evaluated to determine repair strategies.
2. *To Establish Maintenance and Rehabilitation Strategies*. Data, such as type, extent, and severity of distress, are used to develop an action plan on a year-to-year basis; i.e., which strategy (repairs, surface treatments, overlays, recycling, etc.) is most appropriate for a given pavement condition.
3. *To Project Pavement Performance*. Data, such as ride, skid resistance, distress, or a combined rating, are projected into the future to assist in preparing long-range budgets or to estimate the condition of the pavements in a network given a fixed budget.

These uses for pavement data differ somewhat from the broader definition of pavement management developed by Hudson et al. (*1*): "An all-encompassing process that covers all those activities involved in providing and maintaining pavements at an adequate level of service. These range from initial information acquisition to planning and programming of maintenance, rehabilitation and new construction, to the details of individual project design and construction to periodic monitoring of pavements in service."

Hudson et al. also state: "A pavement management system (PMS) is a tool that provides decision-makers at all management levels with optimum strategies derived through clearly established rational procedures." By this definition, the applications described above (establish priorities, select maintenance and rehabilitation strategies, and project pavement performance) easily fall within the framework of a pavement management system (PMS).

A PMS permits determination of the action required, when it should be scheduled, and the road on which it is needed. There is presently considerable interest in developing this type of system (*2*, *3*) to assist in:

1. Optimizing use of available funds to maintain a network of roads.
2. Preparing long-range budgets.
3. Estimating conditions of different pavements in the network for a given budget.
4. Evaluating the consequences of budget reductions and deferred maintenance.
5. Scheduling future pavement maintenance activities.
6. Evaluating the performance of various pavement designs, materials, etc.

PURPOSE OF SYNTHESIS

A survey of the current practices of a selected group of states in the collection of pavement condition data for use in maintenance, rehabilitation, and reconstruction decisions was conducted. An attempt has been made to determine the ways the data are used in managing work programs, and the many aspects of funding, decision making, and effectiveness. The extent of the use of pavement condition data and the problems encountered are discussed.

Specific topics discussed include:

1. Type of data collected.
2. Methods of data collection.
3. Use of the data.
4. Sampling programs.
5. Costs of data collection and processing.
6. Problems encountered.
7. Difficulties not resolved by the current collection techniques.

This report is based on information obtained from the transportation departments of Arizona, California, Florida, New York, Pennsylvania, Utah, and Washington, and from the province of Ontario, Canada, and the U.S. Army Construction Engineering Research Laboratory (CERL) (U.S. Air Force airfield pavements). Individual state practices are described in more detail in the appendixes.

CHAPTER TWO

CURRENT PRACTICE

TYPES OF DATA COLLECTED

The agencies surveyed for this report collect the following types of data, which are primarily used to assist in making decisions on pavement maintenance and rehabilitation:

- Roughness (ride),
- Surface distress,
- Structural evaluation (surface deflection), and
- Skid resistance.

Table 1 lists the types of data collected by the nine agencies in this study. Essentially all the agencies collect roughness, distress, and skid data for monitoring pavement conditions. Only one of the agencies collects deflection data on a regular basis.

TABLE 1

TYPES OF DATA ROUTINELY COLLECTED FOR MONITORING PAVEMENT NETWORK CONDITION

Agency	Type of Data Collected			
	Ride	Distress	Deflection	Skid
Arizona DOT	●	●		●
California DOT	●	●		●
Florida DOT	●	●		●
New York DOT	●			●
Ontario MTC	●	●		
Pennsylvania DOT	●	●		●
U.S. Air Force (CERL)		●		
Utah DOT	●	●	●	●
Washington DOT	●	●		●

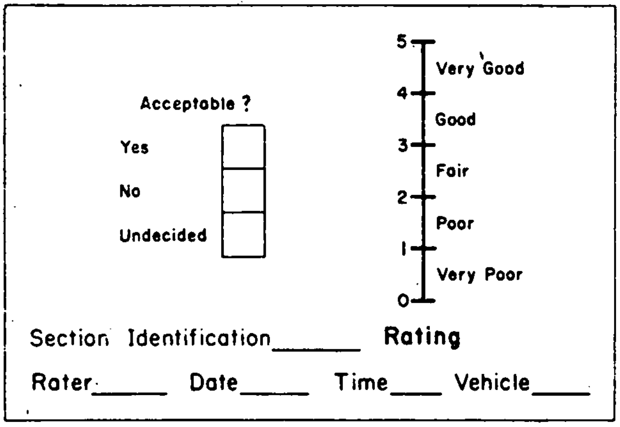


FIGURE 1 Individual present serviceability rating used for the AASHO Road Test (*4*).

Roughness (Ride)

Pavement roughness is generally defined as irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user). The activities associated with the AASHO Road Test (*4*) produced a more precise definition of roughness that is widely used at this time. The following terms are relevant to this synthesis:

1. *Present Serviceability Rating (PSR)*. "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve." The quantitative scale used by the panels (observers) in the AASHO Road Test is shown in Figure 1. The subjective scale ranges from 5 (excellent) to 0 (essentially impassable).

2. *Present Serviceability Index (PSI)*. "An estimate of the mean of serviceability ratings made by a panel of judges." Usually this estimate is obtained with some type of equipment that is correlated to panel ratings.

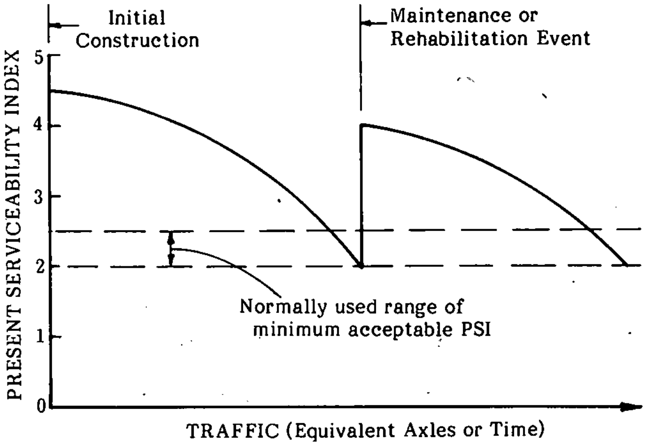


FIGURE 2 Concept of pavement performance using present serviceability index.

3. *Performance.* "The serviceability trend of a . . . [pavement segment] with increasing number of axle applications." Figure 2 further demonstrates this concept.

Although some equipment for measuring pavement roughness existed before the AASHO Road Test was conducted, the PSI concept greatly accelerated development in this area. Some of the earlier equipment and techniques included the U.S. Bureau of Public Roads roughometer, the CHLOE profilometer, and precise leveling. More recently developed equipment includes: car ride meters [Mays meter, PCA meter, Cox meter, New York, and Saab (recently developed in Sweden)]; the surface dynamics profilometer; and the laser profilometer (U.S. Air Force).

Current practices for ride evaluation, including the ride measuring equipment used by the agencies surveyed, are summarized in Table 2. This table is a modification and update of similar information contained in the Tumwater Pavement Management Workshop report (*3*). In addition, some agencies, including those in Pennsylvania and Texas, use the surface dynamics profilometer for calibrating Mays meters.

Of the nine agencies surveyed, seven use some type of car ride meter for measuring ride. The advantages of using ride meters include:

- Relatively low cost.
- Simplicity and ease of operation.
- Capability for acquisition of large amounts of data.
- Adequate repeatability.
- Output correlated with PSI.

Disadvantages associated with ride meters include:

- Relatively frequent calibration needed to assure repeatability.
- Inability to measure pavement profiles.

TABLE 2

CURRENT PRACTICE FOR RIDE EVALUATION

Agency	Comments
Arizona	Mays meter used to rate annually. Panel rating used to develop a rideability index that is similar to PSI.
California	PCA meter used. Ride score (and other data) used in identifying corrective work.
Florida	Mays meter correlated to CHLOE profilometer. Ride rating (RR) based on calibration for each vehicle is determined.
New York	Unique mobile vehicle response profiler used to monitor PRI (similar to PSI). Entire system monitored annually. Serves a central computer by analog tape.
Ontario	Subjective rating of ride on a scale of 0-10. Riding comfort index (RCI) is determined.
Pennsylvania	Mays meter used on 100% of Interstate, expressways, principal highways, and minor arterials annually
U.S. Air Force (CERL)	Pavement surface profile of airfield pavements measured with laser profilometer.
Utah	Cox meter used on 1-mi increments. Roughness reported in form of serviceability (PCI).
Washington	Cox meter used on all sections to calculate ride score as part of overall rating.

- Data are a function of automobile operating characteristics [including shock absorbers and springs; gross vehicle weight and distribution; tire pressure, wear, and condition (balance and alignment); and the effects of temperature and wind].

Several agencies have placed Mays meters in towed trailers to help overcome some of these problems.

Surface Distress

As shown in Table 1, surface distress data are collected regularly by the agencies surveyed (except New York). In describing agency practices, the following definition of distress is used: "Any indication of poor or unfavorable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure" (*5*).

Distress surveys are commonly grouped into three categories: (a) fracture, (b) distortion, and (c) disintegration. For each category of distress data, it is necessary to identify individual distress types, corresponding amount and severity, and locations. Detailed definitions for individual distress types are provided by Smith et al. (*6*). Table 3 presents an overview of this concept along with examples of the causes of these types of distress.

The types of distress data collected by the agencies are summarized in Tables 4 (flexible pavements) and 5 (rigid pavements). As shown in Table 4, essentially all agencies use some measure of cracking in evaluating flexible pavement conditions. Specifically, transverse, longitudinal, and alligator cracking are measured by six of the nine agencies. Measures of generalized and block cracking are used to a lesser extent. Most agencies measure rutting, raveling, patching, and flushing. Corrugations, stripping (similar to raveling), polishing, and potholes are measured to a lesser extent.

There appears to be less uniformity among the agencies regarding the practices for collection of distress data to evaluate rigid pavement conditions. General measures of cracking (primarily transverse, longitudinal, and corner), spalling, faulting, settlement, pumping, joint separation, raveling, popouts, scaling, and patching are the most common types of data collected. A procedure for systematically collecting distress data has been developed for NCHRP Project 1-19 (*8*).

TABLE 3

DISTRESS GROUPS (*7*)

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

TABLE 4

TYPES OF DISTRESS DATA COLLECTED FOR FLEXIBLE PAVEMENTS[a]

Distress Mode	Distress Type	Agency								
		Ariz.	Calif.	Fla.	N.Y.	Ont.	Pa.	USAF	Utah	Wash.
Fracture	Cracking									
	Generalized	●		●						
	Transverse		●			●	●	●	●	●
	Longitudinal		●			●	●	●	●	●
	Alligator		●			●	●	●	●	●
	Block		●				●	●		
	Other					●	●	●		
Distortion	Rutting	●	●	●		●	○	●	●	●
	Corrugations					●	●	●		●
Disintregation	Raveling		●	◐		●	○	●	●	●
	Stripping						○	●		
	Polishing							●	●	
Other	Patching		●	●		●	○	●	●	●
	Potholes			◐			●			
	Flushing			◐		●	○	●	●	●

[a] ●Required; ○optional; ◐data collected on specific projects only.

The data in Table 6 indicate that measures of distress are usually subjectively obtained instead of being collected with distress detection equipment. Pavement, in lengths ranging from 100 to 500 ft (30 to 150 m), is usually surveyed at 1-mi (1.6-km) intervals. Research conducted in Texas verifies this approach (*9*). Photologging, as a method for detecting distress, does not appear to be commonly used by the agencies interviewed.

Typical recording methods are described in the appendixes. The recording form currently used by the Washington Department of Transportation (WSDOT) is shown in Figure 3. The form is primarily used to record the location, extent, and severity of pavement distress. All types of distress measurements used for both flexible (bituminous) and rigid (portland cement concrete) pavements are listed in this single form. A column for recording roughness counts obtained from the ride meter formerly used in Washington is also included in the form. Other agencies have also developed forms to accommodate specific evaluation procedures.

The agencies use various methods to condense distress data into useful information. One common procedure is to associate deduct (penalty) points with specific distress type, severity, and extent combinations. These points can then be summed and subtracted from some upper limit or maximum value (usually 100). A generalized relationship for this concept was described by Shahin and Darter (*10*):

$$\text{Rating (distress) score} = C - \left[\sum_{i=l}^{n} \sum_{j=l}^{m} a\,(T_i, S_j, E_{ij}) \right]$$

where

C = initial rating (distress) number, and

$a\,(\;)$ = weighting factor or deduct points, which is a function of distress type T_i, severity of distress S_j, and extent of distress E_{ij}

This basic concept is used by three of the nine agencies reviewed [Florida, U.S. Air Force (CERL), and Washington]. Other procedures used by the individual agencies for summarizing data are described in the appendixes.

Possible causes for variations in subjectively obtained distress data and subsequent ratings or distress scores were discussed by Mahoney and Lytton based on studies conducted in Texas (*9*):

1. Rater error: The inability of a rater(s) to replicate an evaluation on a given pavement.
2. Evaluation procedure change. [Any changes made in a distress rating procedure can cause variations in the resulting scores.]
3. Variation within a highway segment:
   (a) Pavement distress variation within highway segments often causes the rater difficulty in arriving at a "composite" rating which is representative of the whole highway segment being evaluated.
   (b) Pavement distress variation within highway segments also causes the evaluation to be somewhat dependent upon where the rater stops to make the evaluation. [This appears to be one of the largest causes of errors in year-to-year evaluations for any highway segment.]
4. True year-to-year differences [for a pavement segment]: Major maintenance [or rehabilitation] (such as overlays) and minor [or routine] maintenance (such as patching, crack sealing, etc.) are performed annually on many pavement seg-

TABLE 5

TYPES OF DISTRESS DATA COLLECTED FOR RIGID PAVEMENTS

Distress Mode	Distress Type	Agency								
		Ariz.	Calif.	Fla.	N.Y.	Ont.	Pa.	USAF	Utah	Wash.
Fracture	Cracking									
	General	●	●[a]					●		●
	Transverse			●		●	●	●		
	Longitudinal			●		●	●	●		
	Diagonal			●		●				
	D					●		●		
	Corner			●		●		●		
	Other					●				
	Spalling		●	●		●	●	●		●
	Shattered Slab			●			●			
Distortion	Rutting									●
	Settlement					●	●	●		●
	Faulting		●	●		●	●	●		●
	Pumping			●				●		●
	Joint Separation		●	●		●				
	Blow Up					●	●	●		●
	Warping					●				●
Disintegration	Raveling			●[b]		●				●
	Popouts			●[b]		●		●		●
	Scaling			●[b]		●		●		●
	Polishing					●				
Other	Patching		●	●		●	●	●		●
	Potholes					●	●			

[a] Composed of 1st, 2nd, and/or 3rd stage cracking.
[b] Evaluated by use of one distress type termed "surface deterioration."

TABLE 6

CURRENT PRACTICE FOR SURFACE DISTRESS EVALUATION

Agency	Comments
Arizona	Primary evaluation consists of crack survey. Distress compared with standard photos. Other distress parameters determined to be too time-consuming. 1000 ft^2 for each 1/3 mi is evaluated.
California	Structural defects such as cracking, rutting, etc., rated for extent and severity. Entire state highway system rated on a biennial basis.
Florida	Structural defects including rutting, cracking, and patching are rated for 100-ft as reoresentative of 1-mi sections. Defect rating (DR) is determined as part of overall evaluation.
New York	Not made routinely.
Ontario	Pavement condition rating (PCR) determined by rater as set forth in manuals. 1- or 3-yr rating frequency. Ride and distress combined to determine PCR.
Pennsylvania	Trained observer survey performed on a floating sample of the highway system.
U.S. Air Force (CERL)	Pavement condition index (PCI) is determined based on objective measurement of pavement distress. Sampling (within a project) is used to expedite the condition survey.
Utah	Detailed evaluation of cracking, rutting, patching, wear, weathering, etc., on 500-ft of 1-mi sections made from subjective analysis. Eleven parameters used.
Washington	Structural defects, such as cracking and rutting, measured every other year, on a subjective basis, on a 200-ft section within each 1-mi section.

ments. Both types of maintenance can cause significant annual changes [in recorded distress data. Additionally, pavement distress, once present, increases with time if no maintenance or rehabilitation is performed.]

The year-to-year variation caused by the first three factors listed above should be reduced or eliminated; the fourth factor is the only one that is actually desired. To reduce unwanted variations, a number of relatively straightforward techniques have been suggested (*9*), including:

1. Each year the rater(s) should stop at the same location within each segment (possibly keyed to mileposts). A minimum permissible area should be evaluated at each stop.
2. The number of rating locations (stops) should be at a frequency of every 1 to 0.5 mi (1.6 to 0.8 km).
3. The rating for each segment should be obtained by a consensus of at least two raters whenever possible.
4. Rating procedures should be as simple as possible.

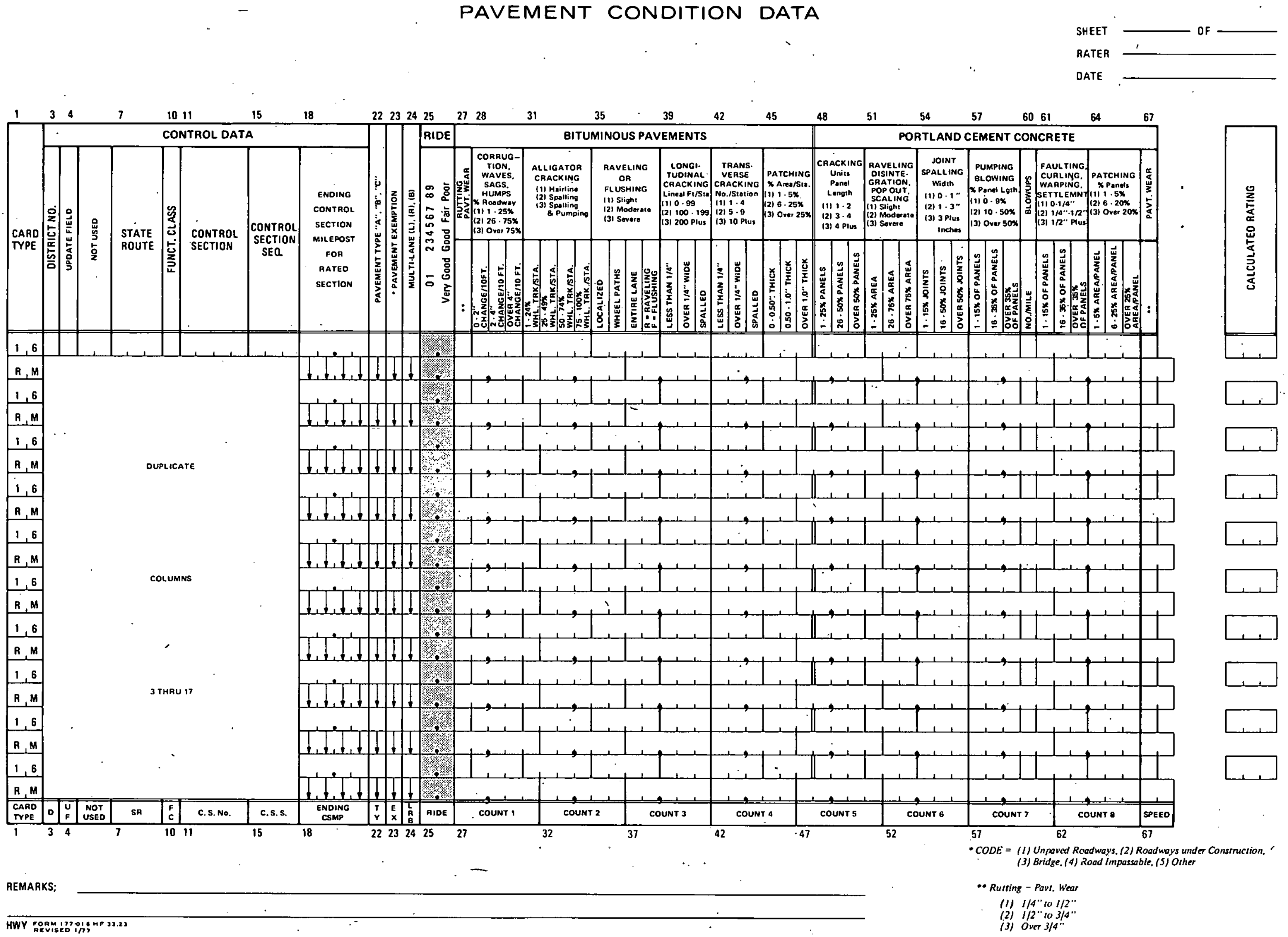
However, these techniques may not be equally useful to all agencies that collect such information. The composition of rating teams, rating frequency, available equipment, structure and condition of pavement network, and other factors must be considered in utilizing these recommendations.

Structural Evaluation (Surface Deflection)

Structural data are not routinely collected for pavement monitoring by most of the agencies surveyed (only one of the nine still does so; see Table 1). However, several agencies use surface deflection data in designing and selecting specific rehabilitation strategies for pavement segments. The following definitions are relevant to a discussion on surface deflection measurements:

- *Structural Adequacy.* "The ability of a pavement to support traffic without developing appreciable structural distress" (*11*).
- *Nondestructive Structural Evaluation.* "Consists of making nondestructive measurements on a pavement's surface and inferring from these measurements *in situ* characteristics related to the structural adequacy or loading behavior" (*12*).

Surface deflection measurements are obtained by using



PAVEMENT CONDITION DATA

SHEET ______ OF ______
RATER ______
DATE ______

CONTROL DATA

- 1 CARD TYPE
- 3 DISTRICT NO.
- 4 UPDATE FIELD
- NOT USED
- 7 STATE ROUTE
- 10 FUNCT. CLASS
- 11 CONTROL SECTION
- 15 CONTROL SECTION SEQ.
- 18 ENDING CONTROL SECTION MILEPOST FOR RATED SECTION
- 22 PAVEMENT TYPE "A", "B", "C"
- 23 * PAVEMENT EXEMPTION
- 24 MULTI-LANE (L), (R), (B)

RIDE

- 25 01 Very Good 2 3 4 5 Good 6 7 Fair 8 9 Poor

BITUMINOUS PAVEMENTS

- 27 RUTTING PAVT. WEAR: **
- 28 CORRUGATION, WAVES, SAGS, HUMPS % Roadway (1) 1 - 25% (2) 26 - 75% (3) Over 75%: 0 - 2" CHANGE/10FT. | 2 - 4" CHANGE/10 FT. | OVER 4" CHANGE/10 FT.
- 31 ALLIGATOR CRACKING (1) Hairline (2) Spalling (3) Spalling & Pumping: 1 - 24% WHL. TRK/STA. | 25 - 49% WHL. TRK/STA. | 50 - 74% WHL. TRK/STA. | 75 - 100% WHL. TRK./STA.
- 35 RAVELING OR FLUSHING (1) Slight (2) Moderate (3) Severe: LOCALIZED | WHEEL PATHS | ENTIRE LANE | R = RAVELING F = FLUSHING
- 39 LONGITUDINAL CRACKING Lineal Ft/Sta (1) 0 - 99 (2) 100 - 199 (3) 200 Plus: LESS THAN 1/4" | OVER 1/4" WIDE | SPALLED
- 42 TRANSVERSE CRACKING No./Station (1) 1 - 4 (2) 5 - 9 (3) 10 Plus: LESS THAN 1/4" | OVER 1/4" WIDE | SPALLED
- 45 PATCHING % Area/Sta. (1) 1 - 5% (2) 6 - 25% (3) Over 25%: 0 - 0.50" THICK | 0.50 - 1.0" THICK | OVER 1.0" THICK

PORTLAND CEMENT CONCRETE

- 48 CRACKING Units Panel Length (1) 1 - 2 (2) 3 - 4 (3) 4 Plus: 1 - 25% PANELS | 26 - 50% PANELS | OVER 50% PANELS
- 51 RAVELING DISINTEGRATION, POP OUT, SCALING (1) Slight (2) Moderate (3) Severe: 1 - 25% AREA | 26 - 75% AREA | OVER 75% AREA
- 54 JOINT SPALLING Width (1) 0 - 1" (2) 1 - 3" (3) 3 Plus Inches: 1 - 15% JOINTS | 16 - 50% JOINTS | OVER 50% JOINTS
- 57 PUMPING BLOWING % Panel Lgth. (1) 0 - 9% (2) 10 - 50% (3) Over 50%: 1 - 15% OF PANELS | 16 - 35% OF PANELS | OVER 35% OF PANELS
- 60 BLOWUPS: NO./MILE
- 61 FAULTING, CURLING, WARPING, SETTLEMNT (1) 0-1/4" (2) 1/4"-1/2" (3) 1/2" Plus: 1 - 15% OF PANELS | 16 - 35% OF PANELS | OVER 35% OF PANELS
- 64 PATCHING % Panels (1) 1 - 5% (2) 6 - 20% (3) Over 20%: 1 - 5% AREA/PANEL | 6 - 25% AREA/PANEL | OVER 25% AREA/PANEL
- 67 PAVT. WEAR: **

CALCULATED RATING

CARD TYPE
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M
1 6
R M

DUPLICATE

COLUMNS

3 THRU 17

CARD TYPE	D	UF	NOT USED	SR	FC	C. S. No.	C. S. S.	ENDING CSMP	TY	EX	LRB	RIDE	COUNT 1	COUNT 2	COUNT 3	COUNT 4	COUNT 5	COUNT 6	COUNT 7	COUNT 8	SPEED
1	3	4		7	10	11	15	18	22	23	24	25	27	32	37	42	47	52	57	62	67

* CODE = (1) Unpaved Roadways, (2) Roadways under Construction, (3) Bridge, (4) Road Impassable, (5) Other

** Rutting – Pavt. Wear
(1) 1/4" to 1/2"
(2) 1/2" to 3/4"
(3) Over 3/4"

REMARKS; ______

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FIGURE 3 Pavement distress recording form (Washington Department of Transportation).

TABLE 7

CURRENT PRACTICE FOR STRUCTURAL EVALUATION (SURFACE DEFLECTION)

Agency	Comments
Arizona	Annual Dynaflect deflections at three locations per mile as routine measure up to 1980. Now only used for design purposes. Recently purchased a falling-weight deflectometer.
California	Dynaflect deflections used in design but not in monitoring system.
Florida	Dynaflect deflections for design and some monitoring purposes. Recently used a falling-weight-deflectometer in a research study.
New York	Deflection data obtained for research purposes only.
Ontario	Data collected on selective basis only. Both the Dynaflect and Benkelman beam have been used.
Pennsylvania	Road Rater deflections used to evaluate selected sections that have reached terminal serviceability (flexible pavements only).
U.S. Air Force (CERL)	No single device used. Structural evaluation is presently based on measurement of field "CBR" and "K" values, and various other material properties.
Utah	Dynaflect deflection measurements used to predict remaining life based on projected 18-kip loads. One test per mile with temperature corrections (candidate projects are tested more extensively for overlay design).
Washington	Benkelman Beam deflections used for selected locations, but not for routine monitoring.

three types of nondestructive tests: static deflections, steady-state deflections, and impact load response (*12*). Some examples of equipment associated with these tests are:

1. Static deflections: Benkelman beam; traveling deflectometer; and plate bearing test (ASTM D 1196).
2. Steady state deflections: Dynaflect; Road Rater equipment (several models); Waterways Experiment Station (WES) (vibrators); and FHWA deflection van (Cox).
3. Impact load response: falling weight deflectometer.

The types of equipment listed above are fully reviewed in Moore et al. (*12*) and Bush (*13*).

Table 7 provides a summary of current practices for structural evaluation. Only one agency (Utah) uses surface deflection data for routine pavement monitoring. On an individual project basis, surface deflection data are commonly collected and then utilized in the detailed design and rehabilitation selection process. Most agencies use the Benkelman beam and the Dynaflect; however, at least three agencies have used the falling weight deflectometer equipment since 1979. It appears that surface deflection data are not routinely collected networkwide because of the associated high costs. In 1980 the Arizona DOT eliminated the collection of such data by the Dynaflect for this reason (G. Way, *personal communication*).

Skid Resistance

Skid resistance data are routinely collected by eight of the nine agencies (the U.S. Air Force collects such data on a project-by-project basis). The following definitions are relevant to a discussion of agency practices for the measurement of skid resistance:

- *Skid Resistance.* "The force developed when a tire that is prevented from rotating slides along the pavement surface" (*14*).
- *Hydroplaning.* Separation of the tire and the pavement surface by water (*15*). This tends to occur when there is an abnormally thick layer of water on the pavement and vehicle speed is high.
- *Pavement Texture.* Generates resistance to sliding and facilitates expulsion of water from the tire-pavement interface.
- *Pavement Microtexture.* Fine texture of a bituminous concrete surface; provides adhesion component of skid resistance (*15*).
- *Pavement Macrotexture.* Coarse texture of a bituminous surface; provides escape channels for water, thus providing for a large amount of the tire area to remain in contact with the pavement surface (*15*).
- *Texturing.* Surface of portland cement concrete includes

TABLE 8

CURRENT PRACTICE FOR SKID RESISTANCE

Agency	Comments
Arizona	Mu-Meter used for 500-ft in each mile of entire system on annual basis.
California	Measured periodically with locked-wheel trailer manufactured by K. J. Law, Inc.
Florida	Skid resistance measured with locked-wheel trailer. Approximately 35 to 40% of Interstate and primary network evaluated each year.
New York	Skid trailer covers entire system about every 3 yr. Test is conducted every 0.1 or 0.2 mi. Data used separately, mostly in connection with accident surveillance and analysis.
Ontario	Skid resistance measurements made on selective basis.
Pennsylvania	Skid resistance measured with locked-wheel trailer. Measurements made on every other 250-ft segment, or approximately 10 tests per mi. Data evaluated separately from other condition information.
U.S. Air Force (CERL)	Mu-Meter used approximately every 5 yr.
Utah	Mu-Meter used on wet pavement. 0.1-mi sections measured at every milepost (closer intervals where low SN measured).
Washington	Skid trailer measurements made with locked-wheel trailer manufactured by K. J. Law, Inc. High accident locations are checked; 1-mi sections are routinely measured every other year. Data considered separately.

both fine and coarse texture. Fine texture (grittiness) results from sand in the cement-mortar layer. Coarse texture produced by surface irregularity resulting from the method of finishing (*15*).

The primary reason for collecting skid resistance data is to prevent or reduce skid-related accidents. The agencies use the data in the following ways:

1. To identify the pavement segments with low skid resistance.
2. To plan pavement maintenance and rehabilitation.
3. To evaluate various types of surfacing materials, mix design, and construction practices.

Generally, the single value used to represent skid resistance data is skid number (SN). This number approximates the term more commonly known in physics as the "coefficient of friction." It is not strictly correct to say that a pavement has a certain coefficient of friction (or friction factor) because friction involves two bodies. For pavement applications, these two bodies are the pavement surface and vehicle tires—both of which are extremely variable due to such factors as pavement wetness, vehicle speed, temperature, tire wear, etc. ASTM E 274 is a test standard used to provide a standardized measure of pavement skid potential (or skid number).

The forces required to calculate skid number are usually obtained with a towed trailer equipped with standardized tires (in accordance with ASTM E 274); however, other measures of skid resistance are also used by some of the agencies interviewed.

There are at least three principal methods for measuring skid resistance: (a) locked-wheel trailers, (b) yaw mode trailers, and (c) the British Portable Tester. These methods are separately identified and the characteristics (physical and operational features) of each procedure are listed below.

1. Locked-wheel trailers
   a. Most commonly used skid testing device.
   b. Two-wheel trailer with test wheel locked and locking force measured. Pavement surface artificially wetted.
   c. Standard tire with seven circumferential grooves is used.
   d. Test speed is normally 40 mph.
   e. Some state DOT's have developed their own skid trailers.

2. Yaw mode trailer
   a. Commonly used, commercially available device is the Mu-Meter.

   b. Two wheels turned in opposite directions to create transverse forces to estimate skid resistance.
   c. Trailer travels in straight line without restraining mechanism.
   d. Both wheels cannot be in wheelpaths; thus may indicate higher friction than locked-wheel trailer.

3. British Portable Tester
   a. Can be used in laboratory or field.
   b. Uses a pendulum with a spring-loaded rubber shoe. Pendulum drops and shoe slides over surface to be tested. Determines a measure of friction. Results reported as British Pendulum Number (BPN) (ASTM E 303).
   c. Results have not correlated well with those obtained with locked-wheel trailers.

Table 8 provides a summary of the current methods for collecting skid resistance data. As shown in the table, the locked-wheel trailer is the most common device used by the nine agencies surveyed for this synthesis, and the Mu-Meter is second. However, locked-wheel trailers are by far the most commonly used skid-resistance measuring device used by state DOT's throughout the country (*16*).

Other information made available by the agencies surveyed indicates that skid-resistance data are not usually used directly with other pavement condition data in making maintenance and rehabilitation decisions. Such data are generally treated separately to eliminate or reduce the amount of pavement with potential skid hazards.

SAMPLING PROGRAMS

The sampling programs used by the agencies to obtain the four types of data vary substantially; however, some common characteristics have been observed.

Roughness

The sampling programs used to collect roughness data are summarized in Table 9. The amount of pavement network sampled annually varies from 100 percent for Arizona, Florida, and New York to approximately 25 percent for Ontario. (The Air Force does not collect roughness data on a routine basis.) Generally, because of the type of equipment used, such data are obtained on a more-or-less continuous sampling basis. It also appears that the use of mileposts is a commonly used data reference method. All the agencies interviewed, except New York, hand-reduce the data for entry into computer files. In New York, a fully automated data

TABLE 9

SUMMARY OF SAMPLING PROGRAMS TO COLLECT ROUGHNESS DATA

Agency	Percent of Network Sampled	Interval of Sampling	Time Required to Obtain Sample	Total Network Size	Data Reference System	Reduction and Storage Methods
Arizona	100% annually	Continuous	3 mo/yr	6,200 mi	-	Recorded on strip chart; plan to convert to automated processing.
California	100% biennially	-	6 mo/biennium	47,000 lane mi	Milepost	Data hand-reduced, keypunched, and edited before computer storage.
Florida	100% annually	Continuous	-	33,000 lane mi	Milepost	Data hand-reduced, keypunched, edited, and report published.
New York	100% annually	Network divided into 137,000 segments	Approx. 5 mo/yr	16,800 mi	-	Data recorded on magnetic tape. All processing automated.
Ontario	3-yr or annual cycles; approx. 25% annually	-	Approx. 4 mo/yr	13,400 mi	-	Data stored in central computer file.
Pennsylvania	10% of Interstate, expressways, and major and minor arterials annually	-	-	-	Milepost or stationing	Data hand-reduced, keypunched, edited, and stored in computer file.
U.S. Air Force (CERL)	Not collected on a systematic basis	-	-	-	-	-
Utah	50% annually	Continuous	3 mo/yr	5,570 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.
Washington	100% biennially	Continuous	3 mo/biennium	8,000 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.

reduction and storage system is used. The length of time required to obtain roughness data appears to be approximately 3 to 5 months (not necessarily including processing time).

Surface Distress

The sampling used to collect surface distress data are summarized in Table 10. The amount of pavement network sampled annually varies from 100 percent in Florida to 8 percent in Pennsylvania. In California and Washington, samplings are conducted biennially. Sampling intervals (number of rating stops) range from 1000-ft^2 (90-m^2) areas every ⅓ mi (0.5 km) (Arizona) to 500-ft (150-m) (Utah) or 100-ft long (Florida) segments every 1 mi (1.6 km). Thus, according to the information supplied by the agencies, sampling intervals of 1 mi (1.6 km) or less appear to produce adequate results, and distress data are recorded for preselected lengths of pavement segments.

As in the collection of roughness data, the use of mileposts is the most commonly used data reference method. Essentially all agencies that collect this type of data use keypunched cards to enter the information into computer files. The time required to collect the data varies from 12 months (Arizona) to about 4 months (Ontario), and is a direct function of the amount of the network sampled and the personnel and equipment resources available.

Structural Evaluation

The sampling programs used to collect surface deflection data are described in Table 11. None of the agencies, except for Utah, routinely collects this type of data for pavement monitoring; instead, the data are obtained on a selective basis (project by project). In Arizona, the practice of collecting deflection data for monitoring purposes has recently been discontinued (G. Way, *personal communication*). Sampling intervals for monitoring range from 1 to 3 test locations every 1 mi. For design purposes, most agencies obtain data at

TABLE 10

SUMMARY OF SAMPLING PROGRAMS TO COLLECT DISTRESS DATA

Agency	Percent of Network Sampled	Interval of Sampling	Time Required to Obtain Sample Total Network Size	Data Reference System	Reduction and Storage Methods
Arizona	40% annually	1000 ft^2 area each 1/3 mi	12 mo/yr 6,200 mi	Milepost	Data hand-reduced, then stored in computer file.
California	100% biennially	Flexible: min. 300-ft section per mi; rigid: every panel with 1st, 2nd, and 3rd degree cracking	6 mo/biennium 47,000 lane mi	Milepost	Data hand-reduced, keypunched, and edited; then entered into computer file.
Florida	100% annually	100-ft section per mile	- 33,000 lane mi	-	Data hand-reduced, keypunched, edited, and report published.
New York	Not collected on a systematic basis	-	- -	-	-
Ontario	3-yr or annual cycles; approx. 55% annually	-	Approx. 4 mo/yr 13,400 mi	-	Data stored in central computer file.
Pennsylvania	8% annually	-	- -	Milepost or stationing	Data keypunched, edited, and stored in computer file.
U.S. Air Force (CERL)	Principal airfield features sampled (runway, etc.)[a]	One sample unit = 20 slabs (rigid) or 5000 ft^2 (flexible)	- -	Physical features	Entered into automated file, then processed by computer.
Utah	50% annually	500-ft section per mile	5 mo/yr 5,570 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.
Washington	100% biennially	200-ft section per mile	3 mo/biennium 8,000 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.

[a] Performed at intervals of 6 months to 5 years based on pavement conditions.

TABLE 11

SUMMARY OF SAMPLING PROGRAMS TO COLLECT STRUCTURAL EVALUATION DATA

Agency	Percent of Network Sampled	Interval of Sampling	Time Required to Obtain Sample Total Network Size	Data Reference System	Reduction and Storage Methods
Arizona	40% annually	Three tests per mile	12 mo/yr 6,200 mi	Milepost	Data hand-reduced from coding form for storage in computer file.
California	Not collected on a systematic basis	-	- -	-	-
Florida	Not collected on a systematic basis	-	- -	-	-
New York	Not collected on a systematic basis	-	- -	-	-
Ontario	Deflection measurements made on selective basis; approx. 20% annually	-	250 man day/yr 13,400 mi	-	Data stored in central computer file.
Pennsylvania	Survey conducted on pavements that have reached TSI (approx. 5%/yr)	-	- -	Milepost or stationing	Data hand-reduced, keypunched, edited, and stored in computer file.
U.S. Air Force (CERL)	Several bases surveyed annually	-	- -	-	-
Utah	50% annually	One test every mile	5 mo/yr 5,570 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.
Washington	Not collected on a systematic basis	-	- -	-	-

substantially shorter intervals. The data are generally hand-reduced onto keypunched cards for computer storage.

Skid Resistance

The sampling programs used to collect skid resistance data are summarized in Table 12. The amount of a pavement network sampled in a year varies from approximately 67 percent (Arizona) to 33 percent (New York). Most of the other agencies sample pavement network annually at percentages that fall between these upper and lower values. The sampling intervals vary considerably. Data are collected at frequencies of 1 mi (1.6 km) or less. Because most agencies use locked-wheel or Mu-Meter trailers, the length of pavement actually tested ranges from approximately 250 to about 500 ft (75 to 150 m). Data reduction and storage procedures include both highly automated systems (Arizona) and placement on keypunched cards for entry into computer files.

COSTS

The costs of collecting and processing pavement condition data include (a) program development costs (usually a one-time or infrequent charge) and (b) data collection and processing costs (an annual charge).

Program Development Costs

Determining program development costs is difficult. Frequently the funds for developing data collection, processing, and analysis systems may come from several sources and be expended over several years. In addition, such development work may be tied to other research-related topics, thereby making it difficult to determine separate, distinct charges associated with specific areas. Some agencies have developed programs using in-house personnel; whereas other agencies have used consultants (private and university). Washington used consultants in early development work and then switched primarily to in-house development. In Arizona, a consulting firm has been employed throughout PMS-development efforts.

Among the agencies surveyed for this synthesis, development cost information was provided only from the USAF (CERL) system ($162,000) and agencies in Washington ($250,000) and New York ($450,000). These costs have not been adjusted for inflation or scope and, therefore, are not necessarily directly comparable. The development costs in Washington amount to a one-time charge of about $30 per mile ($19/km). About 20 percent of New York's annual production budget is devoted to continuing development.

Data Collection and Processing Costs

Data collection and processing costs tend to recur on a fixed frequency of every 1 to 2 yr. The nine agencies were asked to provide costs based on actual or estimated 1979 expenditures (approximate base year) in the following categories: personnel, travel, equipment, data processing, miscellaneous, and indirect costs. The agency responses are summarized in Table 13. Also provided in this table are the approximate percentages of the total costs directly attributed to the four types of data collected: roughness, distress, structural (deflection), and skid resistance.

As shown in Table 13, the annual costs of obtaining pavement condition data for monitoring purposes ranges from about $12 to $50 per center-line mile ($7 to $15/km). (Note that the figures for Arizona include the cost of the discontinued practice of collecting deflection data, which accounts for one-half of the annual costs per mile.) The percentage of the total costs attributed to each type of measurement is difficult to determine because the various agencies place different emphases on and use different methods for each type of data collected.

USE OF PAVEMENT CONDITION DATA

Most of the agencies surveyed use pavement condition data in one or more of the following ways:

1. *To establish priorities (priority programming).* Selecting projects to be done on a yearly basis.
2. *To determine maintenance or rehabilitation strategies.* Selecting work (seal coat, overlay, recycling, etc.) to be done on a project-by-project basis.
3. *To predict performance.* Projecting future pavement performance in order to prepare long-range budgets or to predict future pavement conditions given a fixed budget.

The use of pavement condition data by each agency interviewed is shown in Table 14. Immediately evident is the fact that each agency *does* use the information in one or more ways; thus the data are not just collected and then forgotten. The following sections summarize the uses of the data by the nine agencies surveyed. (See the appendixes for additional information.)

TABLE 12

SUMMARY OF SAMPLING PROGRAMS TO COLLECT SKID RESISTANCE DATA

Agency	Percent of Network Sampled	Interval of Sampling	Time Required to Obtain Sample Total Network Size	Data Reference System	Reduction and Storage Methods
Arizona	67% annually	0.1-mi section every mile (both directions)	4 mo/yr 6,200 mi	Milepost	Data stored on cassette tape; then to computer file.
California	50% annually	-	- 45,000 lane-mi	-	Data hand-reduced, keypunched, edited, and entered in computer file.
Florida	40% annually for Interstate and primary	-	- 33,000 lane-mi	-	-
New York	33% annually	Test done every 0.1 to 0.2 mi	- 16,880 mi	-	-
Ontario	Skid measurements made on selective basis; approx. 9%/yr	-	400 man-day/yr 13,400 mi	-	-
Pennsylvania	50% annually for Interstate system	Ten 250-ft sections every mile	- -	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.
U.S. Air Force (CERL)	Each base surveyed approximately every 5 yr	-	- -	-	-
Utah	50% annually	0.1-mi section every mile	3 mo/yr 5,570 mi	Milepost	Data hand-reduced, keypunched, edited, and stored in computer file.
Washington	50% annually	-	1.5 mo/yr 8,000 mi	-	Data hand-reduced from paper tapes to coding forms; then keypunched and edited.

TABLE 13

ESTIMATED COSTS FOR COLLECTION AND PROCESSING OF DATA (APPROXIMATE 1979 BASIS)[a]

Item	Agency Costs ($)								
	Ariz.[b]	Calif.[c]	Fla.	N.Y.[d]	Ont.	Pa.	USAF (CERL)	Utah	Wash.[e]
Costs									
Personnel	190,000	-	48,800	132,000	45,000	368,500	-	75,000	82,800
Travel	43,000	-	9,600	14,000	6,000	84,000	-	5,000	18,890
Equipment	38,000	-	36,400	12,300	90,000[f]	103,000	-	8,000	29,400
Data Processing	12,000	30,000	24,000	-	10,000	9,000	-	5,600	-
Other	15,000	-	-	42,000	19,000	-	-	800	-
Indirect Costs	15,000	-	18,200	-	15,000	238,600	-	-	26,210
Total Costs	313,000	372,700	137,000	200,300	185,000	803,100	-	94,400	157,300
Mileage Surveyed (center-line mileage unless noted)	6,200	15,300	33,000 lane mi	16,880	13,400	-[g]	-	5,070	8,000
Annual Cost/Mile	50	24	-	12	14	-	-	19	20
Data Type	Percentage of Total Annual Collection and Processing Costs for the Four Major Types of Measurements								
Roughness	10	-	-	100	-	31	-	20	28
Distress	25	-	-	-	-	-	-	30	39
Structural (Deflection)	50	-	-	-	-	25	-	30	0
Skid Resistance	15	-	-	-	-	44	-	20	33

[a] Costs are not directly comparable because of differences in scope of data collection programs.

[b] Costs based on previous surveys that include costs of deflection data.

[c] Estimated costs for biennial survey.

[d] Costs of pavement serviceability system only.

[e] Estimated costs.

[f] Includes complete Dynaflect services.

[g] Mileage surveyed varies with type of data.

Arizona

Pavement condition data are used in Arizona for a variety of purposes including priority programming, overlay design, and performance prediction.

Priority programming entails the development of a priority list of potential projects without initial concern as to the specific type of rehabilitation or maintenance needed. Intensive studies are then conducted to select the type of work required. Each project is rated for condition, and a priority score, which is a function of cracking, ride, deflection, skid resistance, age, and average daily traffic, is calculated.

Dynaflect deflection data are used with the California overlay design procedure to determine required overlay thicknesses. Pavement designers also review ride and crack data to determine the need for a leveling course and/or special treatment to prevent reflection cracking. If the data indicate poor highway ride, the designer may consider a 1- to 3-in. (25- to 75-mm) leveling course. If cracking is greater than 10 percent, specialized treatment such as rubberized asphalt or heater scarification may be included in the design.

A pavement management information system (PMIS) was established in Arizona in 1975. The overall goal is to system-

TABLE 14

PRESENT USES OF PAVEMENT CONDITION DATA

Agency	Establish Priorities (Priority Programming)	Selection of Maintenance-Rehabilitation Strategy[a]	Performance Prediction
Arizona DOT	●	●	●
California DOT	●	●	
Florida DOT	●		
New York DOT	●		●
Ontario MTC	●	●	
Pennsylvania DOT	●	●	
U.S. Air Force (CERL)	●	●	
Utah DOT	●	●	●
Washington DOT	●	●	●

[a] Includes overlay design.

atically manage the state pavement network at or above an acceptable level and at a reduced cost. To accomplish this task, both individual project and network optimization procedures are being developed. Currently the PMIS is well-developed and being implemented on the project level. Future development work will be oriented toward network optimization. On the project level, previous condition data have been used to develop predictive equations, which are used to predict future roughness, cracking, skid resistance, and, consequently, by means of utility theory, the optimal strategy for each mile of highway for each year.

California

Pavement condition data are primarily used to assist in determining candidate project locations and pavement rehabilitation strategies and in establishing priorities for these projects. The information is further used to recommend program levels to Caltrans top management. The selection of specific rehabilitation strategies is keyed to preselected types and measures of distress and ride quality.

Florida

Pavement condition data collected in Florida are primarily used for priority programming. The key procedure in accomplishing this task is the computation of various rating scores. The scores are primarily a function of observed distress, roughness, and other highway operational and physical characteristics. Rating scores for all pavement segments are adjusted to a value ranging between 1 and 100 to establish priorities for individual projects.

New York

The uses of ride data include:

1. Establishing yearly priorities for maintenance and rehabilitation to serve as a basis for equitable distribution of resources among the 10 regions;
2. Identifying past and future performance trends; and
3. Determining the effects of known maintenance actions on these performance trends.

Distress and structural behavior (collected by regional forces) are considered in explaining good and bad performance and in making decisions on the scope of the work to be performed. Skid resistance and photolog systems exist independently and serve other management and inventory functions.

Ontario

Pavement condition data are used for priority programming and the selection of rehabilitation and maintenance strategies. Priority programming is a function of the pavement condition rating (PCR). The PCR is used to determine if a pavement section should be placed on a preliminary program listing, and also to compile a list of projects to be completed in the next 1, 2, or 5 yr. When the priority of a specific project changes from a 5-yr to a 2-yr program and then to the final program, the rehabilitation designs are examined and costs are determined. Decisions on specific project designs are based on the availability of funds and other factors.

The pavement condition survey is used to identify structural deficiencies and thus is used in rehabilitation design. This information has also been used in the identification of maintenance requirements and the selection of corrective measures.

The pavement management feedback and information system (PAMFIS) currently being used in Ontario makes design, construction, maintenance, and performance information available on a project basis. In addition, an overview of the pavement network can be obtained. Benefits of the system include:

1. Use of rational engineering and economic procedures in the development of plans and programs.
2. Ability to forecast highway network conditions as fiscal direction and economic development change.
3. Ability to maximize the use of available funds.

Future PAMFIS development work will include procedures to optimize the cost of rehabilitation of all pavements in this network. The goal is to set priorities for projects by year with specific rehabilitation design details.

Pennsylvania

Information from the data collection process is used to identify pavements most in need of rehabilitation (or resurfacing) and to perform overlay design analysis. Distress data obtained from trained observer surveys are used to monitor statewide highway conditions, and as part of the formula used to allocate a portion of the maintenance funds to counties. Roughness data are used to obtain PSI values for individual pavement segments. This information is then compared to terminal serviceability index (TSI) values preselected for various pavement categories (maintenance functional codes) in order to identify pavements in need of rehabilitation. After the initial segment identification, both deflection and distress data may be used to assist in selecting the proper overlay thickness or rehabilitation strategy.

U.S. Air Force (CERL)

The data are used primarily to determine the maintenance and rehabilitation needs of airfield and highway pavements. The resulting pavement condition index (PCI) is used in selecting the appropriate strategy. Local base personnel usually collect the appropriate condition data. The data are also being used at USAF headquarters to develop a 7-yr airfield pavement improvement plan.

Utah

The data are used for a variety of activities, including priority programming, establishing rehabilitation strategies, and prediction of performance. Eventually the data will be used in a pavement management program.

Detailed data sheets and condition-versus-time plots are generated for each pavement. Priority lists for each of the four basic types of data are published. These documents are used by district personnel to establish the type of maintenance or rehabilitation required for individual highway segments.

Washington

In the past the data were used principally for priority programming. However, with the amount of data now being acquired, performance history and future performance projections are being developed. These projections will be used to prepare recommendations for scheduling future highway maintenance and rehabilitation. The data will also be used to tabulate rehabilitation strategies and total costs for a system (or district) of pavements. This information will provide administrators with the necessary information for planning and budgeting in the overall maintenance of the state highway network.

CHAPTER THREE

PROBLEMS WITH PRESENT DATA COLLECTION SYSTEMS

TYPES AND EXTENT OF PROBLEMS

Several types of problems encountered during the data collection and analysis process have been reported, including difficulties associated with equipment, manpower, season of year in which data are collected, and data processing.

Problems With Equipment

Table 15 summarizes the problems reported by the agencies regarding equipment. By far the biggest problems appear to be equipment calibration and maintenance. The output of the car ride meters varies considerably in relation to the suspension of the car used. Most agencies have relied on test sections to calibrate ride meters by using either a GM profilometer or panel ratings. However, the test sections can also vary from year to year (*9*). Arizona is presently experimenting with a bump simulator to calibrate vehicles in the laboratory. Research at the University of Michigan (*17*) indicates that an easily constructed bump or roughness simulator can be used in the field for ride-meter calibration.

Deflection devices, when used to monitor state road systems, have caused problems. In Arizona, it was found that the Dynaflect is not always precisely calibrated and its weight and dynamic load can vary from machine to machine. Downtime has also been a problem in the use of the Dynaflect. In Arizona, the cost of upkeep for two Dynaflects is estimated to be about $20,000 per yr for parts and labor. Similar expenses for maintaining Dynaflects have also been reported in Utah. The other agencies use only deflection data to establish overlay techniques and have not reported equipment maintenance to be a major problem.

There have been few reported problems with skid test equipment.

Manpower Problems

Table 16 summarizes the major manpower problems reported by the agencies. As indicated in the table, most of the problems concern training, motivation of personnel, and obtaining sufficient staff.

For management systems requiring distress data, training of personnel is necessary in order to eliminate subjectivity and ensure consistent data (both extent and severity). In Arizona, a cracking guide is used to ensure consistent data (see Figure A-1 in Appendix A); the rater observes the pavement cracking condition and selects a photograph that most closely matches the pavement condition. The agencies in California, Florida, Ontario, Utah, and Washington also rely on standard pavement condition evaluation forms. Washington reports that even though raters study color slides of all types of distress and are trained on actual pavement sections with veteran crews, ratings are often inconsistent.

Motivation of personnel was reported as a problem, particularly in collecting consistent data in an efficient manner. In Arizona, employees who collect data currently work 4 10-hr days per week. California reports that the repetitive nature of the job makes if difficult to motivate personnel. In New York, data (primarily roughness) are collected and analyzed with automated equipment, which eliminates some of the repetitive nature of the job; as a result, there do not appear to be any problems with motivation. Pennsylvania reports motivation is difficult to achieve because of extensive travel by personnel.

Obtaining sufficient staff to do the needed work is also reported to be a problem in several agencies. Arizona has difficulty in obtaining sufficient personnel to operate the pavement management system. Florida reports frequent personnel changes, which may be the result of a lack of motivation among personnel. Ontario reports a shortage of manpower to conduct surveys.

Season of Year for Collection of Data

The season of year during which pavement condition data are collected has a significant influence on the data (distress, ride, deflection, skid resistance) and thus on the decisions based on the data.

Arizona reports seasonal variations to be a problem in the calibration of ride meters. There is a definite need for development of a laboratory or other standard system for calibrating ride meters. Utah reports that temperature and/or seasons of year affect ride and deflection data; methods are presently being developed to treat these variations. Washington reports that selection of a uniform time of year is essential as ratings can vary with season of the year; biennial surveys are usually started in March and completed in June.

Because of the short time period for producing reports, ratings must be started as early as possible to develop the budget for the following year. In Utah, the data collection process is usually started in May so that reports can be ready by November. Improved data collection and processing techniques would considerably reduce the time required to collect data and prepare reports.

TABLE 15

EQUIPMENT PROBLEMS

Agency	Ride Meters	Deflection	Skid Equipment
ARIZONA	Ride-meter data varies with car suspension, or from year to year. Currently experimenting with a laboratory calibration device.	Dynamic load for the Dynaflect varies from machine to machine. Downtime has been a problem. Back-up equipment is recommended.	No reported equipment problems.
CALIFORNIA	Ride-meter data varies from year to year.		
FLORIDA	Ride-meter data varies from year to year. Standard calibration is needed.		No reported equipment problems.
NEW YORK	No problems with present system. Year-to-year variations with car suspension accounted for through calibration process.		
ONTARIO	Calibration of ride meters to ensure consistent results.	Used only when overlays are needed and for monitoring on a selected basis. No problems.	
PENNSYLVANIA	No reported problems with ride meters.	Road Rater is not used on concrete pavements or asphalt pavements with cement-treated base.	
U.S. Air Force (CERL)	No problems reported.	No problems reported.	No problems reported.
UTAH	Ride equipment needs to be calibrated periodically.	Dynaflect deflection equipment needs to be calibrated periodically. Equipment maintenance is a problem.	Mu-Meter must be calibrated periodically.
WASHINGTON	No problems reported.	No problems reported.	No problems reported.

TABLE 16

MANPOWER PROBLEMS

AGENCY	REPORTED PROBLEMS
ARIZONA	(1) Training of personnel (inconsistent data) (2) Obtaining sufficient staff (3) Motivation
CALIFORNIA	(1) Training of personnel (inconsistent data) (2) Motivation
FLORIDA	(1) Training of personnel (inconsistent data) (2) Frequent personnel changes
NEW YORK	(1) Training of personnel (data quality)
ONTARIO	(1) Shortage of manpower to conduct surveys (2) Training of personnel (inconsistent data)
PENNSYLVANIA	(1) Motivation (2) Scheduling
U. S. Air Force (CERL)	(1) None reported
UTAH	(1) Training of personnel (periodic review) (2) Obtaining sufficient staff
WASHINGTON	(1) Training of personnel (inconsistent data)

Data Processing

Problems have been noted in the following areas:

- Time requirements,
- Referencing techniques,
- Variations in pavement ratings from year to year, and
- Need for computer specialists.

Table 17 summarizes by agency the types of data processing problems reported. Three agencies (Arizona, Ontario, and Utah) report that the time required to process and report the data needs to be shortened. Automation would definitely shorten the time required for processing and improve the chance for acceptability by management.

Referencing of data was reported to be a problem in Utah and Washington. Difficulties can arise if the positions of mileposts change because of road realignment. A milepost equation in the computer program can alleviate this problem.

Pavement ratings can vary from year to year as a result of equipment and/or procedures used. During the development of the pavement rating system in Washington, variation of data from one year to the next was found to be a significant problem. This has become less of a problem because of improved equipment and procedures, but could cause difficulty for an agency just beginning to develop a rating system.

Finally, several states (Arizona, California, Pennsylvania, Washington) indicate that data processing requires a knowledgeable computer specialist. Other agencies indicate that access to computer systems has been limited.

FURTHER OBSTACLES

Not all problems are associated with data collection and processing. Additional difficulties occur in the areas of implementation and communication.

Implementation

Collecting and processing data appear to be less of a problem than getting people to use the data in making decisions. The most effective use of pavement data is made by those agencies that have the support of top-level management. Without total support by management, any program would be difficult to implement. Suggestions to ensure the effective use of data include:

1. Clearly define goals and objectives for the data collection effort or its elements.
2. Establish an organization to involve the needed disciplines (research, design, construction, maintenance, policy, and programming).
3. Provide clear documentation of work achieved and show the expected benefits.

TABLE 17

DATA PROCESSING PROBLEMS

Agency	Problems
Arizona	(1) Excessive time requirements (2) Need for computer specialist
California	(1) No problems reported, but need a computer specialist to manage data.
Florida	(1) No problems reported
New York	(1) No problems reported
Ontario	(1) Data processing at central office causes access by regions to be slow
Pennsylvania	(1) Need a computer specialist to manage data. (2) Independance of different units makes it difficult to coordinate all available data
U.S. Air Force (CERL)	(1) No problems reported
Utah	(1) The time frame to get reports out is short (2) Data processing would be improved if automated (3) Milepost changes lead to difficulties in comparing results from one year to another
Washington	(1) Aligning pavement ratings from year to year (2) Coordinating all data files (3) Milepost changes can lead to difficulties

4. Budget properly to get work done (both time and money).
5. Involve top-level management at an early date and obtain a long-term commitment.
6. Obtain, update, and modify, as necessary, feedback to design, construction and maintenance to assure that the data are usable.

Communication

To attain early success, communication at all levels is necessary. All parties in the development process must be involved.

1. Involve the users of the information. Find out what output is needed to make decisions and the level of detail required.
2. If the system is centralized, ensure that all districts and divisions feel they are involved in the development of the program.
3. Determine that the program is flexible and can accommodate changing attitudes.

IMPACT OF PAVEMENT CONDITION DATA ON PAVEMENT MANAGEMENT COSTS

Although much effort has been devoted to the development of data collection and processing procedures, little has been done to show the impact of this effort on costs of pavement management.

In order to involve more people in pavement evaluation (and pavement management), evidence is needed that pavement data collection and processing systems have a positive, beneficial impact. The existing systems cost from $200,000 to $500,000 to develop and from $100,000 to $200,000 or more per yr to operate. The savings that accrue to the agencies from the use of such systems must be demonstrated. Only two agencies (California and New York) require pavement ratings for the allocation of maintenance dollars.

Answers are needed to the following questions:

- How can the impact of pavement condition data (or cost effectiveness) be determined?
- Are existing systems affecting the management of pavements in a positive manner? If so, what savings or benefits can be expected?

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions are based on the current practices of a selected group of agencies for collecting pavement condition data used in maintenance and/or rehabilitation decisions.

1. Most of the agencies surveyed collect ride and/or distress data to inventory road systems. Deflection data are used routinely by only one of the nine agencies surveyed. Skid resistance data are considered separately for safety. The specific types and methods of data collection vary with each agency.

2. Ride, deflection, and skid resistance data are collected with equipment; distress data are obtained from visual surveys. Most of the information is hand-processed for computer storage for use in making maintenance and/or rehabilitation decisions. Of the agencies interviewed, only New York has a fully automated data collection and processing system (roughness).

3. The data are normally used to develop:

- Yearly work programs. The projects that need to be maintained first.
- Yearly action plans. The maintenance or rehabilitation strategies needed for the identified projects.
- Future budgets to maintain pavements at a given condition.
- Future condition given a fixed budget.

4. Most of the agencies evaluate pavement condition on an annual, biennial, or triennial basis.

5. The costs of data collection and processing range from $12 to $50 per center-line mile ($7 to $15/km). Program development costs range from $200,000 to $500,000.

6. Numerous data collection and processing problems have been identified. Most can be overcome through careful planning and good engineering. Perhaps the most significant problem concerns implementation. Implementation is not possible without top-level management support and the knowledge that the collected, processed, and reported condition data are meeting a genuine need in the management of pavements.

7. The current practices with respect to the collection and use of pavement condition data are dynamic and undergoing constant change in an attempt to approach true pavement management. This trend is expected to continue.

RECOMMENDATIONS

For agencies about to embark on a program for the collection and use of pavement condition data, the following procedures are recommended:

1. *Develop improved data collection processes.* Reliable high-speed methods are needed to reduce data collection costs. New equipment should be fully automated to reduce processing time. Rational decisions cannot be made without meaningful data; data should be continually evaluated in order to attain consistency.

2. *Develop rational sampling programs.* It may not be feasible to sample every road each year. If this is the case, sampling programs should be developed accordingly.

3. *Keep data storage and processing as simple as possible.* If pavement condition data are to be used effectively, data processing should be simple and streamlined in order to make the data available for decision making. The data must be easy to access and easy to alter.

4. *Develop useful prediction models.* For systems requiring prediction models, factors that affect performance should be included. Prediction models developed by other agencies are often not transferable.

5. *Demonstrate impact.* An early indication of the benefits of the developed system is important. This has been a weakness in most agencies and may be one reason why more agencies are not systematically collecting and using pavement condition data.

6. *Encourage communication.* The continued involvement of and feedback between developers and users ensures successful implementation of a system. Cooperation is the key and must involve management, research, design, maintenance, etc.

RESEARCH NEEDS

The following topics are recommended for further research and development:

- Development of high-speed cost-effective equipment to enable consistent measurement of surface distress and pavement deflection.
- Improvement in the handling and processing of pavement condition data.
- Definition and demonstration of impact of the use of pavement condition data in an overall system.

REFERENCES

1. Hudson, W. R., R. Haas, and R. D. Pedigo. 1979. Pavement Management System Development. NCHRP Report 215. Transportation Research Board, National Academy of Sciences, Washington, D.C.
2. Haas, R., and W. R. Hudson. 1978. *Pavement Management Systems*. McGraw-Hill, New York.
3. Terrel, R. L., and R. V. LeClerc (Eds.). 1978. *Pavement Management Workshop—Tumwater, Washington*. Report No. FHWA-TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
4. Highway Research Board. 1962. *The AASHO Road Test. Report 5. Pavement Research*. Special Report 61E. Highway Research Board, National Academy of Sciences, Washington, D.C.
5. Highway Research Board. 1970. *Standard Nomenclature and Definitions for Pavement Components and Deficiencies*. Special Report 113. Highway Research Board, National Academy of Sciences, Washington, D.C.
6. Smith, R. E., M. I. Darter, and S. M. Herrin. 1979. *Highway Pavement Distress Identification Manual for Highway Condition and Quality of Highway Construction Survey*. Report for Federal Highway Administration, developed for Contract Nos. DOT-FH-11-9175/NCHRP 1-19. University of Illinois, Urbana, Ill.
7. McCullough, B. F. 1971. Distress mechanisms—general. Pp. 77–85 in *Structural Design of Asphalt Concrete Pavement Systems*. Special Report 126. Highway Research Board, National Academy of Sciences, Washington, D.C.
8. Darter, M. I. 1979. Part I—Executive Summary of COPES. NCHRP Project 1-19. Report available from National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C.
9. Mahoney, J. P., and R. L. Lytton. 1978. *Measurements of Pavement Performance Using Statistical Sampling Techniques*. Report No. FHWA-TX-78-207-2. Texas Transportation Institute, Texas A&M University, College Station, Tex.
10. Shahin, M. Y., and M. D. Darter. 1975. Development of a pavement evaluation system. In: *Proceedings of ASCE Conference on Pavement Design for Practicing Engineers*. American Society for Civil Engineers, New York.
11. The Asphalt Institute. 1969. *Asphalt Overlays and Pavement Rehabilitation*. Manual Series No. 17. The Asphalt Institute, College Park, Md.
12. Moore, W. M., D. I. Hanson, and J. W. Hall. 1978. *An Introduction to Nondestructive Structural Evaluation of Pavements*. Transportation Research Circular No. 189. Transportation Research Board, National Academy of Sciences, Washington, D.C.
13. Bush, A. J. 1979. Nondestructive Testing for Light Aircraft Pavements—Phase I. U.S. Army Waterways Experiment Station, Geotechnical Laboratory.
14. Highway Research Board. 1972. *Skid Resistance*. NCHRP Synthesis of Highway Practice 14. Highway Research Board, National Academy of Sciences, Washington, D.C.
15. Task Force for Pavement Design of the AASHTO Operating Subcommittee on Design. 1976. *Guidelines for Skid Resistant Pavement Design*. American Association of State Highway and Transportation Officials, Washington, D.C.
16. Gramling, W. L., J. G. Hopkins, G. Cumberledge, A. Bhajandas, and R. M. Nicotera. 1978. *Pavement Condition Measurement Needs and Methods, Final Report*. Report No. FHWA-RD-79-68. Pennsylvania Department of Transportation.
17. Gillespie, T. D., M. W. Sayers, and L. Segel. 1980. *Calibration and Correlation of Response-Type Road Roughness Measuring Systems*. NCHRP Report 228. Transportation Research Board, National Academy of Sciences, Washington, D.C.
18. Way, G. B. 1978. Arizona pavement management systems: pavement monitoring summary. Pp. 60–71 in Report No. FHWA-TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
19. Finn, F. N., R. Kulkarni, and J. McMorran. 1976. *Development of Framework for a Pavement Management System*. Report No. RS 14 (161)-1 by Woodward Clyde Consultants. Arizona DOT.
20. Eisenberg, J. 1978. Decision criteria for the Arizona DOT pavement management information system (PMIS). Pp. 72–80 in Report No. FHWA-TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
21. Way, G. B. 1979. Implementation of ADOT's Pavement Management System (PMS). Research Projects Underway, Arizona Conference on Roads and Streets, 28th Annual Meeting, April 18–19, 1979. University of Arizona, Tucson, Ariz.
22. Kulkarni, R., K. Golabi, K. Finn, and E. Alviti. 1980. *Development of Network Optimization System*. Final report by Woodward Clyde Consultants. Report No. FHWA/AZ-80/155A&B. Arizona DOT.
23. Way, G. B., and J. Eisenberg. 1980. *Verification of Performance Prediction Models and Development of Data Base, Phase II, Arizona Pavement Management System*. Report No. FHWA/AZ-80/169. Arizona Department of Transportation.
24. Bartell, C., and K. Kampe. 1978. *Development of the California Pavement Management System*. Vol 1. *System Description*. Report No. FHWA-CA-HM-7139-78-03. California Department of Transportation.

25. Boucher, F. 1978. *Development of the California Pavement Management System*. Vol. 2. *Manual of Rating Instructions*. Report No. FHWA-CA-HM-7139-78-03. California Department of Transportation.
26. Smith, L. L. 1978. Flexible pavement monitoring in Florida. Pp. 122–135 in FHWA TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
27. Florida Department of Transportation. 1976. Instructions and Procedures for the Flexible Pavement Condition Survey.
28. Florida Department of Transportation. 1978. Instructions and Procedures for the Rigid Pavement Condition Survey.
29. Sharma, J. 1978. Pavement management in Florida (decision criteria). Pp. 136–193 in FHWA TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
30. Weaver, R. J., and J. M. Newman. 1978. The dream versus the reality of a pavement management system. Pp. 267–293 in FHWA Report TS-79-206, Federal Highway Administration, Department of Transportation, Washington, D.C.
31. Weaver, R. J. 1979. Quantifying pavement serviceability as it is judged by highway users. Pp. 37–44 in *Pavement Distress, Evaluation, and Performance*. Transportation Research Record 715. Transportation Research Board, National Academy of Sciences, Washington, D.C.
32. Soil Mechanics Bureau. 1978. The Condition of New York's Pavements—Second Annual New York Summary: January, 1977. New York DOT.
33. Chong, G. J., W. A. Phang, and G. A. Wrong. 1975. *Manual for Condition Rating of Flexible Pavements—Distress Manifestations*. Ontario Ministry of Transportation and Communications.
34. Phang, W. A. 1978. Predicting performance of asphalt overlays in programming rehabilitation. Pp. 294–323 in FHWA Report TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
35. Phang, W. A. 1979. Pavement-condition ratings and rehabilitation needs. Pp. 11–19 in *Pavement Evaluation and Overlay Design: A Symposium and Related Papers*. Transportation Research Record 700. Transportation Research Board, National Academy of Sciences, Washington, D.C.
36. Phang, W. A. Pavement Management in Ontario—1980. Paper presented at the FHWA/TRB Pavement Management Workshop, May 1980, Phoenix, Arizona.
37. Poister, T. H., and W. R. Moyer. 1980. The Pennsylvania DOT trained observer survey: design and preliminary results. Pp. 45–56 in *Maintaining the Maintenance Management System*. Transportation Research Record 781. Transportation Research Board, National Academy of Sciences, Washington, D.C.
38. Cumberledge, G., and A. C. Bhajandas. 1980. Pavement Condition Measurement Unit—Capabilities and Cost of Operation. Draft report. Pennsylvania DOT.
39. Shahin, M. Y., M. I. Darter, and S. D. Kohn. 1979. Evaluation of airfield pavement condition and determination of rehabilitation needs. Pp. 1–10 in *Pavement Evaluation and Overlay Design: A Symposium and Related Papers*. Transportation Research Record 700. Transportation Research Board, National Academy of Sciences, Washington, D.C.
40. Shahin, M. Y., and F. M. Rozanski. 1978. Development of a computerized system for pavement maintenance management. Pp. 3–11 in *Maintenance Decision Making and Energy Use, Roadside and Pavement Management, and Preferential Bridge Icing*. Transportation Research Record 674. Transportation Research Board, National Academy of Sciences, Washington, D.C.
41. Shahin, M. Y., M. I. Darter, and S. D. Kohn. 1978. Pavement condition evaluation of asphalt surfaced airfield pavements. Pp. 190–228 in *Proceedings of the Association of Asphalt Paving Technologists*. Vol. 47. Army Construction Engineering Research Laboratory, University of Minnesota.
42. Anderson, D. I. 1978. Utah's pavement survey. Pp. 423–458 in FHWA-TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.
43. Anderson, D. I., and D. E. Peterson. 1979. Pavement Rehabilitation Design Strategies. Draft final report. FHWA UT-79/6. Utah Department of Transportation.
44. Nelson, T. L., D. B. House, H. E. Sandahl, and R. V. LeClerc. 1978. Washington pavement management system. Pp. 459–523 in FHWA-TS-79-206. Federal Highway Administration, Department of Transportation, Washington, D.C.

APPENDIX A

ARIZONA—CURRENT PRACTICE

The following information was obtained at a meeting with George B. Way, John Eisenberg, and John C. Burns of the Arizona Department of Transportation in December 1978, and was reviewed by George B. Way in March 1980.

TYPES OF DATA COLLECTED

Four basic types of data are currently collected to monitor approximately 6,200 mi of paved roadway (200 mi are portland cement concrete). The monitoring system includes the following measurements of distress (*18*): ride, skid resistance, deflection, and cracking.

Ride

In 1972 the DOT began using a Mays meter to monitor the state highway system. At the present time, the roughness of every mile of state highway is measured annually. It takes about 3 months to physically inventory the entire 6,200 mi of highway and an additional 3 months to interpret the data. The roughness is recorded on a strip chart recorder that requires considerable data processing. Conversion to a microprocessing unit is planned in the near future.

Skid Resistance

Since 1973 skid tests have been conducted with a Mu-Meter—an English device that measures the side friction force generated between the test surface and two pneumatic tires set at a fixed angle to the line of drag.

The output of the test is recorded on a strip chart. The recorder image represents the skid number sensed by the device as it is dragged across the pavement. Tests are currently performed at each milepost of the state highway for a distance of about 500 ft. For each test the high, low, and average skid numbers are determined and recorded. The number is determined in both directions for all roads but only for the inside wheel track of the outer lane of freeways. The physical inventory requires about 4 months to complete; data reduction and entry into computer storage require another 4 months. It is hoped that a more efficient method of converting the analog data to digital form can be implemented.

Deflection

The Dynaflect has been used to monitor deflection since 1972. This device is a dynamic force generator that imparts a 1,000-lb oscillating load to two steel wheels. Five geophone sensors are used to record the deflection. Each geophone deflection is recorded on a coding form as the test is being conducted in the field. The deflection inventory consists of measuring deflection every 1 mi as well as every ⅓ mi; thus three deflection tests per mile are recorded. The Dynaflect is used in the outer wheel track of the outer lane in both directions. Approximately 2.5 yr is required to complete the deflection inventory for the entire state system. Coding work takes approximately 3 more months. Starting in 1980, the Dynaflect is to be used for design only.

Cracking

A cracking and rutting survey was initiated in 1973. In this procedure, at each milepost the rater selected a 1,000-ft^2 area and recorded cracking information in terms of area cracked and length and width of cracks. This process was laborious and the resulting data log too complicated. No further distress inventories were attempted until 1977 when a new crack rating guide was developed. This guide made use of information generated during the course of a research project on reflective cracking. In this project, cracked highways were photographed, the percent cracking was determined by a method developed in the study, and a cracking guide was developed that was used by raters to estimate percent cracking. The cracking guide is shown in Figure A-1. To use the guide, the rater observes the pavement cracking condition and selects the photograph that most closely matches the pavement condition. Two crews are capable of evaluating the entire system within 4 months.

DATA REDUCTION AND STORAGE

Pavement inventory data are hand-reduced on standard coding forms keyed to milepost, keypunched, and edited before filing in the computer. Table A-1 summarizes the data records since 1972. Research is under way to develop an automated system for the Mu-Meter to record skid numbers, location, and direction of traffic on a cassette tape. The data would be directly entered into computer storage, thus reducing the amount of hand labor necessary to complete the annual inventory.

TABLE A-1

SUMMARY OF DATA RECORDS SINCE 1972

Property	Number of Data Records
Ride	60,000
Skid	35,000
Deflection	69,000
Cracking	25,000
Rutting	5,000

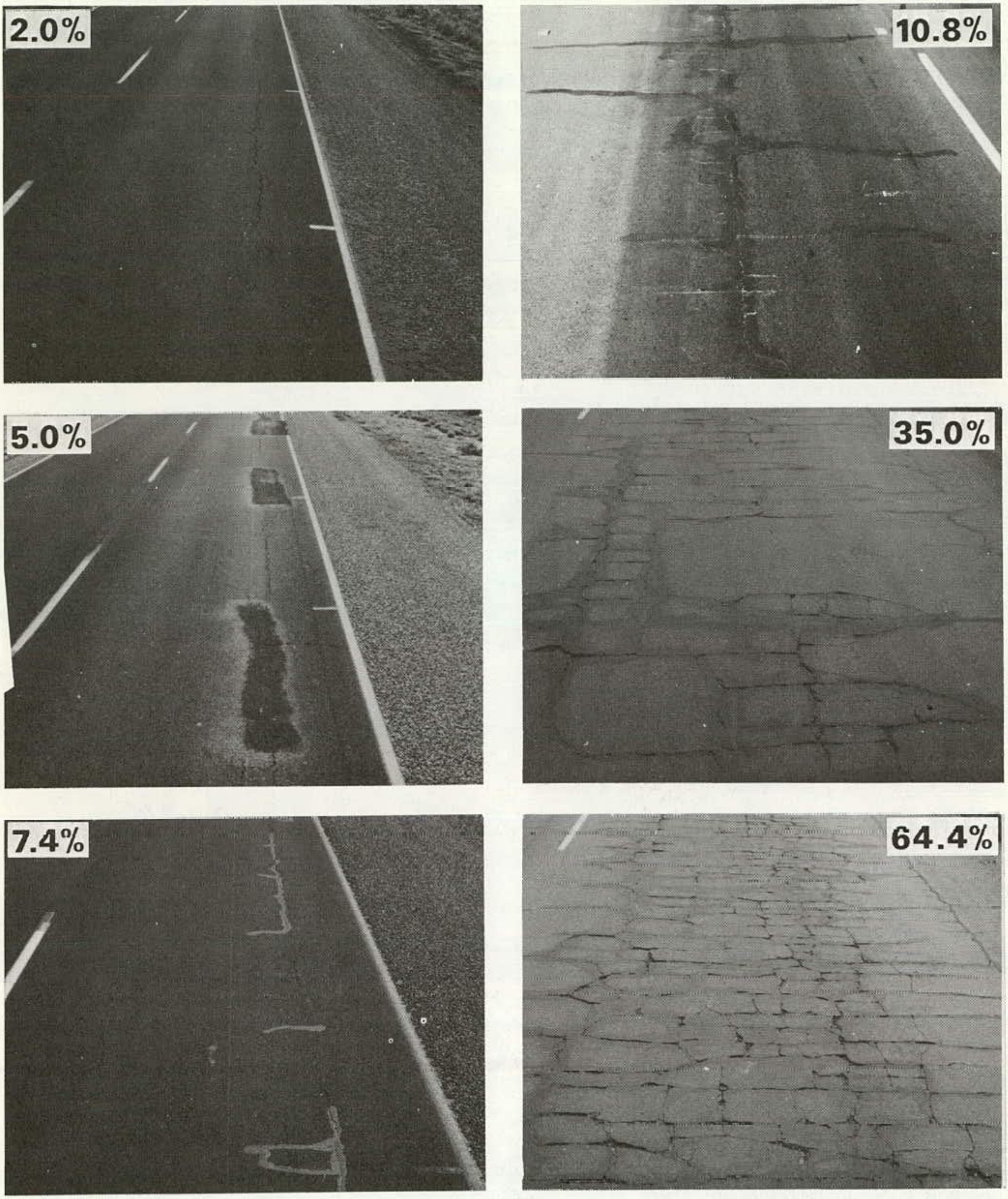


FIGURE A-1 Cracking guide (Arizona).

TABLE A-2

ESTIMATED COSTS

	1978 - 79[a]	1979 - 80
Personnel		$190,000
Travel		43,000
Equipment Rental		38,000
Other		15,000
Data Processing		12,000
Indirect Costs		15,000
	$260,000 about $42/mile	$313,000[b] about $50/mile

[a] Breakdown of costs not available.

[b] Estimated breakdown for 6,200 miles: 50% Dynaflect, 15% skid resistance, 10% ride, and 25% distress.

The DOT has been able to complete the annual inventory for ride each year. Inventories for skid, deflection, and cracking have been fully completed for only 1 yr. Partial inventories of these measurements range from essentially no data to as much as 75 percent of the system.

The estimated costs for the data collection and data reduction are shown in Table A-2. Costs are calculated to be approximately $50 per mile. Approximately 50 percent of the total costs is for Dynaflect measurements, completed on about 40 percent of the roads; 15 percent is for skid, completed on about 75 percent of the roads; and 10 percent is for the Mays meter, completed on 100 percent of the roads. Future costs of inventory and monitoring of the roads are expected to increase about 10 to 15 percent per yr. Seventy percent of the funding is provided by the HP & R monies.

PROBLEMS ENCOUNTERED

1. The ride meter data vary considerably depending on the suspension of the car used. Test sections were developed to calibrate these systems, but even the test sections included some variations. As the cars change from year to year, this expected difference is taken into account through the test sections. The DOT is now experimenting with a bump simulator for calibrating vehicles in the laboratory.

2. The Dynaflect is not always calibrated, and its weight and subsequent dynamic loading may vary from machine to machine. Downtime has also been a problem with the Dynaflect. The cost of upkeep runs about $20,000 per yr for parts and labor. Backup equipment is recommended.

3. The effects of seasonal variations on calibration can be a problem, particularly with the Mays meter. These effects must be considered and emphasize the need for developing a laboratory system for calibrating ride meters.

4. Although training of personnel has not been a serious problem, obtaining sufficient staff to operate the total system has been an issue. With respect to training, it is important to eliminate rater subjectivity as much as possible and provide some method of motivating personnel to ensure that the data are collected in an efficient manner. Workweeks of 4 10-hr days have been suggested.

5. It takes longer to reduce the data than to obtain the data. The time period needs to be shortened if the data are to be collected during the summer for use in planning the next fiscal year's budget.

SAMPLING PROGRAM

Approximately 6,200 mi of road are monitored each year. Ride meters are used to monitor roads continuously on an annual basis. The actual mileage and the portion of mileage tested are given in Table A-3.

To collect skid resistance data, 500 ft per mile is tested annually in both directions on two-lane highways and freeways (the outer lane only). About two-thirds of the total system can be covered each year. For deflection and cracking data, three tests per mile are conducted. Only 40 percent of the total mileage is completed each year.

TABLE A-3

NUMBER OF LANE-MILES MONITORED

Property	Mileage Tested	Lane-Miles
Ride	Both directions for freeways (outer lane only); one direction for highways	7,200
Skid	Both directions, inside wheel track, for highways and freeways (outer lane only)	12,000
Deflection	Outer lane, outer wheel track; 3 readings per mile[a]	6,200
Cracking	Three observations per mile (1000-ft^2 area)	6,200

[a] Currently used for design purposes only.

USE OF DATA

Priority Programming

For a number of years, pavement condition data were used for programming purposes to develop a priority score for maintenance and rehabilitation. The priority score currently used is as follows:

$$\text{Priority score} = 40 \log (\text{cracking}) + \frac{100}{\text{Mays meter}} + \text{Dynaflect}$$

$$(\text{Thickness} - 2) + \frac{1000}{\text{Mu-Meter}} + \text{AGE} + \frac{\text{ADT}}{500}.$$

Each project is rated for condition, and priorities are established according to the above formula. This priority-ranking formula has been used since 1972 to identify yearly needs. Once identified, more intensive studies are undertaken to assess what type of maintenance is needed.

TABLE A-4

PAVEMENT PERFORMANCE PREDICTION MODELS (*23*)

For New or In-Service Pavements

PSI = f (Region or Environment, Deflection, Age, Traffic)

For Overlays

PSI = f (Region or Environment, Heater Scarification or Rubber Membrane, Age, Deflection, Traffic, Thickness)

For All Pavements

SN = f (Age, Aggregate type, Region or Environment, Traffic)

Overlay Design

For overlay construction, Dynaflect measurements are used to determine the overlay thickness for a design period of 10 to 20 yr.

Designers review ride and cracking data to determine the need for a leveling course and/or special treatment to prevent reflective cracking. If a highway has poor ride quality, the designer will probably design for a leveling course 1 to 3 in. thick. If cracking is greater than 10 percent, special treatment, such as asphalt rubber or heater scarification, will most likely become part of the design.

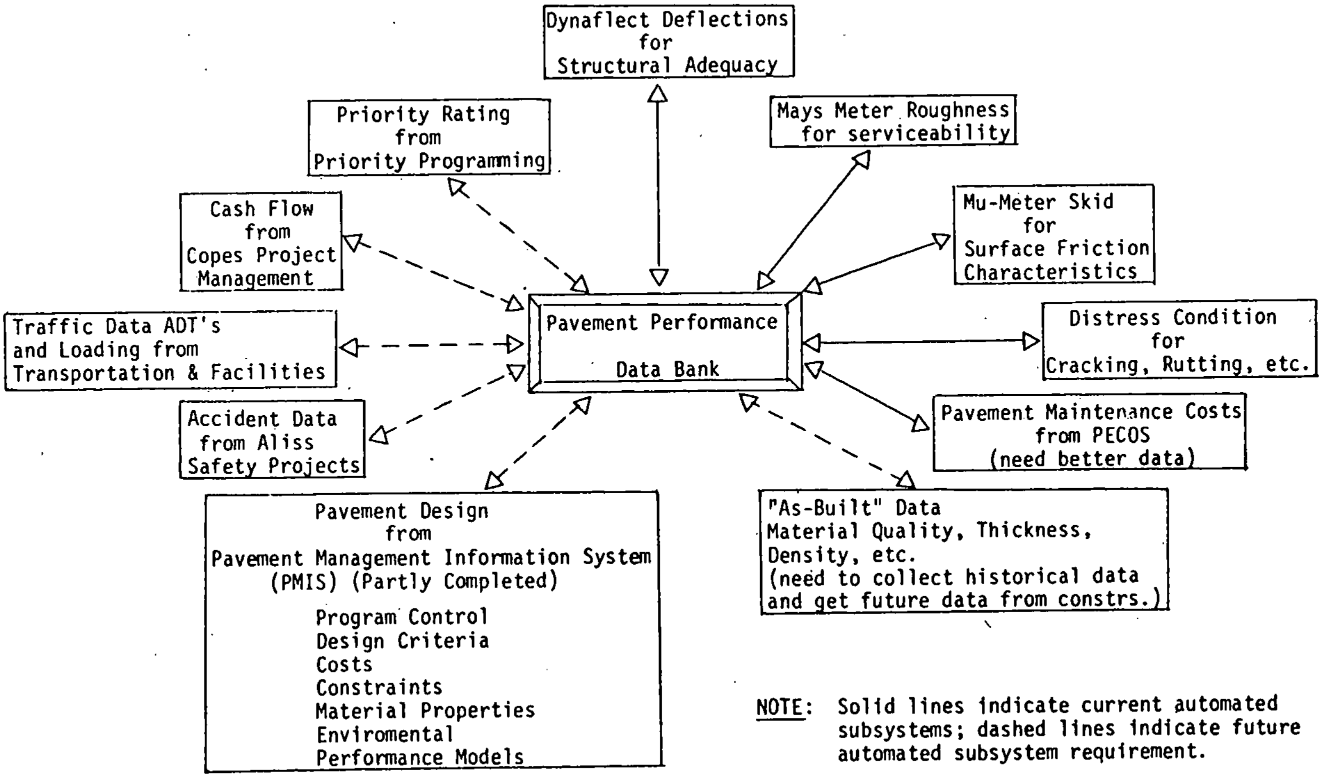
Pavement Management

Since 1975 the DOT has been developing a pavement management information system (PMIS) on the basis that it is possible, through a systematic management methodology, to preserve the condition of state highways at or above an acceptable level at reduced cost (*19–23*). Previous condition data are used to develop prediction equations through regression analysis. These equations predict future roughness (PSI) and skid numbers (SN) from past conditions in addition to traffic, age, region, and thickness (Table A-4).

For a given level of pavement condition, these equations are used to determine the optimal action for each mile of highway for each year. Utility theory is used to rank design and maintenance alternatives. This technique allows the introduction of intuitive judgments directly into the formal analysis. The utility function is multi-attribute (safety, ride, construction, or maintenance and user costs) and represents tradeoffs between conflicting attributes or objectives; e.g., preference for improved riding quality at some acceptable increase in cost.

This method of ranking design and maintenance alternatives has been effective. Its greatest disadvantage is the DOT's unfamiliarity with utility theory. Most engineers are more accustomed to making decisions based on cost. However, the least costly alternative may not always possess the greatest utility. The PMIS ranks alternatives that are in agreement with the district engineers' preferences 90 percent of the time, which greatly enhances the acceptability of the PMIS.

The PMIS is summarized in Figure A-2. The computer



NOTE: Solid lines indicate current automated subsystems; dashed lines indicate future automated subsystem requirement.

FIGURE A-2 Pavement Management Information System.

program developed produces feasible maintenance strategies. The condition of projects would be monitored to check actual performance against the predicted performance. In this way, prediction models can be continuously updated.

At the present time, the PMIS is being implemented on a project-by-project basis and a network optimization system is being developed (*22*). Where federal monies are involved, the PMIS is not utilized to its fullest extent. However, for nonfederal projects, the PMIS is being used as a decision tool with increasing confidence and frequency.

FURTHER OBSERVATIONS

To make effective use of pavement condition data, support of top-level DOT management must be obtained. Management must be kept well-informed on why and how the data are used. Further, the following disciplines are essential to the development of any pavement management system:

- Pavement design and performance,
- Management science, and
- Computer technology.

It is also recommended that the computer program be modular and readily modifiable. District engineers need to be familiar with the uses of pavement condition information and to be aware that although the data cannot replace the judgment of the experienced engineer, the pavement information system can be used to increase the information available for making rational decisions. Other suggestions include:

1. Developing a standard reference for ride;
2. Determining the effects of seasonal variation on measurements, particularly ride quality;
3. Refining the relationship between maintenance costs and distress type; and
4. Collecting as-built pavement data.

APPENDIX B

CALIFORNIA—CURRENT PRACTICE

The following information is based on meetings with C. D. Bartell, Karl Kampe, and Fred Boucher of the California Department of Transportation, and was reviewed by Karl Kampe in April 1980.

TYPES OF DATA COLLECTED

Three types of data are collected to monitor approximately 47,000 lane-miles of roadway: ride, surface distress, and skid resistance. Deflection measurements are made only on selected roadway segments for design purposes.

Ride

Ride quality is measured on all lanes for both flexible and rigid pavements. Bridge approach and leave slab ride ratings are also measured. PCA meters are used for making all ride measurements. The ride score for the traveled way is calculated as follows:

$$\text{Ride score} = \frac{\text{sum of PCA meter counts}}{50 \times \text{odometer length (miles)}} \times \text{vehicle factor.}$$

Ride score is a significant determinant in California's pavement rehabilitation process.

Surface Distress

Distress is determined for both flexible and rigid pavements. The extent and severity of the flexible pavement distress types (see Figure B-1) are determined in the field and then keypunched for storage in a computer.

Surface Deflection

Surface deflection measurements, using the Dynaflect or traveling deflectometer, are not performed on a systematic basis.

Skid

Skid resistance is measured with a skid tester manufactured by K. J. Law, Inc.

DATA REDUCTION AND STORAGE

The data, which include project location, road type, traffic characteristics, etc., are hand-recorded in the field, keypunched, and edited before entry into computer storage.

The estimated program development cost was reported to be $150,000. The estimated biennial cost for data collection is approximately $373,000 ($12 per lane-mile for each biennial survey). Table B-1 presents a detailed cost summary for three recent surveys. All monies used to monitor highways are derived from maintenance administration funds. No federal monies are used.

PROBLEMS ENCOUNTERED

1. Dividing locations into uniform segments is difficult. Flexible pavements are segmented on a job basis and rigid pavements on a 1-mi basis.
2. The flexible and rigid pavement distress rating systems are different; thus it is difficult to compare flexible pavement

PROBLEM	SEVERITY		EXTENT
ALLIGATOR AND BLOCK CRACKING	TYPE		% LENGTH
	A	LONGITUDINAL CRACKING IN WHEEL PATHS ①	1 3
	B	ALLIGATOR CRACKING IN WHEEL PATHS ①	33
	BLK	BLOCK CRACKING IN MAJORITY OF LANE WIDTH	99
	C	SPECIAL OR UNUSUAL ALLIGATOR CRACKING	DESCRIBE & EXPLAIN SEVERITY & EXTENT IN NOTES

PROBLEM	SEVERITY	EXTENT
LONGITUDINAL CRACKING	CRACK WIDTH	LENGTH/STA.
	< 1/8" (HAIRLINE)	≤ 100'
	1/8"-1/4"	200' 300'
	> 1/4"	900'

PROBLEM	SEVERITY	EXTENT
TRANSVERSE CRACKING	CRACK WIDTH (MEAN)	NO. CRACKS/STA.
	< 1/8"	1 2
	1/8"-1/4"	3
	> 1/4"	9

PROBLEM	SEVERITY		EXTENT
RAVEL AND WEATHERING	CONDITION	RATING	% OF LENGTH
	LOSS OF FINE AGGREGATE	FINE	1 3
	LOSS OF COARSE AGGREGATE	COARSE	33 99

PROBLEM	SEVERITY	EXTENT
RUTTING	DEPTH	% OF LENGTH ①
	≥ 3/4"	1 3 33 99

PROBLEM	SEVERITY		EXTENT
PATCHING	QUALITY	RATING	% AREA
	SOUND	GOOD OR FAIR	1 3
	UNSOUND	POOR	33 99

PROBLEM	SEVERITY	EXTENT
DRIP TRACK (RAVEL)	CONDITION	OCCURRENCE/SEC.
	EXISTS	1 2 3 9

① ONE WHEEL PATH CRACKED OR RUTTED THE ENTIRE LENGTH OF SEGMENT = 50% OF LENGTH

FIGURE B-1 Flexible pavement condition rating system.

TABLE B-1

PAVEMENT CONDITION SURVEY COSTS (CALIFORNIA)

	Center-Line Miles			Lane-Miles			1975-1976 Survey		1977-1978 Survey		1979-1980 Survey[a]	
District	Flexible	Rigid	Total	Flexible	Rigid	Total	P.Y.	$	P.Y.	$	P.Y.	$
01 - Eureka	1,008	10	1,018	2,419	40	2,459	0.7	14,000	0.8	25,900	0.4	14,400
02 - Redding	1,548	160	1,708	3,345	580	3,925	0.6	11,000	0.6	20,000	0.5	20,700
03 - Marysville	1,104	360	1,464	2,706	1,510	4,216	1.0	20,000	1.7	50,000	1.1	39,000
04 - San Francisco	1,037	330	1,367	3,600	1,750	5,350	1.2	25,000	1.3	36,600	1.1	36,000
05 - San Luis Obispo	884	180	1,064	2,313	550	2,863	1.0	20,000	0.7	22,000	0.6	44,000
06 - Fresno	1,393	390	1,783	3,270	1,630	4,900	1.2	24,000	0.8	24,200	0.8	30,100
07 - Los Angeles	743	730	1,473	2,285	5,330	7,615	4.2	83,000	3.5	125,300	1.6	47,000
08 - San Bernardino	1,479	150	1,629	4,336	1,040	5,376	1.1	22,000	0.3	12,000	0.7	20,000
09 - Bishop	908	60	968	2,016	230	2,246	0.6	11,000	0.3	9,500	0.4	9,600
10 - Stockton	1,321	280	1,601	3,115	1,170	4,285	1.2	24,000	1.0	35,000	0.7	21,600
11 - San Diego	994	260	1,254	2,756	1,560	4,316	1.2	23,000	0.6	18,000	0.6	16,000
Headquarters	-	-	-	-	-	-	2.5	50,000	1.0	38,500	1.1	44,300
Data Processing	-	-	-	-	-	-	1.8	35,000	1.5	29,500	1.3	30,000
Totals	12,419	2,910	15,329	32,161	15,390	47,551	13.3	362,000	14.1	446,500	10.9	372,700

[a] Estimated cost (survey underway). P.Y. = person-years.

	PROBLEM TYPE	PRIORITY CATEGORY		
		ADT RANGE		
		> 5,000	1,000 to 5,000	< 1,000
RIDE ≥ 45	MAJOR STRUCTURAL PROBLEM AND BAD RIDE Flex: Allig.B = 11-29% & Patch > 10% or Allig.B ≥ 30% Rigid: 3rd Stg. Crk. ≥ 10%	①	②	⑪
	MINOR STRUCTURAL PROBLEM AND BAD RIDE Flex: Allig.B = 11-29% & Patching ≤ 10% Allig.B ≤ 10% & Patching > 10%	③	④	⑫
	BAD RIDE ONLY	⑤	⑥	☒
RIDE < 45	MAJOR STRUCTURAL PROBLEM ONLY Flex: Allig.B = 11-29% & Patch > 10% or Allig.B ≥ 30% Rigid: 3rd Stg. Crk. ≥ 10%	⑦	⑧	⑬
	MINOR STRUCTURAL PROBLEM ONLY Flex: Allig.B = 11-29% & Patching ≤ 10% Allig.B ≤ 10% & Patching > 10%	⑨	⑩	⑭

FIGURE B-2 New reconstruction program-priority system. Note: Ties are broken by $(1,000)/mi/ADT (e.g., unit cost per unit of traffic service).

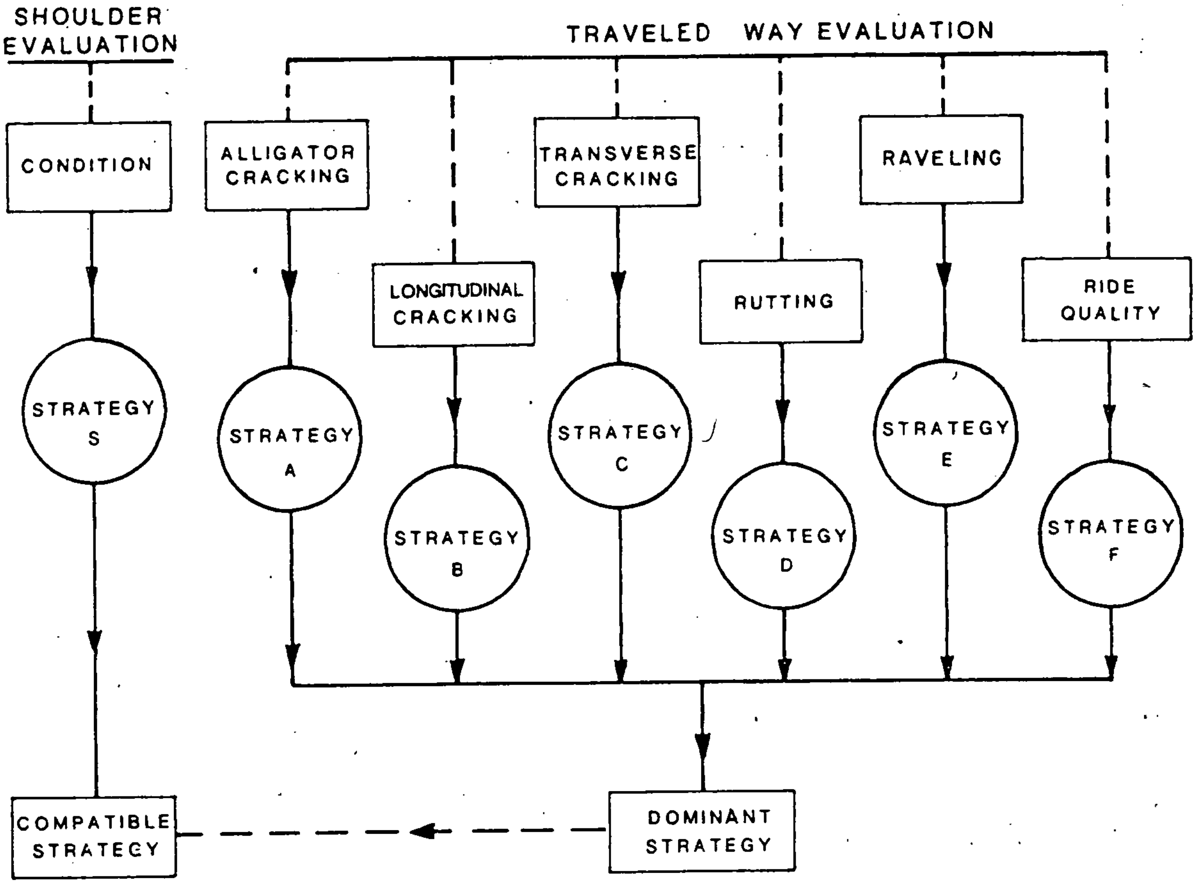


FIGURE B-3 Defect evaluation procedure for flexible pavement.

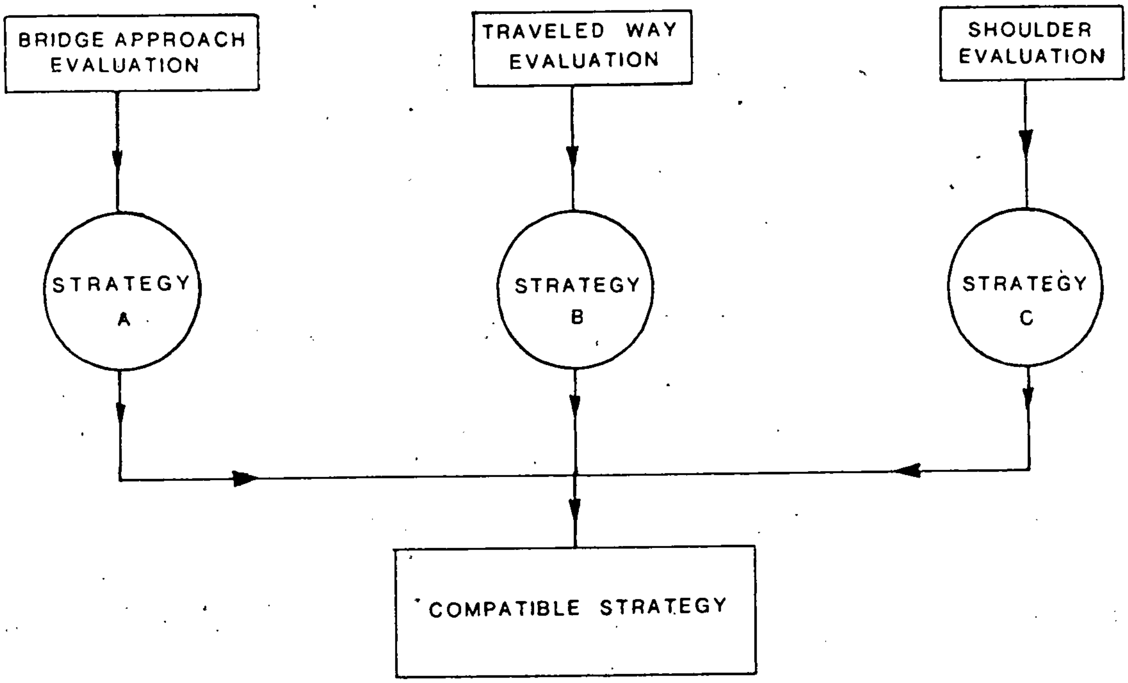


FIGURE B-4 Defect evaluation procedure for rigid pavement.

problems with rigid pavement problems (e.g., in making project tradeoffs between rigid and flexible pavement problem locations).

3. The use of visual observations, instead of a mechanistic rating process, and the selection by raters of typical sample sites produce some variance in data. (This is not considered a serious problem.)

4. Thorough training of personnel and periodic quality monitoring are needed to ensure consistent data. The repetitive nature of the job makes motivation of personnel difficult.

SAMPLING PROGRAM

Each lane-mile of both flexible and rigid pavements is surveyed every 2 yr. It is estimated that approximately 30 lane-miles of pavement can be evaluated daily by one rater. The first statewide flexible pavement survey (about 30,000 lane-mi) was conducted in 1969, and the first rigid pavement survey (about 15,000 lane-mi) was conducted in 1976.

USE OF DATA

The data are used primarily to select both candidate project locations and approximate pavement rehabilitation strategies for the state-maintained highway network (*24, 25*). Summary reports are produced in both standardized and exception formats. The standardized reports include:

1. Inventory of pavement conditions for each lane-mile of pavement.
2. Approximate rehabilitation strategy for each lane of a pavement location.
3. Candidate location lists for all pavements requiring repair or rehabilitation with generalized cost estimates.
4. Priority list of all rehabilitation locations for each district (Figure B-2).

The selection of rehabilitation strategies is keyed to specific types and measures of distress and ride quality. An overview of this procedure is shown in Figures B-3 (flexible) and B-4 (rigid). The dominant strategy (the one that will correct all defects) required by any one distress type is selected. The selection of various rehabilitation strategies for flexible pavements is shown for alligator/block cracking (Figure B-5), longitudinal and transverse cracking (Figure B-6), rutting (Figure B-7), raveling and weathering (Figure B-8), and ride quality (Figure B-9). Corresponding rigid pavement rehabilitation strategies are a function of distress or ride data observed in the traveled way, bridge approaches, or shoulder. Traveled-way rehabilitation strategies are determined by use of slab breakup, ride score, crack spalling, and other factors (Figure B-10). Rehabilitation strategies for bridge approaches and shoulders are shown in Figures B-11 and B-12, respectively.

FURTHER OBSERVATIONS

Future needs include: (a) a rapid technique for measuring severity of faulting; and (b) rating of freeway ramps and collection roads.

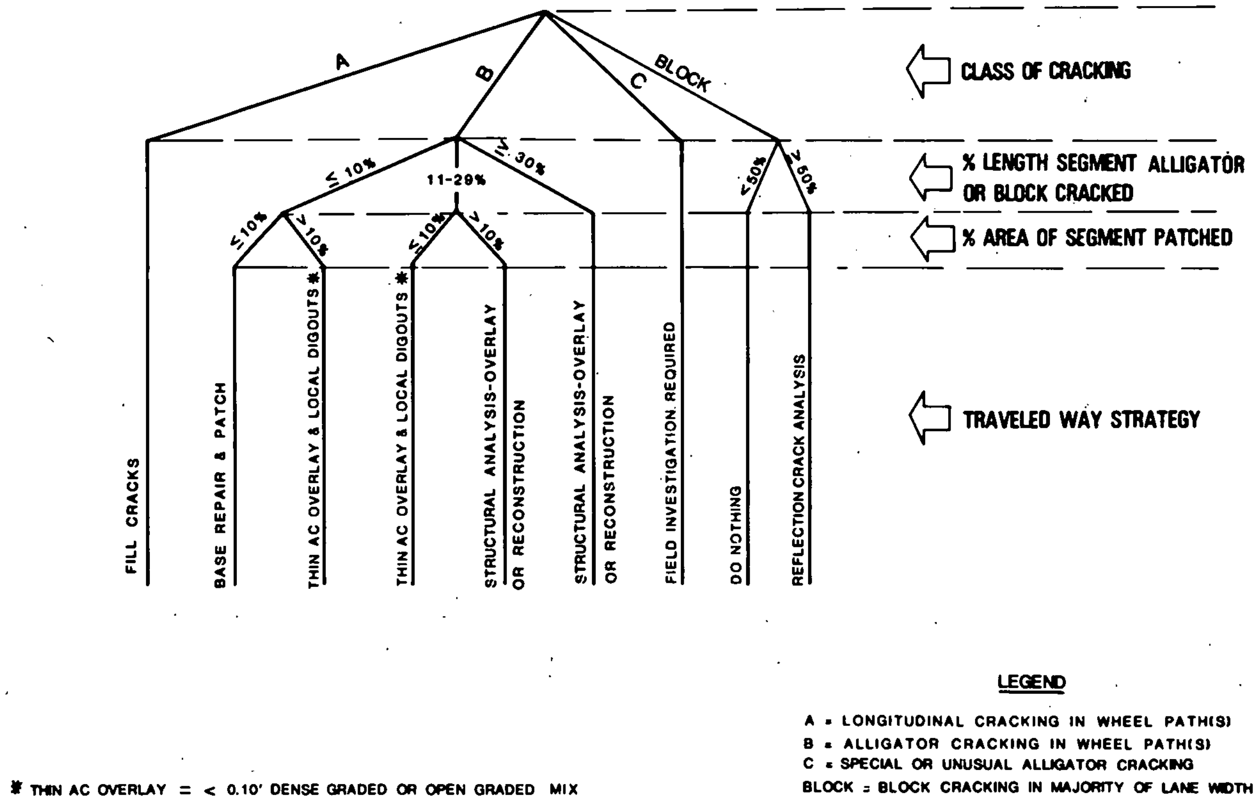


FIGURE B-5 Rehabilitation strategy for flexible pavement with alligator/block cracking.

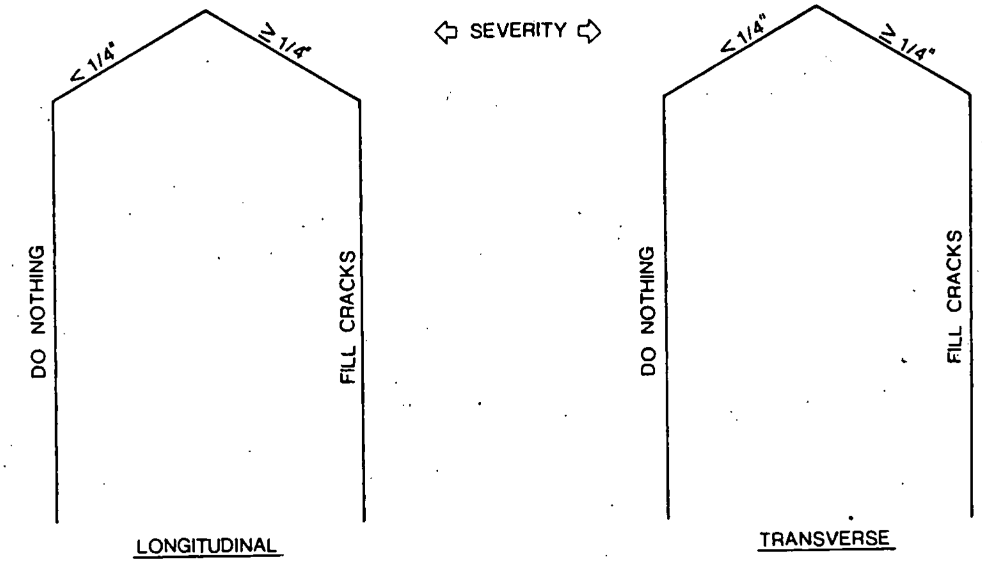


FIGURE B-6 Rehabilitation strategies for flexible pavement with longitudinal and transverse cracking.

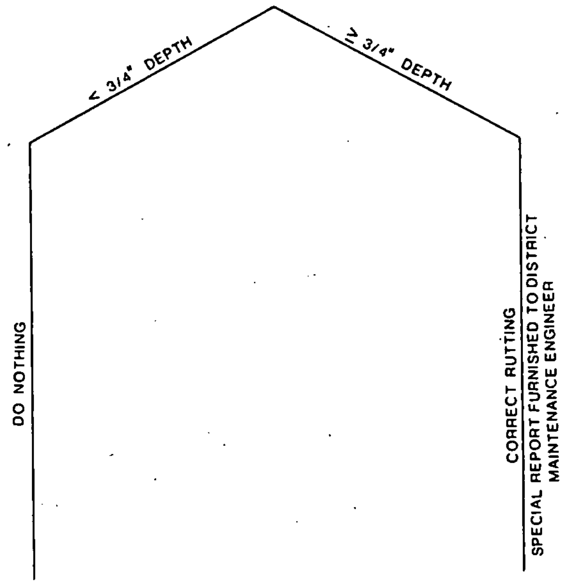
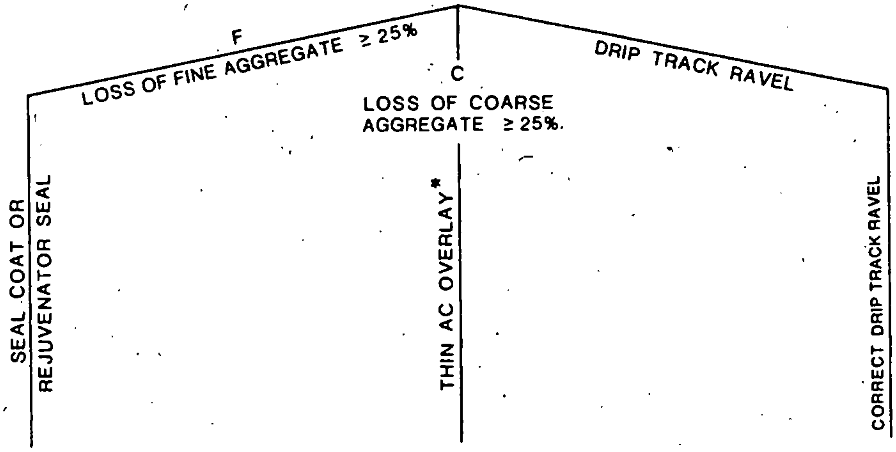
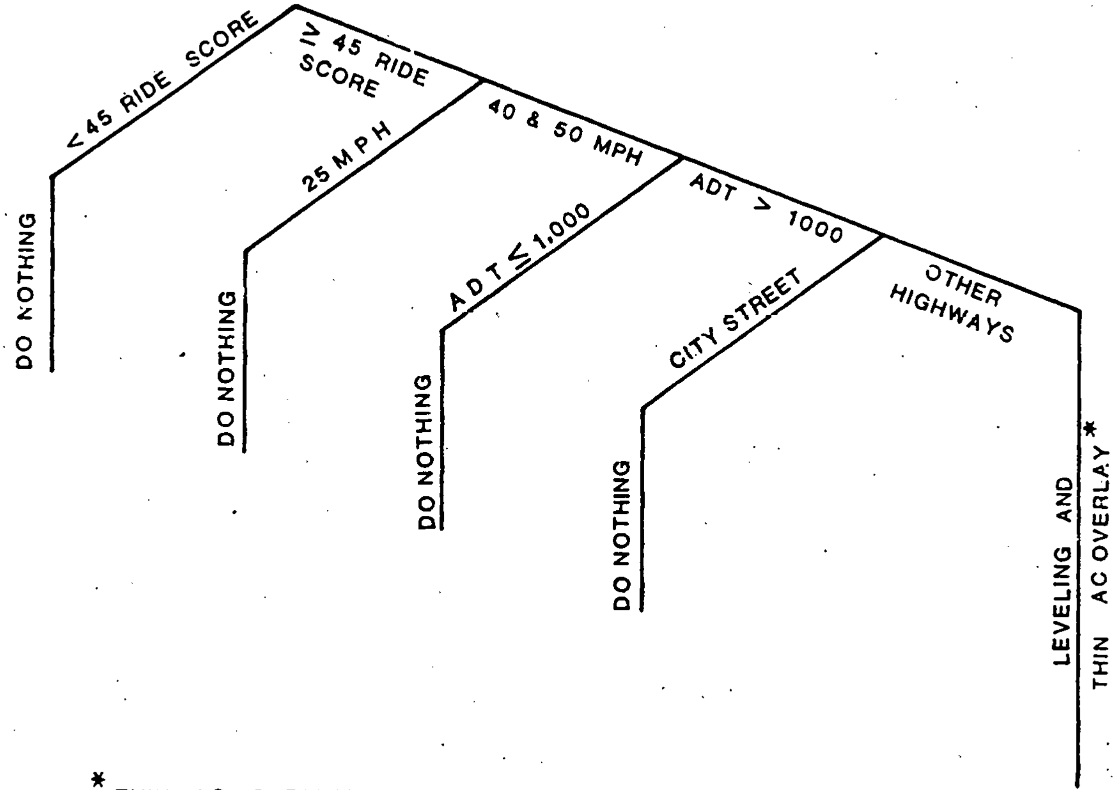


FIGURE B-7 Rehabilitation strategy for flexible pavement with rutting.



*THIN AC OVERLAY =< 0.10' DENSE GRADED OR OPEN GRADED MIX

FIGURE B-8 Rehabilitation strategy for flexible pavement with raveling and weathering.



* THIN AC OVERLAY = < 0.10′ DENSE GRADED OR OPEN GRADED MIX

FIGURE B-9 Rehabilitation strategy for flexible and rigid pavements based on ride quality.

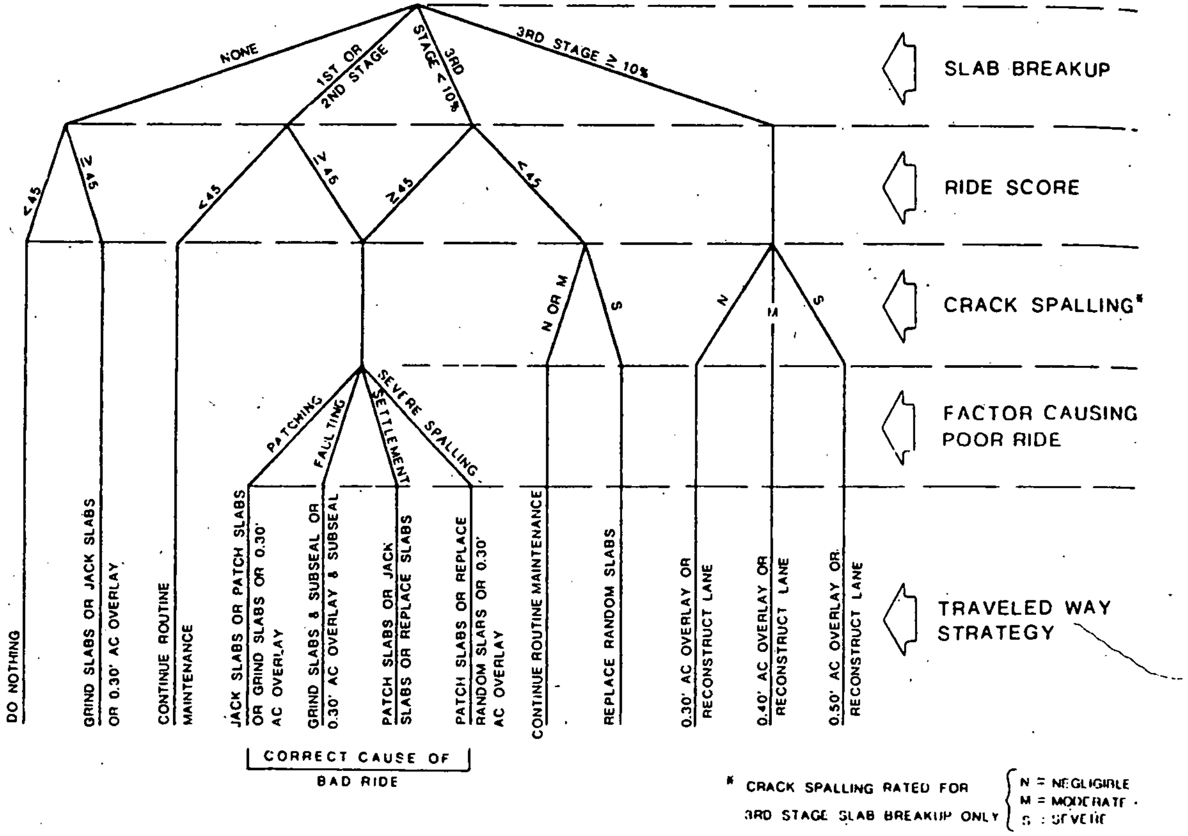


FIGURE B-10 Traveled-way maintenance rehabilitation strategy for rigid pavement.

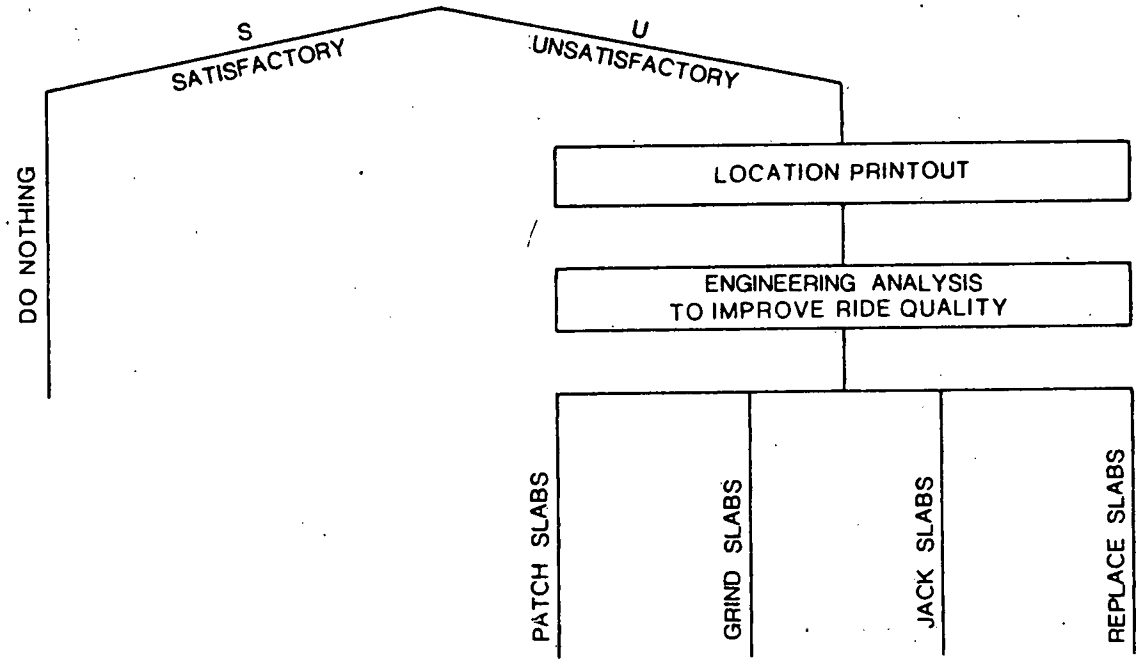


FIGURE B-11 Bridge approach maintenance and rehabilitation strategy for rigid pavement.

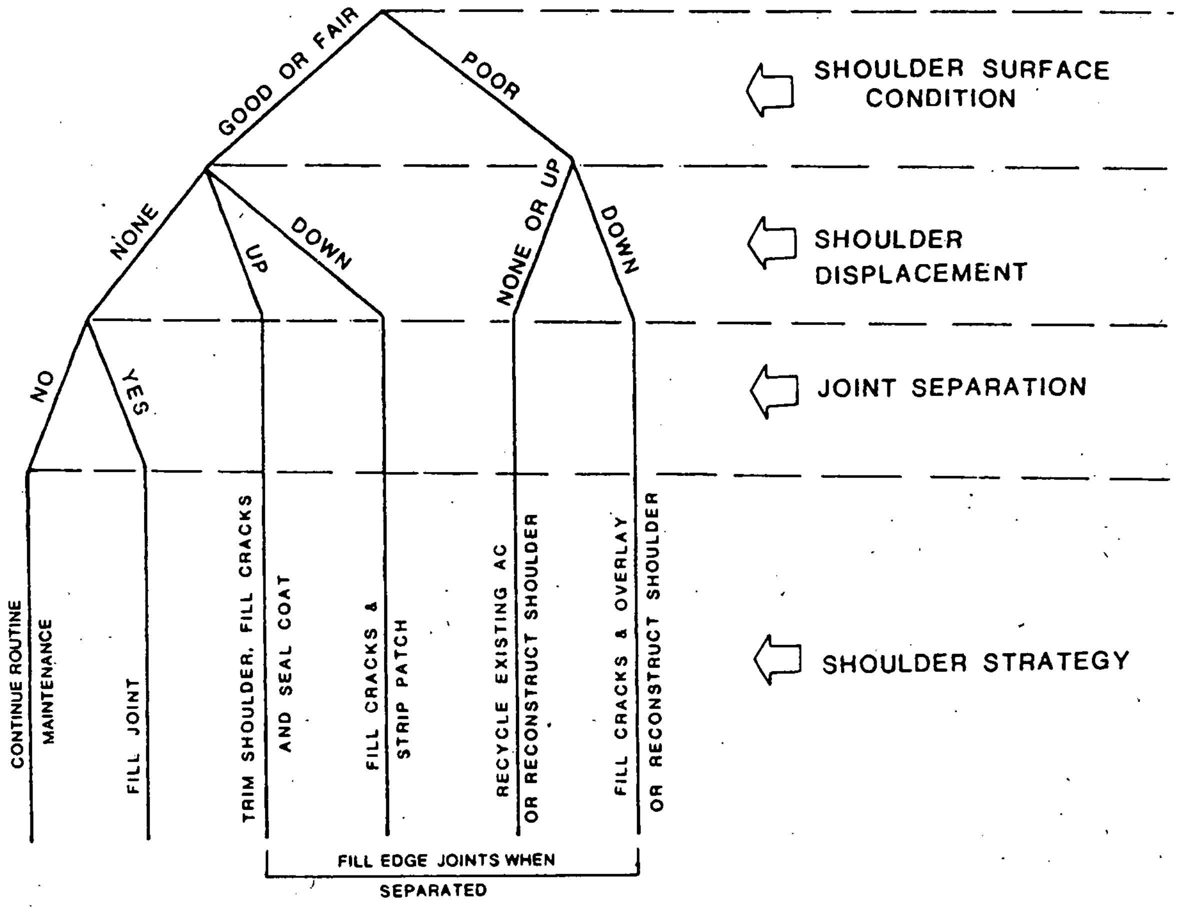


FIGURE B-12 Shoulder maintenance and rehabilitation strategy for rigid pavement.

APPENDIX C

FLORIDA—CURRENT PRACTICE

The following information is based on communications with Larry Smith and Jatinder Sharma of the Florida Department of Transportation, and was reviewed by Larry Smith in June 1980.

TYPES OF DATA COLLECTED

Four types of data are collected for flexible and rigid pavements: ride, distress, deflection, and skid resistance (*26–29*).

Ride

Development of a pavement condition rating was initiated in 1972. The Mays meter was chosen because of its speed, ease of operation, low cost, minimum manpower requirements, and ability to be correlated with the CHLOE profilometer. With the model currently used, a photocell transmitter and strip chart recorder continuously records pavement ride characteristics. The unit is placed in a Mays meter trailer, which is towed by a pickup truck at normal traffic speeds. A ride rating (RR) is calculated from the results. The RR equations are based on the CHLOE present serviceability index values multiplied by 20 (original PSI scale of 0 to 5 was expanded to 0 to 100) and include a relationship developed for each Mays meter trailer at a specified speed. The equation is of the following general form:

$$Y = a + bx$$

where

Y = ride rating (RR) = $\text{PSI}_{\overline{SV}} \times 20$ ($\text{PSI}_{\overline{SV}}$ = PSI value attributed to CHLOE slope variance),
a = regression constant for intercept (generally 100 or less),
b = negative constant slope of regression line, and
x = Mays meter reading = MMR = Mays meter excursions (in./mi) = [chart paper length (in.) × 6.4] ÷ segment length (mi).

Surface Distress

Measures of pavement distress were developed by the DOT in 1972. The rater visually selects a pavement section at least 100-ft long and then measures or observes rutting, cracking, and patching. The form used to record all measurements of distress is shown in Figure C-1.

Rutting measurements are conducted in the outside wheel path of the lane being evaluated. A 6-ft straight edge and ruler are used at 25-ft intervals (longitudinally) in the sampled segment, and average rutting is reported to the nearest 1/8-in. interval. This measurement process is shown in Figure C-2.

Cracking measurements for flexible pavements are divided into four classes:

Class	*Description*
1	Hairline, minimum branching
1B	Approximately 1/16-in. to 1/8-in. wide; slight spalling, slight to moderate branching
2	Approximately 1/8-in. to 1/4-in. wide; moderate spalling, severe branching; formation of cells
3	Progressive class 2 cracking resulting in severe spalling; chunks breaking out

The method used to measure all classes of cracking is shown in Figure C-3. For distress measurements, only the classes 1B, 2, and 3 are reported. The unit of measurement used in this procedure is area. A percentage of cracking area is obtained by dividing the cracking area by the total area in the sampled pavement segment.

Patching measurements are made for the entire lane by the same procedure used to evaluate cracked pavement areas. Patching is classified by degree:

Degree	*Description*
Light	Less than 50 ft^2 per 100-ft lane
Moderate	50 to 100 ft^2 per 100-ft lane
Severe	More than 100 ft^2 per 100-ft lane

Deflection

The Dynaflect is used to collect deflection data for both flexible and rigid pavements. Deflection measurements are used to estimate layer modulus and develop appropriate design sections.

Skid Resistance

A towed two-wheel trailer based on ASTM E 274-70 is used to measure skid resistance. A skid number is calculated based on skid testing conducted at 40 mph; skid numbers of 45 and above are considered desirable. Currently, approximately 40 percent of the Interstate and primary systems are evaluated each year.

PROBLEMS ENCOUNTERED

1. Frequent personnel changes.
2. Subjective evaluation of classification of cracks.
3. Variability of Mays meter from year to year.

SAMPLING PROGRAM

The complete primary roadway network is evaluated annually for both ride and distress. Approximately 40 percent of the Interstate and primary system is evaluated for skid resistance. The overall cost of sampling and data processing is estimated to be about $4 per lane-mile or $137,000 per yr. (See Table C-1.)

USE OF DATA

The data are used for priority programming and identification of projects needing further examination (*29*). A key ele-

PAVEMENT CONDITION SURVEY

Test Sect. No.__________
State Road No.__________
S.R. Sect. No.__________
Location__________

Date__________
D.O.T. No.__________
Speed__________
Direction__________

Rater__________
Ride__________
Defect__________
Final__________

RIDE RATING

Paper length (inches)		Total Excursions (inches)		Sect. length (miles)		Excursions in./mi.
________	x 6.4 =	________	÷	________	=	________

Excursions in./mi.		Ride Rating
________	→ Chart =	☐

DEFECT RATING

CRACKING
(TYPE)

(up to)	IB	II	III
25	5	7	10
50	10	15	20
75	15	22	30
100	20	30	40

Note: Combine types but do not exceed 100%

RUTTING
Average Depth - (pts.)

1/8" - 5	5/8" - 25
1/4" - 10	3/4" - 30
3/8" - 15	7/8" - 35
1/2" - 20	1" - 40

Note: indicate 40 pts. in excess of 1".

PATCHING
Lane-(pts.)

5 - light (less than 50 sq. ft. per 100' of lane)
10 - Moderate (50-100 sq.ft. per 100' lane)
15 - severe (more than 100 sq.ft. per 100' of lane)

CRACKING		RUTTING		PATCHING		DEFECT VALUE
________	+	________	+	________	=	________

	Defect Value		Defect Rating
100 —	________	=	☐

BASIC RATING

Ride Rating		Defect Rating				Basic Rating
☐	x	☐	=	$\sqrt{\quad}$	=	☐

FIGURE C-1 Pavement condition survey form.

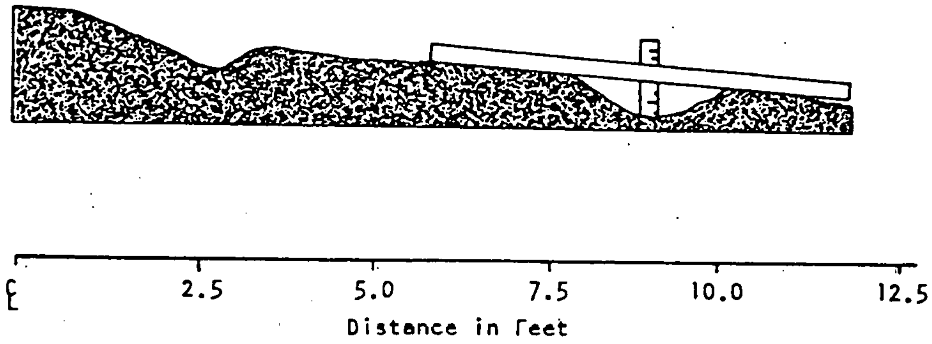


FIGURE C-2 Method for measuring roadway rutting.

ment in the data utilization is the computation of various rating scores.

First, a defect rating (DR) is calculated by a procedure in which defect points are assigned to several combinations of cracking area and class, average rut depth, and area of patching. These defect point combinations are given in Table C-2. The defect rating is calculated as follows:

$$DR = 100 - \Sigma \text{ (defect points)}$$

The ride rating (RR) is obtained by use of the Mays meter and is calculated as described previously. The defect rating and ride rating are then combined to form the basic rating (BR):

$$BR = \sqrt{RR \times DR}.$$

Finally, the basic rating is adjusted for average daily traffic. The adjusted rating has a maximum value of 100.

The criterion used for determining the need for resurfacing is an adjusted rating of 70 and below. In 1976 10 percent of the pavements with an adjusted rating of 60 and above and approximately 90 percent of the pavements with an adjusted rating of 50 and below were resurfaced. In addition, a skid number of 35 or less for a pavement segment indicates that skid resurfacing treatment is required. To further aid in establishing priorities for projects, an engineering rating (ER) is determined, which is based on an operational rating (OR) (a measure of the ability of a roadway to handle traffic) and the adjusted rating [structural rating (SR)]:

$$ER = \sqrt{OR \times SR}.$$

The ER is projected ahead to future years to aid in scheduling planned improvements.

Information for each project, including location, length, estimated cost, proposed work type, status of plans, etc., is maintained in a project record system (PRS). PRS data are combined with the pavement condition information to calculate the change in ER (ΔER) for the scheduled year of project construction. Then cost effectiveness (CE) is calculated to measure the benefit to be derived from the expenditure of monies:

$$CE = \Delta ER \times ADT \times \text{length} \div \text{project costs (\$)}.$$

The project with the lowest initial ER, highest ΔER, and largest CE becomes the project with the highest priority. The project priorities determined are ranked by assigning values ranging between 1 and 100.

TABLE C-1

ESTIMATED COSTS FOR DATA COLLECTION AND PROCESSING (1980)

Personnel	$ 48,800
Travel	9,600
Equipment	36,400
Other (computer)	24,000
Indirect Costs	18,200
Total	$ 137,000
Mileage Monitored (lane-miles)	33,000
Cost/Lane-Mile	$4.15

TABLE C-2

DEFECT POINTS ASSOCIATED WITH CRACKING, RUTTING, AND PATCHING

Cracking Defect Points

Area (%)	Cracking Class 1B	2	3
25	5	7	10
50	10	15	20
75	15	22	30
100	20	30	40

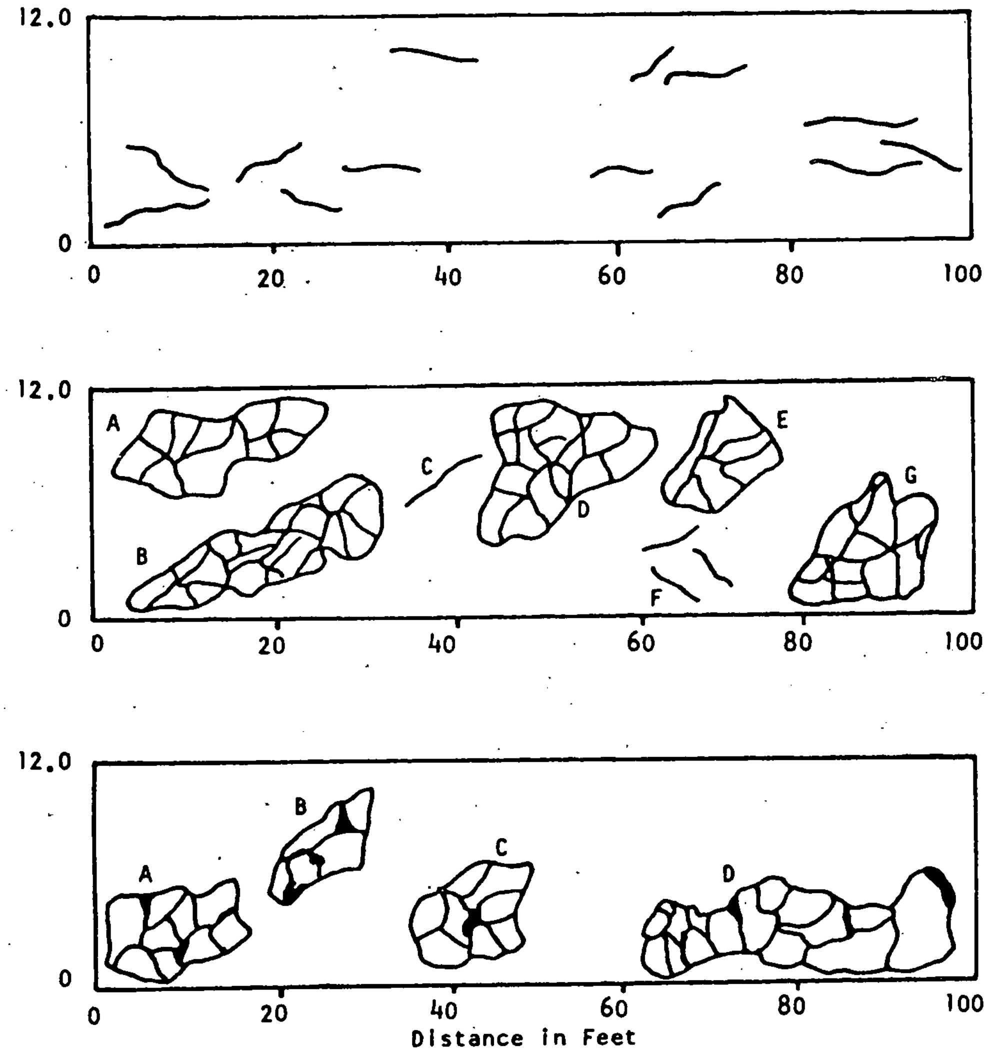
Note: Classes can be combined (not to exceed 100%).

Rutting

Rut depth (in.)	Defect Points
1/8	5
1/4	10
3/8	15
1/2	20
5/8	25
3/4	30
7/8	35
1	40

Patching

Degree of Patching	Defect Points
Light	5
Moderate	10
Severe	15



Class 1B Cracking

128 Lin. Ft. x 1' = 128 Sq. Ft. ÷ 1200 Total Sq. Ft.
= 11% Cracking

Measure Individual Cracks

Class 2 Cracking

Area	Dimensions
A & B	24' x 12' = 408 Sq. Ft.
C	10' x 1' = 10 Sq. Ft.
D	18' x 12' = 216 Sq. Ft.
E	12' x 12' = 144 Sq. Ft.
F	4' x 1' = 4 Sq. Ft.
G	14' x 12' = 168 Sq. Ft.

TOTAL = 950 Sq. Ft. ÷ 1200 Total Sq. Ft.
= 79%

Class 3 Cracking

Area	Dimensions
A	16' x 12' = 192 Sq. Ft.
B	12' x 12' = 144 Sq. Ft.
C	14' x 12' = 168 Sq. Ft.
D	36' x 12' = 432 Sq. Ft.

TOTAL = 936 Sq. Ft. ÷ 1200 Total Sq. Ft.
= 78%

FIGURE C-3 Method for measuring cracking.

APPENDIX D

NEW YORK—CURRENT PRACTICE

The following summary of the current practice for the collection and use of pavement condition data in New York (*30, 31*) was reviewed by Robert Weaver in May 1980.

TYPES OF DATA COLLECTED

User-serviceability data are collected annually on the 16,880 mi of pavement in the state. User serviceability is measured by the present rideability index (PRI), which is defined as the "user-serviceability of the pavement surface, *at* the posted speed, *on* the survey date." Secondary requirements for the pavement serviceability system (PSS) include (a) survey completeness and frequency, (b) locational referencing, (c) segmenting of the pavement network, and (d) the system update cycle.

Ride

The design of the network monitoring system [Pavement Serviceability System (PSS)] is shown in Figure D-1. The major purpose of the PSS is the precise documentation, on an annual basis, of the serviceability of network pavements in order to measure pavement life and performance.

The state DOT specifies that a desirable measuring system must have two basic characteristics: it must be extremely stable and have excellent correlation with serviceability. The measuring system now used evolved from a long series of trials with various approaches and refinements involving panel ratings and the vehicle motion typical of car ride meter devices. Repeatability and serviceability correlations were used as tools in the refinement process.

The present sensing device, a DC differential transducer mounted on the floor of a station wagon, electronically measures all motion within the movement range of the rear suspension. An electronically established datum reduces the effects of varying vehicle attitudes caused by grades, passenger movement, and varying loads. The transducer puts out a continuous electronic analog of the interaction amplitude of the vehicle response to pavement profile and speed. An example of the amplitude versus time signal (vehicle response profile) obtained from travel over pavement surface is shown in Figure D-2. This complete signal is recorded and used to establish the average serviceability of a finite length of pavement.

Integration of the amplitude-time profile allows characterization of the "energy of disturbance" present at the running speed. The result is termed the survey "E-value," expressed in E-units per mile (Figure D-3). The "E-value" obtained at the survey speed for a given test vehicle is converted into a serviceability index called the PRI (Figure D-4). The calibration of physical systems to measured serviceability is accomplished using the concepts presented in Weaver (*31*). Once calibrated each test vehicle would have a set of 18 curves to turn an energy value into PRI at a posted travel speed (Figure D-4).

Skid

Skid data are collected only to corroborate the need for correction of excessively slippery pavement at a high accident frequency location.

Distress and Deflection

Distress and deflection data are not currently collected in the state, nor are there any plans to do so. Since 1975 the annual monitoring of network serviceability has provided direct measurements of pavement surface life and performance. Statewide collection of distress data is not considered necessary.

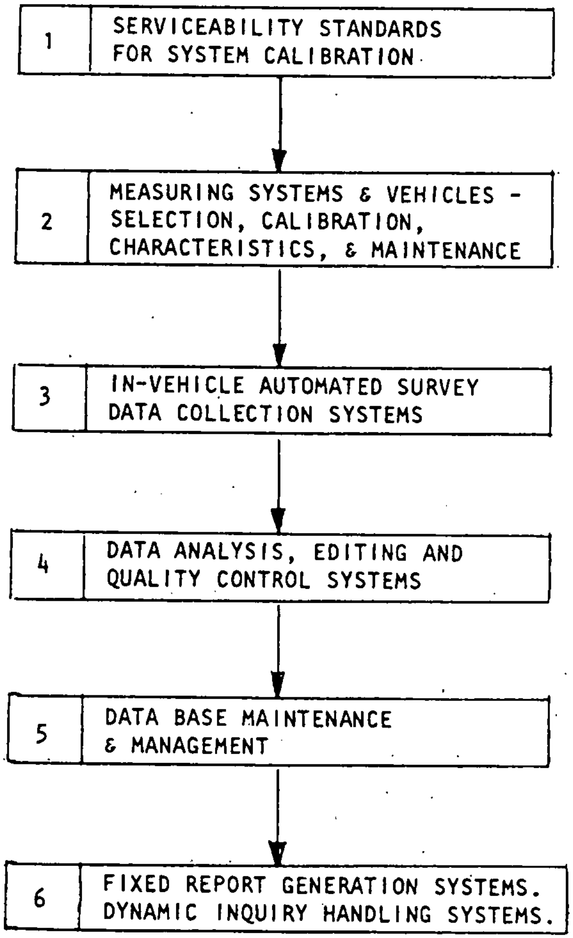


FIGURE D-1 Pavement serviceability system.

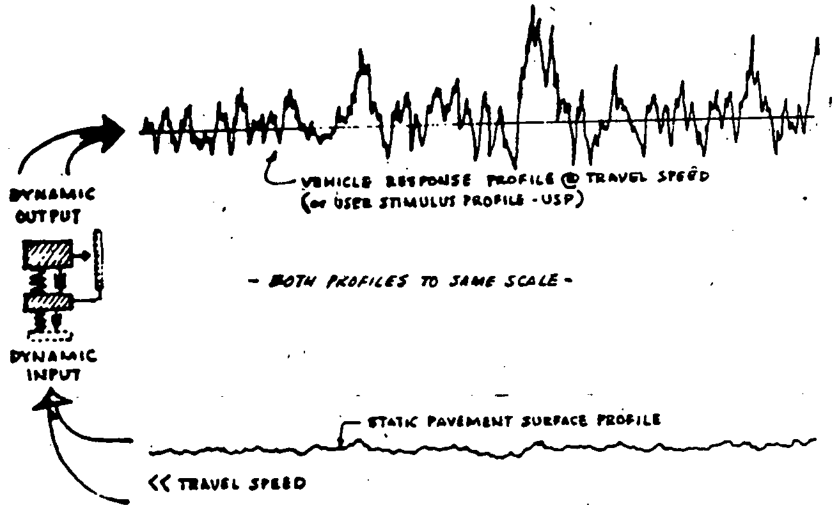
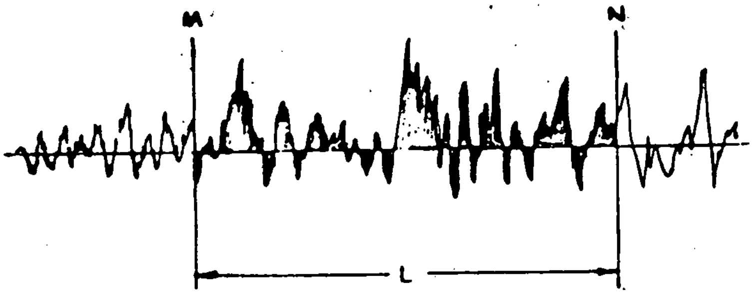


FIGURE D-2 Vehicle response profile obtained from travel over pavement surface (*30*).



$$E_{M-N} = \frac{1}{L} \int_{X=M}^{X=N} |y| \, dx$$

FIGURE D-3 Method for determining an E-value (*30*).

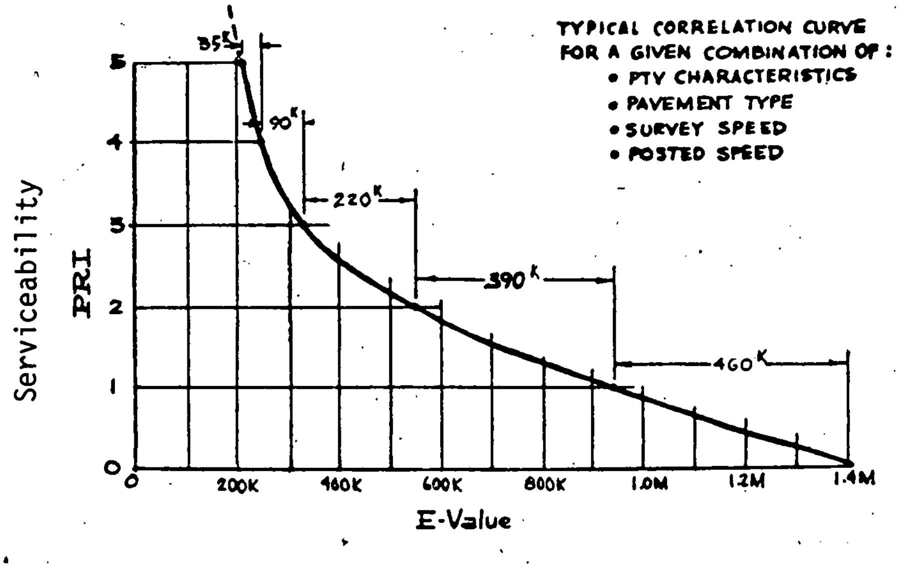


FIGURE D-4 Typical relationship between E-value and serviceability (*30*).

Additional Data

Knowledge of any preventive or corrective maintenance performed relative to survey dates is vital to the prediction of future serviceability and the performance and benefits of the various alternatives. Plans are being developed to involve resident engineers in relating maintenance activities to serviceability trends. There are also plans to relate factors such as climate, gradeline, drainage, soil type, and traffic to pavement performance.

DATA REDUCTION AND STORAGE

An automated system is used to obtain error-free data rapidly at the lowest possible cost. The design criteria for in-vehicle systems included: high-speed, nonstop surveys; long maintenance-free life of equipment; stability of operation; full analog recording of survey data to avoid loss of data through digital recording; and operation on low power from standard vehicles. These systems were custom designed and built for the specific application. Data are recorded on cassettes, each containing up to 80 mi of survey data. The information is transferred to a mini-computer (DEC 11/40), digitized, integrated to get the E-value, and then transferred to the terminal to sequence and order the data. There is no coding or keypunching.

The costs for data collection, data reduction, and services to data users are presented in Table D-1. Total system operating costs are calculated to be $8.47 per mile in 1977-1978, $9.62 in 1978-1979, and $12.00 in 1979-1980. The following costs are not included:

- Equipment amortization.
- Vehicle calibration [required when a new test vehicle goes on-line and continues until it is replaced ($25,000)].
- Development costs before 1975.

The entire program is state funded.

TABLE D-1

SYSTEM OPERATING COSTS[a]

	1977-78	1978-79	1979-80
Field Surveys	$ 51,960	$ 71,574	--
Reduction, Analysis, and Data Base Formulation	48,047	67,197	--
Support, Administration, Continuing Development	37,122	15,200	--
	$137,129	$153,971	$200,350
Manpower (man-yr)	7.89	6.43	--
Test Vehicles	2	2	--

[a] Development costs: $450,000.

PROBLEMS ENCOUNTERED

The data collection process appears to be an efficient and well-managed program. Through careful engineering, system design, and testing, many problems facing other agencies appear to have been eliminated. The typical problems of vehicle calibration and measurement stability over time have been reduced. The complete serviceability monitoring of an entire network demands total objectivity and up-to-date information on factors that affect serviceability or location referencing. Severe shortcomings in existing record keeping with respect to location referencing, pavement construction details, and maintenance history have been encountered.

SAMPLING PROGRAM

All state routes are surveyed annually between May and November. The resulting data files consist of about 120,000 segments, each determined by physical field references. The smallest pavement segment measured is about 0.008 mi long, and the average segment is 0.129 mi long. Several years of experience with surveys has indicated that any partial sampling program of pavement condition makes assessment of network pavement condition difficult, and that practical use of the data for project selection would be severely limited to those pavements actually surveyed.

USE OF DATA

The uses of the data collected in the Pavement Serviceability System have been expanding since 1975 when the annual surveys were initiated, despite the lag in development of supporting computer systems to facilitate use of the data. At the network level, annual summaries of data provide a rough indication of

1. The changes in network serviceability (a significant factor in funding for preventive and corrective pavement work); and
2. A more equitable distribution of resources among the 10 regions based on pavement condition at the project level (the data are needed to establish priorities for resurfacing or pavement reconstruction).

Trend analyses of PRI are used to estimate the time of rehabilitation. Roads with a PRI of 2.4 or less are considered deficient and those with a PRI of 1.5 or less are considered essential for maintenance. Computer reports for each survey are used to graph serviceability versus time for analysis and review before projects are submitted for approval.

The use of the PRI has resulted in improved justifications for maintenance and rehabilitation. Documentation of the need for initiating a project is required when the PRI is acceptable (i.e., above 2.4). For example: rehabilitation of pavements with adequate serviceability, but having high maintenance costs, can be funded only if the maintenance costs are adequately documented; and rehabilitation of pavements with a high accident rate resulting from rutting or low skid resistance must be justified by documentation of safety considerations.

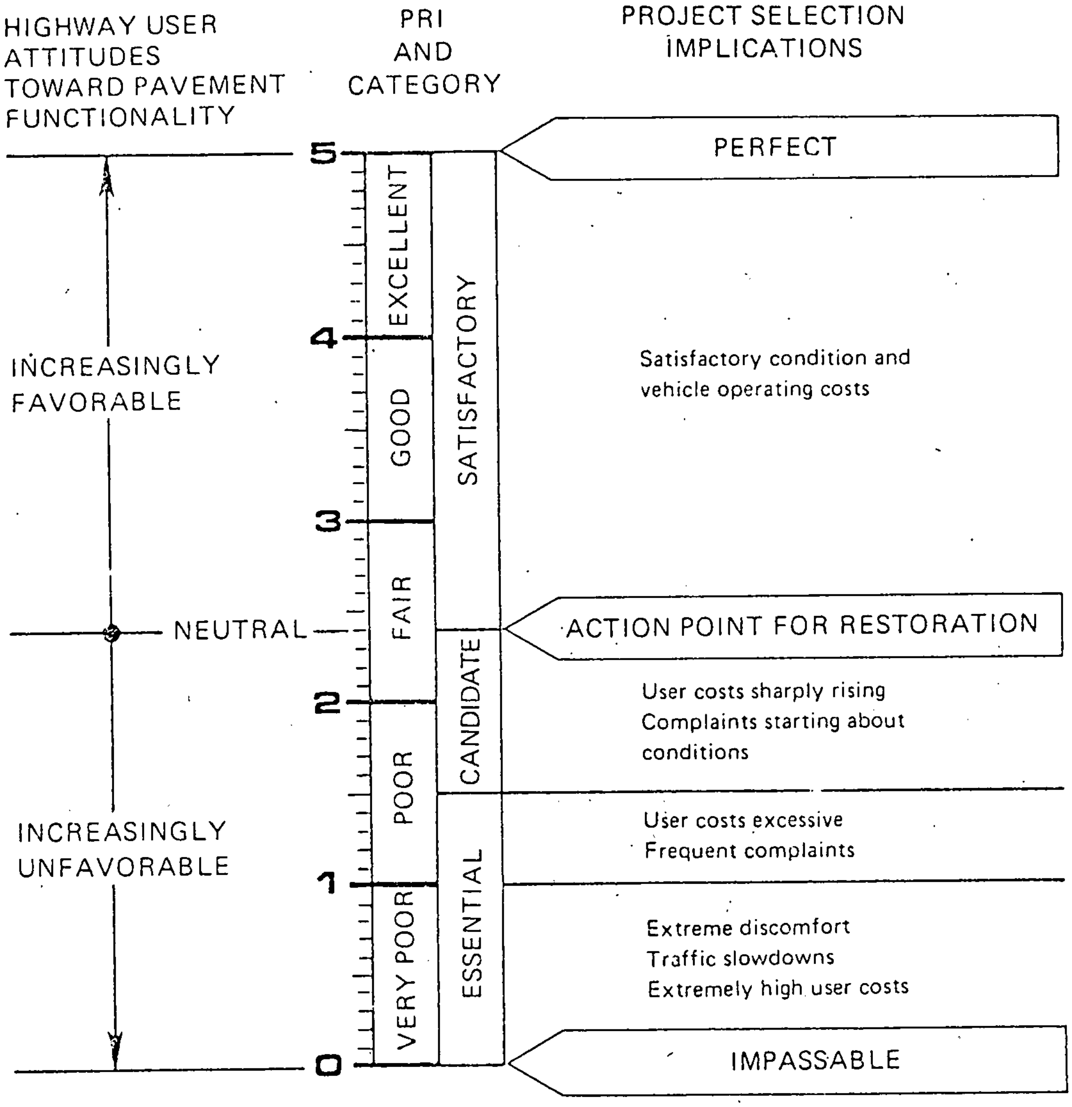
FURTHER OBSERVATIONS

This system is one of the simplest and most effective for gradually establishing on a year-to-year basis the connection between the serviceability of pavements and the following issues:

1. How much money is needed?
2. Where is it needed?
3. Is enough being spent to keep up with our pavement needs?
4. Is it being spent wisely?

The system is effective because:

1. There is top-level management support.
2. Serviceability is measured in a rapid, simple, and useful manner, and is adequate for defining performance in the state.
3. Experience with public protests concerning both premature and overdue rehabilitation of pavements conform to that predicted by PRI (Figure D-5).



NOTE All PRI values are dependent on travel speed which is taken to be the posted speed; both PRI and User Attitudes vary with travel speeds.

FIGURE D-5 Use of present rideability index (PRI) in effective management (*32*).

APPENDIX E

ONTARIO—CURRENT PRACTICE

The following information is based on communications with W. A. Phang of the Ontario Ministry of Transportation and Communications, and was reviewed in August 1980.

TYPES OF DATA COLLECTED

Four types of data are currently collected for flexible and rigid pavements: ride, surface distress, deflection (flexible only), and skid resistance (*33–36*).

Ride

The ride quality of the pavement is determined by the riding comfort rating (RCR), which is based on a subjective 0 to 10 scale. A rating of 10 represents a perfectly smooth pavement, whereas 0 indicates rough, essentially impassable road. To determine the RCR value for a pavement segment, the rater drives the segment at a speed of 50 mph. The RCR is then estimated to one decimal place according to the following scale:

Riding Comfort Rating	*Description*
10–8	Excellent
8–6	Good
6–4	Fair
4–2	Poor
2–0	Very poor

Roughness measurements may also be obtained by a car ride meter and are usually calculated in terms of inches per mile.

Surface Distress

The distress visually observed on the pavement surface is specified using uniform descriptions for frequency and severity of various distress types. There are three groups of distress types: surface defects; distortion or permanent deformation; and cracking. These distress categories are shown in Figures E-1 and E-2, which are the recording forms used for flexible and rigid pavements. Emphasis has been placed on developing clear work and picture descriptions of the various distress types to aid the rater.

The pavement condition rating (PCR), a numeric value, is determined from the ride and distress information, which includes descriptions of riding quality, distortion, and distress. These PCR ranges are listed in eight possible stages for flexible pavements (Figure E-3) and in six stages for rigid pavements (Figure E-4). For each stage there is a general description of the desired maintenance or rehabilitation level with an estimate of when such work should be performed.

Deflection

Deflection measurements are made on a selective basis to assess pavement strength. Both the Dynaflect and Benkelman beam have been used in this process. The data are presented in a standard format that includes the mean plus two standard deviations ($\bar{x} + 2s$).

Skid Resistance

Skid resistance measurements are made on a selective basis similar to that for deflection measurements. A brake-force trailer and stereo photographs have been used to collect data at high-accident locations, monitor suspect pavement segments, and verify the effectiveness of treatments.

PROBLEMS ENCOUNTERED

The major problems associated with the data collection process include:

- A wide range of subjectively obtained distress observations and ride comfort ratings; and
- Sensitivity of system to inaccurate ride comfort ratings.

The major problem associated with sampling is the training of personnel. Other problems include: (a) equipment calibration; (b) shortage of manpower to conduct surveys; and (c) data processing at central office, which hinders quick access by regions.

SAMPLING PROGRAM

The pavement condition rating (PCR) surveys are conducted in each of the five regions by two or three raters. Generally, these surveys are accomplished during the late spring and early summer. Four regions conduct surveys on a 3-yr cycle; one region surveys pavements annually. The data are stored in a central computerized file and are retrievable by each region by means of remote terminal. In addition, a hard copy of the data is maintained by each region.

The first step in the procedure for surveying specific pavement segments is to drive the segment at 50 mph to assess ride quality. The rater then returns driving along the shoulder at a slow speed (not to exceed 30 mph) to evaluate cracking and other distress types. The rater may stop to examine in detail particular distress types.

The data collection and reduction costs are summarized in Table E-1.

USE OF DATA

The data are used for priority programming, rehabilitation, design, and development of maintenance programs. A comprehensive pavement information system aids in the use of the data.

The objectives of the Pavement Management Feedback and Information System (PAMFIS) include:

1. *Management*. Provides pavement information to administrators and engineers for making decisions on various pavement design, construction, maintenance, and rehabilitation programs (see Figure E-5).
2. *Design*. Provides history of performance information on in-service pavements to guide decision making and judgment on various pavement design problems.
3. *Construction*. Provides feedback information to evaluate and improve specifications, tests, techniques, and requirements for highway construction in light of in-service pavement performance (e.g., ride data are used in monitoring construction quality).
4. *Pavement Research*. Provides feedback information necessary for verifying, analyzing, and continuously improving design, performance, and cost models. Provides accessible and reliable information for pavement investigations and analyses.

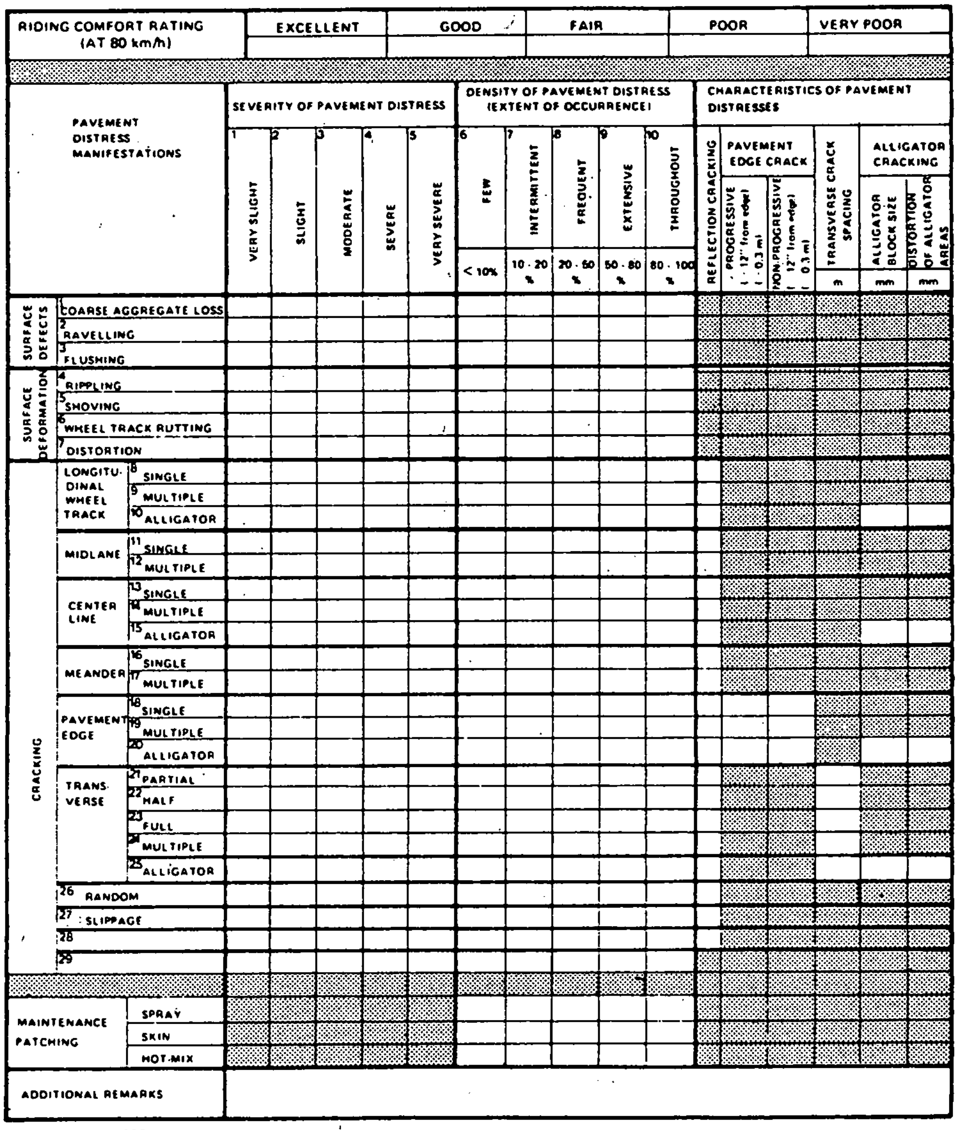
TABLE E-1

ESTIMATED COSTS FOR DATA COLLECTION AND ANALYSIS[a]

	1978 - 79	1979 - 80
Personnel	$ 40,000	$ 45,000
Travel	5,000	6,000
Equipment[b]	70,000	90,000
Other	12,000	19,000
Data Processing	10,000	10,000
Indirect Costs	12,000	15,000
	$ 149,000	$ 185,000

[a] Based on 21,500 km.

[b] Includes complete Dynaflect services.



RIDING COMFORT RATING (AT 80 km/h)	EXCELLENT	GOOD	FAIR	POOR	VERY POOR

PAVEMENT DISTRESS MANIFESTATIONS			SEVERITY OF PAVEMENT DISTRESS					DENSITY OF PAVEMENT DISTRESS (EXTENT OF OCCURRENCE)					CHARACTERISTICS OF PAVEMENT DISTRESSES					
			1 VERY SLIGHT	2 SLIGHT	3 MODERATE	4 SEVERE	5 VERY SEVERE	6 FEW	7 INTERMITTENT	8 FREQUENT	9 EXTENSIVE	10 THROUGHOUT	REFLECTION CRACKING	PAVEMENT EDGE CRACK		TRANSVERSE CRACK SPACING	ALLIGATOR CRACKING	
								< 10%	10 - 20 %	20 - 50 %	50 - 80 %	80 - 100 %		PROGRESSIVE (< 12" from edge) (< 0.3 m)	NON-PROGRESSIVE (> 12" from edge) (> 0.3 m)	m	ALLIGATOR BLOCK SIZE mm	DISTORTION OF ALLIGATOR AREAS mm
SURFACE DEFECTS		1 COARSE AGGREGATE LOSS											▨	▨	▨	▨	▨	▨
		2 RAVELLING											▨	▨	▨	▨	▨	▨
		3 FLUSHING											▨	▨	▨	▨	▨	▨
SURFACE DEFORMATION		4 RIPPLING											▨	▨	▨	▨	▨	▨
		5 SHOVING											▨	▨	▨	▨	▨	▨
		6 WHEEL TRACK RUTTING											▨	▨	▨	▨	▨	▨
		7 DISTORTION											▨	▨	▨	▨	▨	▨
CRACKING	LONGITUDINAL WHEEL TRACK	8 SINGLE												▨	▨	▨	▨	▨
		9 MULTIPLE												▨	▨	▨	▨	▨
		10 ALLIGATOR												▨	▨	▨		
	MIDLANE	11 SINGLE												▨	▨	▨	▨	▨
		12 MULTIPLE												▨	▨	▨	▨	▨
	CENTER LINE	13 SINGLE												▨	▨	▨	▨	▨
		14 MULTIPLE												▨	▨	▨	▨	▨
		15 ALLIGATOR												▨	▨	▨		
	MEANDER	16 SINGLE												▨	▨	▨	▨	▨
		17 MULTIPLE												▨	▨	▨	▨	▨
	PAVEMENT EDGE	18 SINGLE														▨	▨	▨
		19 MULTIPLE														▨	▨	▨
		20 ALLIGATOR														▨		
	TRANSVERSE	21 PARTIAL												▨	▨		▨	▨
		22 HALF												▨	▨		▨	▨
		23 FULL												▨	▨		▨	▨
		24 MULTIPLE												▨	▨		▨	▨
		25 ALLIGATOR												▨	▨			
		26 RANDOM												▨	▨	▨	▨	▨
		27 SLIPPAGE												▨	▨	▨	▨	▨
		28												▨	▨	▨	▨	▨
		29											▨	▨	▨	▨	▨	▨
MAINTENANCE PATCHING		SPRAY	▨	▨	▨	▨	▨						▨	▨	▨	▨	▨	▨
		SKIN	▨	▨	▨	▨	▨						▨	▨	▨	▨	▨	▨
		HOT-MIX	▨	▨	▨	▨	▨						▨	▨	▨	▨	▨	▨
ADDITIONAL REMARKS																		

Revised October 1977

FIGURE E-1 Flexible pavement condition evaluation form (*35*).

The PAMFIS was developed in 1971–1972 with the goal of establishing a comprehensive pavement performance evaluation scheme. Pavement projects were selected for which design, construction, and subsequent pavement performance information was to be organized, checked, stored, analyzed, and retrieved through a computerized process.

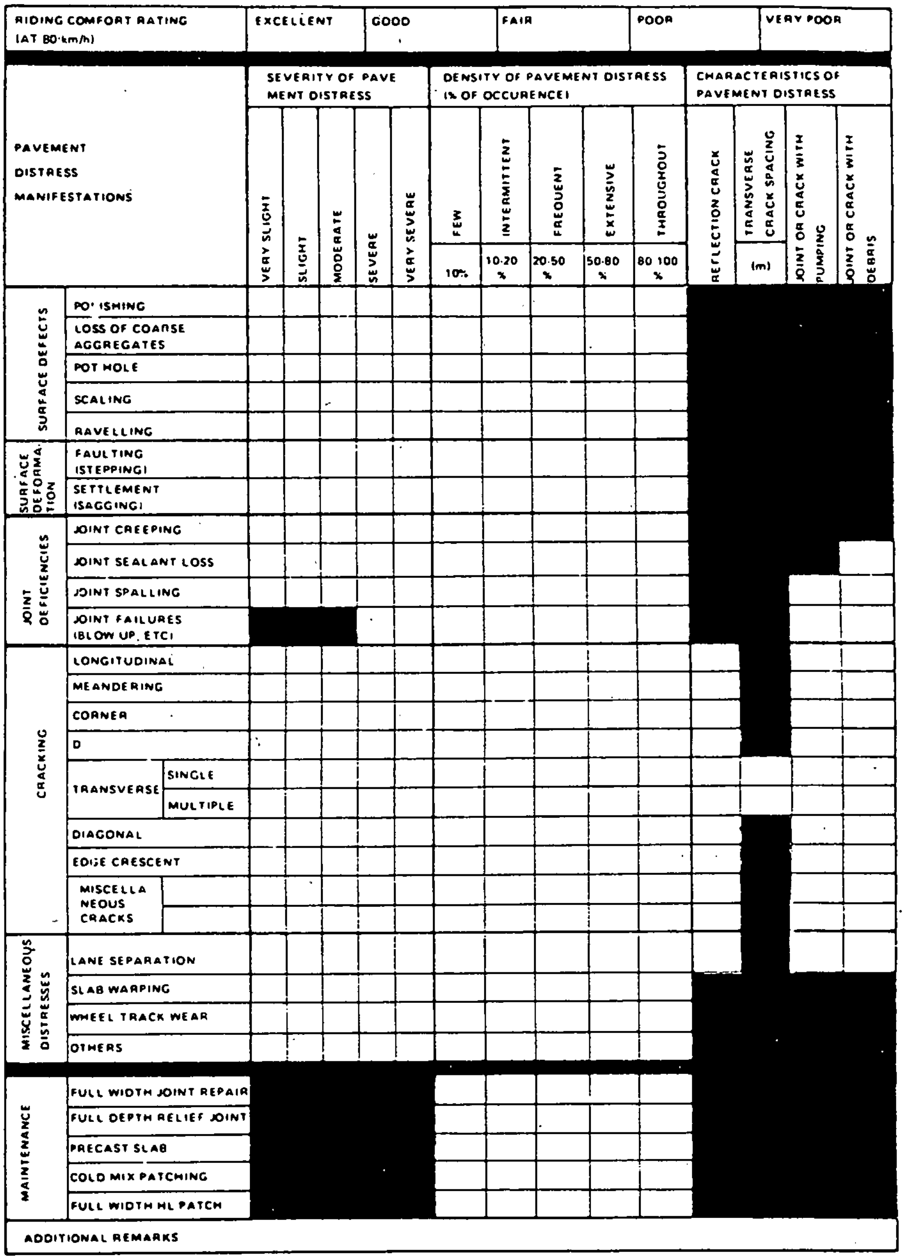
The data collected and stored in the PAMFIS are classified as follows:

1. *Design Data*. Includes layer types, thicknesses, expected performance history, and costs.
2. *Construction Data*. Includes cross-section data, materials sources and types, quality of materials and construction, and some quality-control measurements.
3. *Maintenance Data*. Includes subjective evaluation of maintenance type and extent.
4. *Performance Evaluation*. Includes pavement strength, roughness, skid resistance, condition rating survey of cracks, ride quality, and traffic (Figure E-6).

Using the data described above, PAMFIS can provide pavement administrators, designers, and researchers with relevant reports and information on numerous projects.

Priority Programming

The pavement condition rating (PCR) is used to determine whether a pavement section should be placed on a prelimi-



RIDING COMFORT RATING (AT 80·km/h)	EXCELLENT	GOOD	FAIR	POOR	VERY POOR

PAVEMENT DISTRESS MANIFESTATIONS			SEVERITY OF PAVEMENT DISTRESS					DENSITY OF PAVEMENT DISTRESS (% OF OCCURENCE)					CHARACTERISTICS OF PAVEMENT DISTRESS			
			VERY SLIGHT	SLIGHT	MODERATE	SEVERE	VERY SEVERE	FEW	INTERMITTENT	FREQUENT	EXTENSIVE	THROUGHOUT	REFLECTION CRACK	TRANSVERSE CRACK SPACING	JOINT OR CRACK WITH PUMPING	JOINT OR CRACK WITH DEBRIS
								10%	10-20 %	20-50 %	50-80 %	80 100 %		(m)		
SURFACE DEFECTS	POLISHING												■	■	■	■
	LOSS OF COARSE AGGREGATES												■	■	■	■
	POT HOLE												■	■	■	■
	SCALING												■	■	■	■
	RAVELLING												■	■	■	■
SURFACE DEFORMATION	FAULTING (STEPPING)												■	■	■	■
	SETTLEMENT (SAGGING)												■	■	■	■
JOINT DEFICIENCIES	JOINT CREEPING												■	■	■	■
	JOINT SEALANT LOSS												■	■	■	
	JOINT SPALLING												■	■		
	JOINT FAILURES (BLOW UP, ETC)		■	■	■								■	■		
CRACKING	LONGITUDINAL													■		
	MEANDERING													■		
	CORNER													■		
	D													■		
	TRANSVERSE	SINGLE														
		MULTIPLE														
	DIAGONAL													■		
	EDGE CRESCENT													■		
	MISCELLANEOUS CRACKS													■		
														■		
MISCELLANEOUS DISTRESSES	LANE SEPARATION													■		
	SLAB WARPING												■	■	■	■
	WHEEL TRACK WEAR												■	■	■	■
	OTHERS												■	■	■	■
MAINTENANCE	FULL WIDTH JOINT REPAIR		■	■	■	■	■						■	■	■	■
	FULL DEPTH RELIEF JOINT		■	■	■	■	■						■	■	■	■
	PRECAST SLAB		■	■	■	■	■						■	■	■	■
	COLD MIX PATCHING		■	■	■	■	■						■	■	■	■
	FULL WIDTH HL PATCH		■	■	■	■	■						■	■	■	■

ADDITIONAL REMARKS

FIGURE E-2 Rigid pavement condition evaluation form (*35*).

A Guide for the Estimation of Pavement Condition Rating and Priority for Flexible Pavements

Reconstruct within 2 years	0 - 20	Pavement is in poor to very poor condition with extensive severe cracking, alligatoring and dishing. Ridability is poor and the surface is very rough and uneven.
Reconstruct in 2 - 3 years	20 - 30	Pavement is in poor condition with moderate alligatoring and extensive severe cracking and dishing. Ridability is poor and the surface is very rough and uneven.
Reconstruct in 3 - 4 years	30 - 40	Pavement is in poor to fair condition with frequent moderate alligatoring and extensive moderate cracking and dishing. Ridability is poor to fair and surface is moderately rough and uneven.
Reconstruct in 4 - 5 years or resurface within 2 years with extensive padding	40 - 50	Pavement is in poor to fair condition with frequent moderate cracking and dishing, and intermittent moderate alligatoring. Ridability is poor to fair and surface is moderately rough and uneven.
Resurface within 3 years	50 - 65	Pavement is in fair condition with intermittent moderate and frequent slight cracking, and with intermittent slight or moderate alligatoring and dishing. Ridability is fair and surface is slightly rough and uneven.
Resurface in 3 - 5 years	65 - 75	Pavement is in fairly good condition with frequent slight cracking, slight or very slight dishing and a few areas of slight alligatoring. Ridability is fairly good with intermittent rough and uneven sections.
Normal maintenance only	75 - 90	Pavement is in good condition with frequent very slight or slight cracking. Ridability is good with a few slightly rough and uneven sections.
No maintenance required	90 - 100	Pavement is in excellent condition with few cracks. Ridability is excellent with few areas of slight distortion.

FIGURE E-3 Guide for estimating pavement condition rating for flexible pavements (35).

nary program listing for further consideration. Projects are listed according to when the project is scheduled (1, 2, or 5 yr). As the priority of a specific project changes from the 5-yr to the 2-yr program and then to the final program, rehabilitation designs are examined and costs calculated. Decisions on specific project designs are based on availability of funds and such factors as regional equity, regional development policy, and general public acceptability.

Rehabilitation Design

The pavement condition survey is used to identify structural deficiencies based on the types of observed distress. For example, the presence of alligator cracking indicates the need to upgrade the structural capacity. Rutting not accompanied by cracking of the asphalt surface may be attributed to instability of underlying layers. For such areas, overlay thickness is designed using nondestructive testing instruments such as the Benkelman beam or Dynaflect.

Maintenance Activities

The pavement distress manifestations currently recorded are too detailed for maintenance purposes. A maintenance manual is planned that will include descriptions of distress types, such as "slight," "moderate," and "severe." Inspections will be conducted and the data used only as required to plan immediate and short-term maintenance activities.

Reconstruct within 2 years.	0 - 20	Pavement is in very poor condition with severe cracking and stepping. Frequent badly broken and tilted slabs. Ridability is very poor. Extremely rough and uneven throughout.
Reconstruct in 2 - 3 years.	20 - 40	Pavement is in poor condition with severe cracking and stepping. Intermittent badly broken or tilted slabs. Ridability is poor. Very rough and uneven throughout.
Cut relief joints if necessary. Resurface within 2 years.	40 - 50	Pavement is in fair to poor condition with moderate to severe stepping at cracks and joints. Ridability is fair to poor and the surface is moderately rough and uneven throughout. Occasional blow ups may occur. Surface moderately polished by traffic.
Cut relief joints if necessary. Resurface in 2 - 5 years.	50 - 75	Pavement is in fair condition with moderate stepping at cracks and joints. Ridability is fair and the surface is slightly to moderately rough and uneven throughout. Occasional blow ups may occur. Surface moderately polished by traffic.
Grooving or resurfacing to restore skid resistance if necessary. Otherwise normal maintenance only.	75 - 90	Pavement is in fair to good condition with slight stepping at cracks and joints. Ridability is fair to good with intermittent slightly rough sections. Surface slightly polished by traffic.
Normal maintenance only. Repair joint seals as necessary.	90 - 100	Pavement is in good condition with little cracking between joints. Intermittent slight stepping at joints. Ridability is good. Skid resistance is satisfactory.

FIGURE E-4 Guide for estimating pavement condition rating for rigid pavements (*35*).

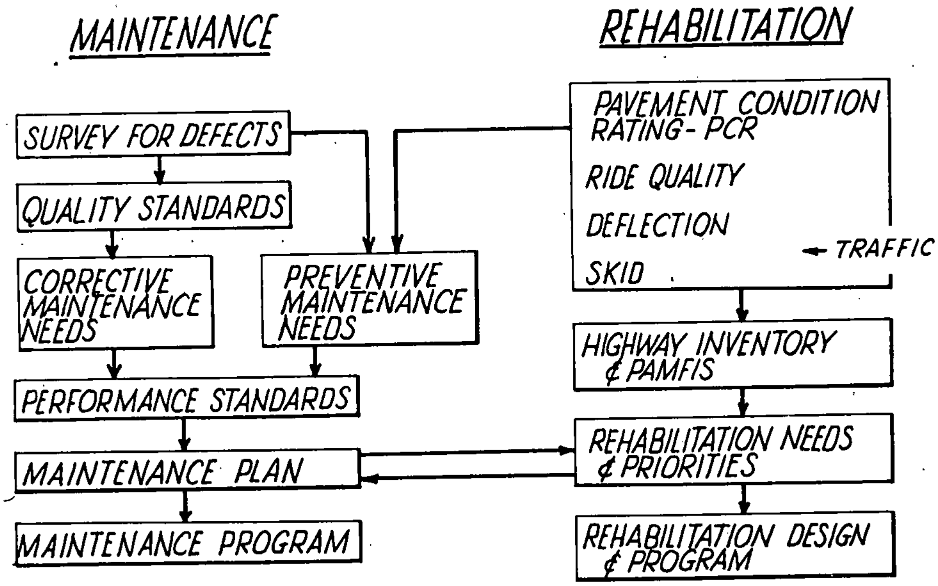


FIGURE E-5 Pavement management (Ontario, 1980).

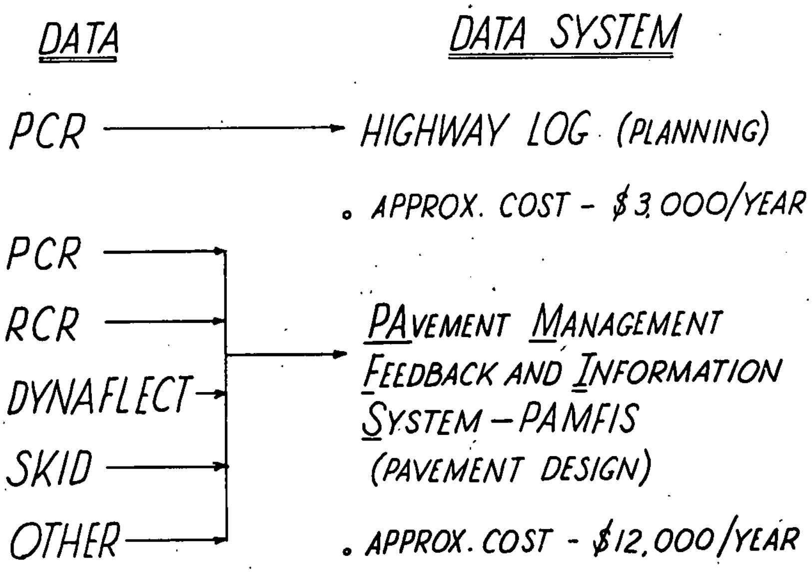


FIGURE E-6 Types of data contained in the PAMFIS.

APPENDIX F

PENNSYLVANIA—CURRENT PRACTICE

The following information is based on an interview with Gaylord Cumberledge and John Hopkins of the Pennsylvania Department of Transportation in June 1978, and was reviewed by John Hopkins in June 1980.

TYPES OF DATA COLLECTED

Approximately 45,000 mi of roadway are monitored. Pavement condition measurements include evaluation of ride quality, structural capacity, and skid resistance. Trained observer surveys are used to obtain data on surface distress.

Skid Resistance

Skid resistance data are not used directly in the management program. Roads with poor skid resistance are considered separately. The measurement of skid resistance is performed using a single locked-wheel trailer according to the specifications given in ASTM E 274. Skid tests are performed on pavements suspected to be inadequate (Figure F-1). The length of test (wheel lockup) is about 250 ft. Test data are taken 10 times per mile and indexed according to stationing and/or mileposts.

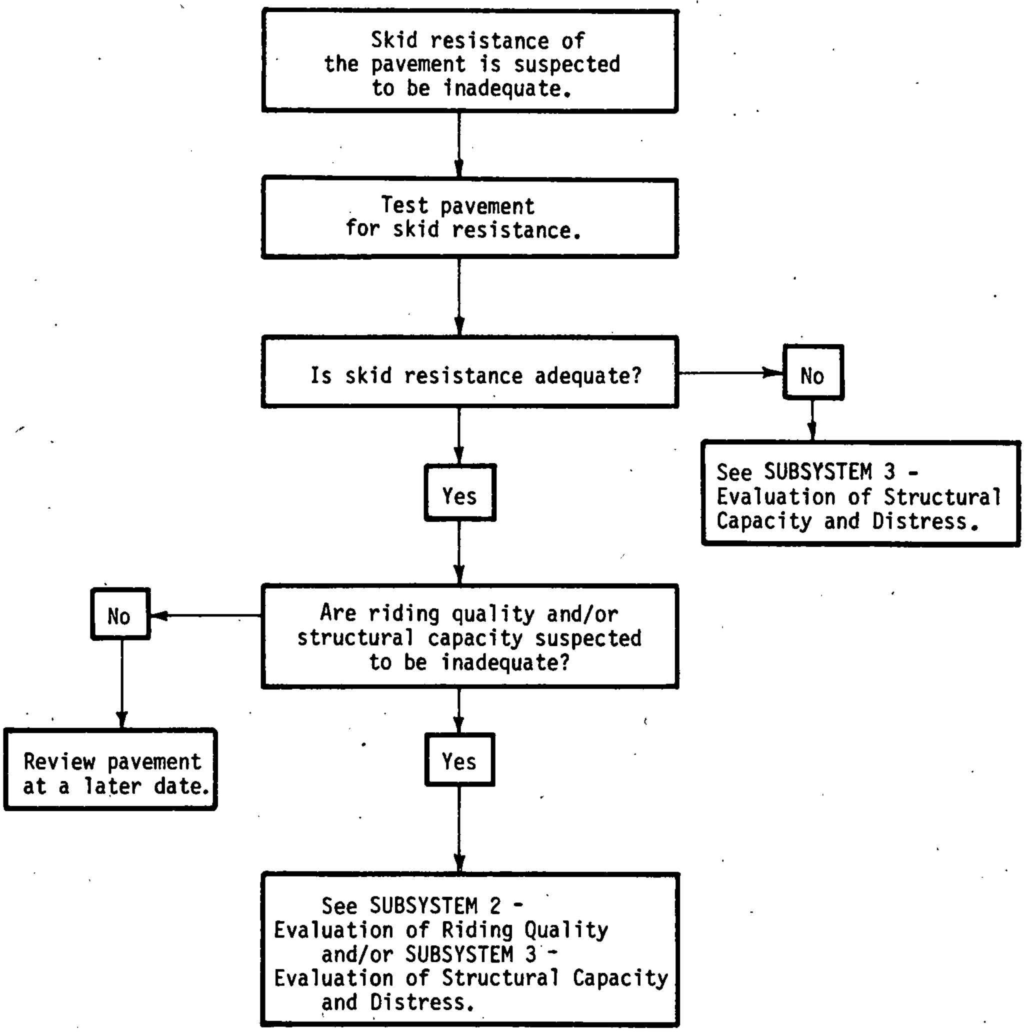


FIGURE F-1 Subsystem 1—Evaluation of skid resistance (*16*).

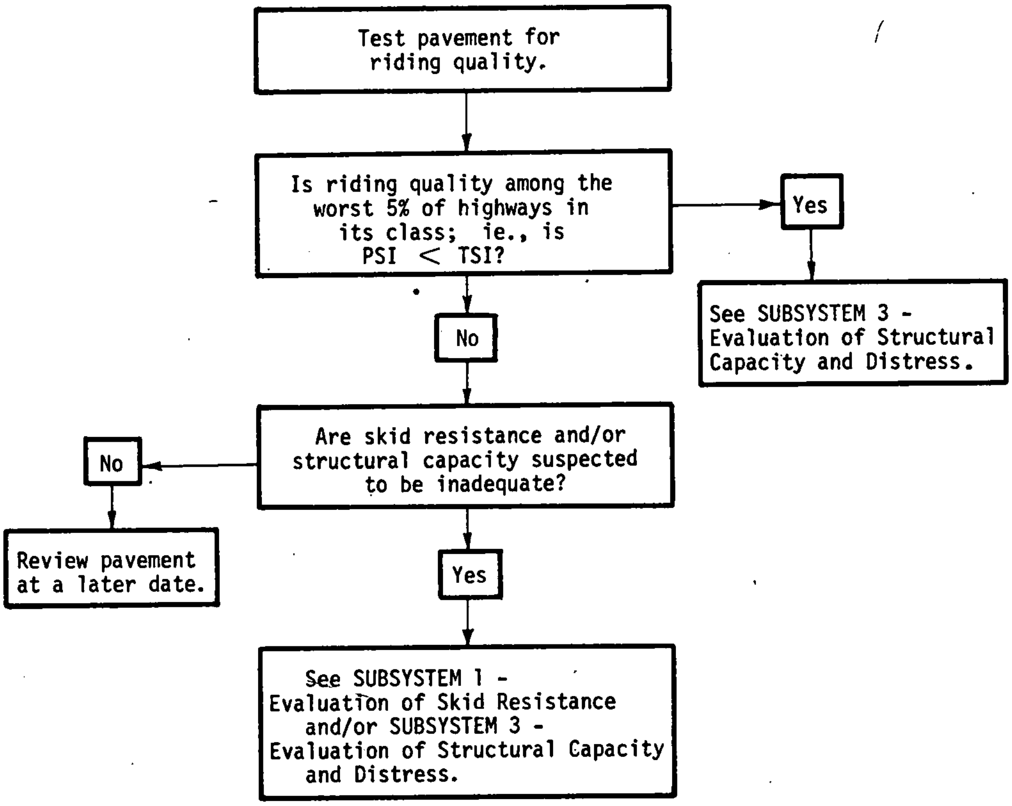


FIGURE F-2 Subsystem 2—Evaluation of riding quality (*16*).

Ride

A program for gathering roughness data using the BPR roughometer was initiated in 1965. Beginning in 1968 a version of the PCA meter, the Autoflect, was used to collect the data; this was replaced in 1973 by the Mays meter. The Mays meter is inexpensive and has the advantage of providing continuous logs of the pavement surface along with synchronized distance increments and landmarks. Correlations between the three devices and the GM profilometer are performed to provide a consistent data base.

Ride evaluations are currently performed each year on all pavements in maintenance functional classes A, B, and C, or on approximately 15,000 center-line mi. The data are indexed according to stationing and/or mileposts (Figure F-2).

Deflection

Road Raters are used to measure the deflection of flexible pavements. Dynamic loads are superimposed over static loads to produce the desired test. The Road Rater has the advantages of requiring low maintenance, operating at high speed, and being easily transportable. No structural testing is presently performed on rigid pavements.

Structural capacity testing is performed on pavements that qualify for resurfacing as determined by skid resistance and/or ride quality tests. In the deflection survey, the type and amount of distress are determined. The data are used only to temper the decision on the type of maintenance needed. A computer program is used to convert the actual deflection measurements to the conditions in spring months (weakest time of the year). Once the 18-kip axle load equivalencies are determined, overlay thickness can be designed to reduce deflections to acceptable levels (Figure F-3).

Surface Distress

Trained observer surveys are performed semiannually on a floating sample of about 4 percent of the highway system (a total of 8 percent annually). Trained professionals physically inspect conditions on samples of highway sections in each of the state's 67 counties (*37*).

DATA REDUCTION AND STORAGE

Ride and deflection data are hand-reduced on the coding form by stationing or milepost, keypunched, edited, and stored in the computer. A pavement condition information sheet is also completed.

The estimated costs of data collection and data reduction are given in Table F-1. These costs are based on a sampling of approximately 20 percent of the highway system for ride and 5 percent for deflection and skid resistance. The sampling is funded by HP & R funds (90 percent) and the state (10 percent). The annual cost of the trained observer surveys is approximately $320,000.

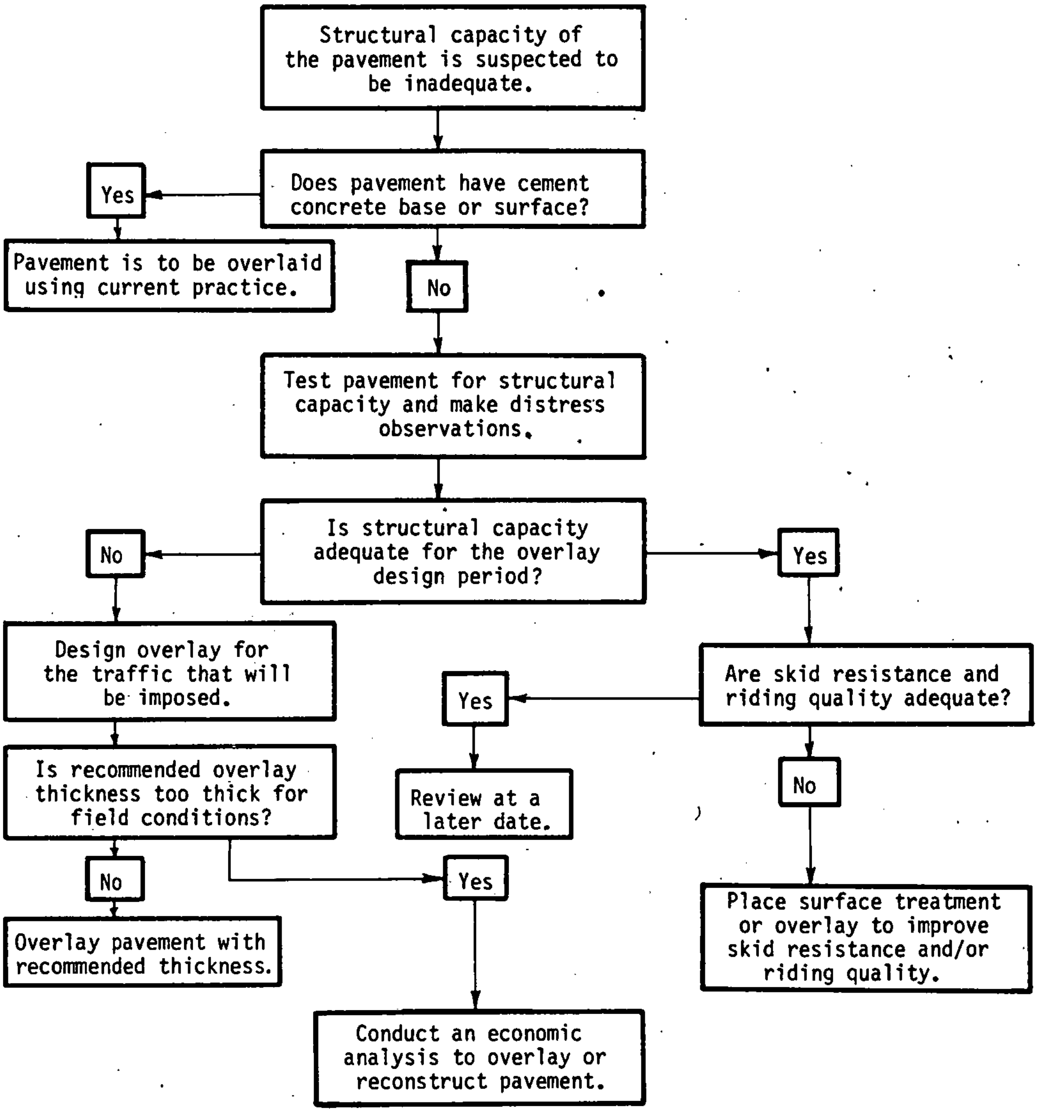


FIGURE F-3 Subsystem 3—Evaluation of structural capacity and distress (*16*).

PROBLEMS ENCOUNTERED

1. Deflections are not measured on rigid pavements or on flexible pavements with cement-treated bases.
2. Personnel problems include scheduling and motivating personnel to travel statewide.
3. Improved communication among the several units involved in the management program is essential.
5. Independence of units makes it difficult to coordinate all available data (traffic, road log, etc.).
5. Accurate 18-kip axle loading is required.

SAMPLING PROGRAM

The data collection process is performed on an annual basis. The sampling program includes the following steps:

1. District personnel subjectively rate pavements in each maintenance functional code (MFC). Pavements considered to be in the lowest 5 to 10 percent of their class are nominated for objective evaluation.
2. Roads selected by the districts are rated with the Mays meter. The PSI is calculated from this sampling.
3. Roads falling below the terminal serviceability index (TSI) are then evaluated using the Road Rater.

Skid resistance measurements are a separate area in the sampling program. Skid tests are performed on the Interstate highway system every 2 yr. Ten 250-ft sections per mile are evaluated.

USE OF DATA

The information from the data collection process is used primarily to program the pavements most in need of resurfacing.

Programming

The highway system is divided into five categories using the maintenance functional code (MFC) system established by the FHWA:

MFC A = Interstate highways
MFC B = Other expressways and principal highways
MFC C = Minor arterial highways
MFC D = Collector highways
MFC E = Local access highways

Roughness data are used to calculate the PSI of the test sections. The acceptable level of riding quality has been established by plotting PSI distributions for individual MFC

TABLE F-1

ESTIMATED YEARLY COSTS FOR TESTING OF PRESENT PAVEMENT CONDITIONS ($) *(38)*[a]

Item	Description	Testing For Skid Resistance	Testing For Riding Quality	Testing For Structural Strength
1.	Salaries and Wages[b]			
	a) Engineering & Supervision	35,000	35,000	35,000
	b) Technicians	108,500	93,000	31,000
	c) Personnel for Traffic Control			31,000
	Subtotal	$143,500	$128,000	$97,000
2.	Equipment Rental			
	a) Test Equipment (depreciation - 5 yr)	85,000	6,000	12,000
	Subtotal	$85,000	$6,000	$12,000
3.	Travel			
	a) Lodging	8,000	9,000	6,000
	b) Subsistence	5,000	4,000	4,000
	c) Mileage - Mays Meter (17¢/mi) Skid (40¢/mi) Road Rater (40¢/mi)	17,000	17,000	14,000
	Subtotal	$30,000	$30,000	$24,000
4.	Reports (including computer costs)	3,000	3,000	3,000
	Subtotal	$3,000	$3,000	$3,000
5.	Benefits			
	a) 64.76% of Salaries	92,900	82,900	62,800
	Subtotal	$92,900	$82,900	$62,800
	TOTAL[c]	$354,400	$249,900	$198,800
		$208/mi	$25/mi	$99/mi

[a] The cost of operating the core drilling function is not included in these cost estimates.

[b] Technicians are assigned to the various testing areas as the work load shifts. Work force required for each unit consists of one Soils Engineer IV, eight for skid resistance, seven for serviceability, five for structural strength, and one drill operator.

[c] Personnel are reassigned to other work in winter and during slow periods. Time did not permit accounting for these costs. Thus the actual cost for pavement condition testing is lower than these estimates.

categories. The minimal level of acceptable ride quality, referred to as the terminal serviceability index (TSI), has been defined as the 95 percent PSI level for each functional code:

MFC	TSI
A	3.30
B	2.20
C	3.00
D	2.50
E	2.20

The use of the 95 percent PSI level for the TSI is arbitrary and reflects funding and construction availability. The TSI values can be increased or lowered when these factors change. The TSI concept ensures that the available funds will be spent on the pavements most in need of repair in each MFC category.

Overlay Design

Both deflection and distress data are used in determining the required overlay thickness. A computer program is used to design the thickness of structural overlay required to reduce deflections to acceptable level. The design analysis is performed primarily on the basis of deflection measurements and the design number of 18-kip equivalent axle loads.

Maintenance Management

The results of the trained observer surveys are a major factor in the procedure for allocating maintenance funds to the counties. The data from the trained observer surveys are used also to monitor the statewide condition of the highway system.

FURTHER OBSERVATIONS

The following procedures are essential in an effective system:

- Keep the system simple and implement in stages.
- Provide good communication among all work units.
- Use the data collected (this provides evaluators with job motivation).

APPENDIX G

U.S. AIR FORCE—CURRENT PRACTICE

An airfield pavement condition evaluation procedure has been developed for the U.S. Air Force by the U.S. Army Construction Engineering Research Laboratory to assist in the development of maintenance and rehabilitation (M & R) needs for the airfield pavements maintained by the U.S. Air Force. The following information was obtained from communications with Dr. Mohamed Shahin (U.S. Army Construction Engineering Research Laboratory) and from various technical papers and reports (*39–41*).

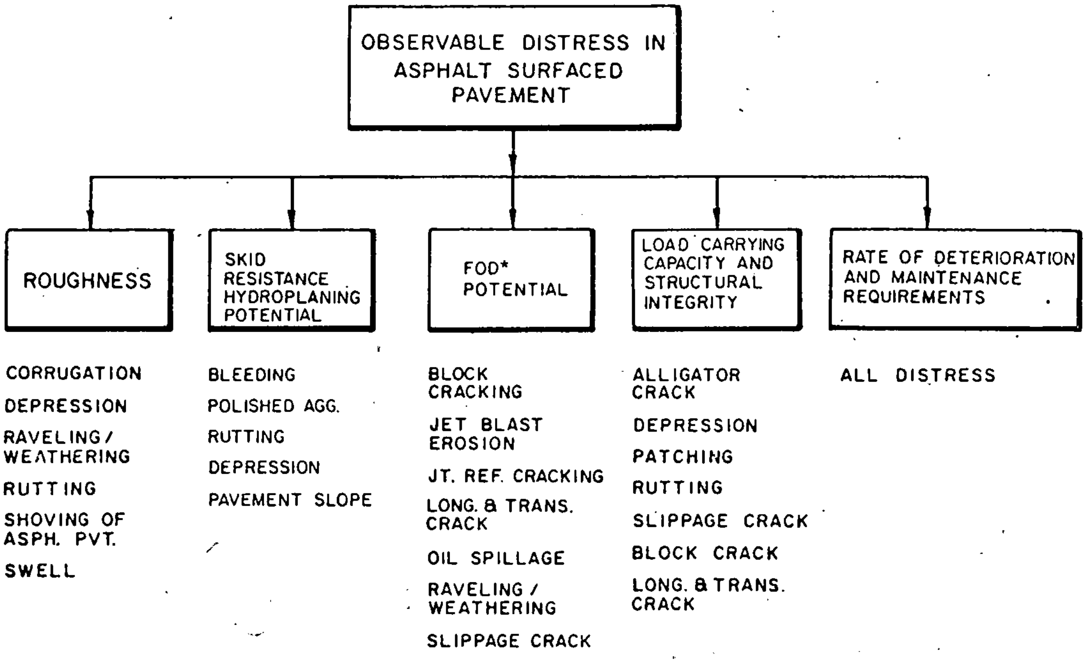
TYPES OF DATA COLLECTED

A primary source of information used for determining airfield pavement condition is visually determined distress data. The pavement condition index (PCI) is calculated using the distress data from 15 distress types for concrete-surfaced pavements and 14 distress types for asphalt- or tar-surfaced pavements. The PCI score ranges from 100 (no distress) to 0 (highly distressed) and is used to quantify the pavement structural integrity and surface operational condition. The PCI and the resulting pavement condition rating (excellent, very good, good, fair, poor, very poor, or failed) closely agree with the collective judgment of experienced pavement engineers. The PCI and condition rating also highly correlate with the level of needed maintenance and rehabilitation.

The airfield pavement condition rating procedure is based on factors called condition indicators:

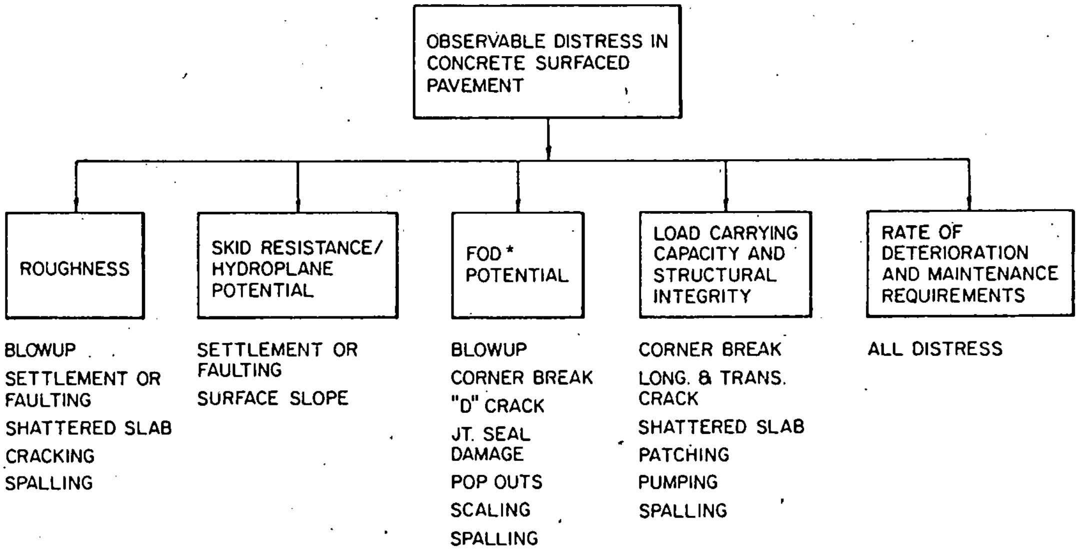
1. Operational surface indicators
   a. Roughness
   b. Skid resistance by hydroplaning potential
   c. Foreign object damage potential
2. Structural indicators
   a. Structural integrity
      (i) Cracking
      (ii) Distortion
      (iii) Disintegration
   b. Load carrying capacity
3. Other indicators
   a. Rate of deterioration
   b. Amount of previous M & R applied

The above pavement condition indicators are related to observable pavement distress as shown in Figures G-1 (asphalt-surfaced pavements) and G-2 (jointed concrete pavements).



* Foreign Object Damage (FOD) to Jet Engines.

FIGURE G-1 Pavement condition indicators as related to observable distress—for asphalt-surfaced pavements (*39*).



* Foreign Object Damage (FOD) to Jet Engines.

FIGURE G-2 Pavement condition indicators as related to observable distress—for concrete pavements (*39*).

Specifically, the PCI is a function of the following:

1. Type of distress,
2. Severity of distress, and
3. Density of distress (area).

The formula used to calculate the PCI is a function of deduct points:

$$\mathrm{PCI} = \mathrm{C} - \left[\sum_{i=1}^{p} \sum_{j=1}^{M_i} a(T_j, S_j, D_{ij}) \right] \times F(t,q)$$

where

PCI = pavement condition index,
C = constant depending on desired maximum scale value (normally 100),
$a(\ )$ = deduct weighting value depending on distress type T_i, level of severity S_j, and density of distress D_{ij},
M_i = number of severity levels on the ith type of distress,
$F(t,q)$ = adjustment function for multiple distresses that varies with total summed deduct value (t) and number of deducts (q),
i = number of types of distress,
j = number of levels of severity, and
p = total number of types of distress pavement type.

DATA REDUCTION AND STORAGE

All information is stored and fully processed in a computer program.

The costs associated with the sampling and data processing for a typical U.S. Air Force base are not well-documented. The development costs associated with the PCI concept were reported to be $161,700.

PROBLEMS ENCOUNTERED

No significant problems exist in the data collection system.

SAMPLING PROGRAM

Individual pavement features (runway, taxiway, etc.) are defined as those pavement sections (within runways, taxiways, and aprons) with consistent structural thickness and materials and identical construction (type and time), and subjected to similar amounts and types of traffic. The PCI of a feature is sampled by the following procedure:

1. Pavement feature is divided into sample units. Sample unit for concrete pavement is approximately 20 slabs, and for asphalt, approximately 5,000 ft^2 surfaced pavement (Step 1, Figure G-3).
2. Sample units are inspected and distress types, along with corresponding severity and densities (areas), are recorded (Step 2, Figure G-3).
3. For each distress type recorded, deduct values are determined (Step 3, Figure G-3).
4. Total deduct value is determined by adding all deduct values in sample unit (Step 4, Figure G-3).
5. Corrected deduct values are determined (Step 5, Figure G-3).
6. PCI for sample unit is calculated.
7. Overall PCI for a feature is determined by averaging the PCI's from all sample units inspected.
8. Pavement condition rating (verbal description) is determined (Step 8, Figure G-3).

After the overall PCI rating is determined, a condition evaluation summary is made in accordance with the form shown in Figure G-4.

The recommended minimum sampling frequency is every 5 yr. The PCI and evaluation summary (Figure G-4) are determined at shorter intervals for project justification or if the pavement is deteriorating at a rapid rate.

USE OF DATA

The data are used primarily to determine the maintenance and rehabilitation needs of airfield pavements. Possible maintenance and rehabilitation strategies are divided into three general categories:

1. Routine M & R: Consists of performing preventive and/or localized maintenance and rehabilitation by such methods as crack sealing, joint sealing, and application of fog seals and rejuvenators.
2. Major localized M & R: An extensive form of localized M & R, which includes partial-depth or full-depth patching, slab replacement, slab undersealing, and slab grinding. The area of a feature within this category is generally greater than 3.5 percent of the total surface area.
3. Overall M & R: Includes the entire pavement feature. Load-carrying capacity is usually improved, and such strategies as overlaying, recycling, and total reconstruction are included.

Figure G-5 shows the ranges of PCI within each maintenance and rehabilitation category (zone), based on the opinions (without knowledge of the PCI values) of experienced engineers with respect to the required maintenance and rehabilitation activity for numerous pavements. Figure G-6 shows the variations of the PCI along a runway feature. Specific routine or major maintenance and rehabilitation alternatives for various types of existing distress and associated severities are given in Tables G-1 and G-2.

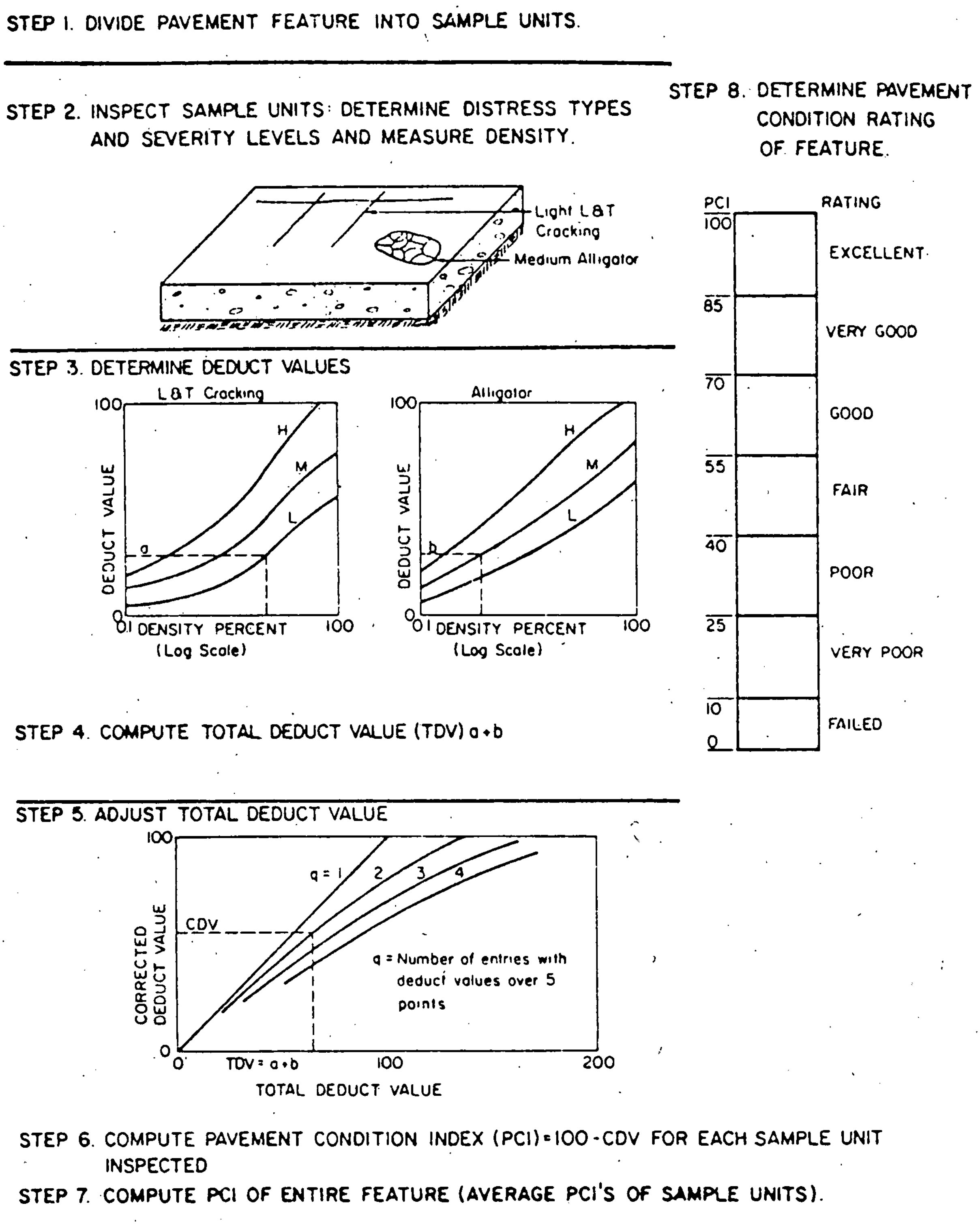


FIGURE G-3 Process for determining the PCI of a pavement feature (*39*).

1. Overall Condition Rating - PCI
   Excellent, Very Good, [✓ Good,] Fair, Poor, Very Poor, Failed.
2. Variation of Condition Within Feature - PCI
   a. Localized Random Variation — [✓ Yes,] No
   b. Systematic Variation — [✓ Yes,] No
3. Rate of Deterioration of Condition - PCI
   a. Long-term period (since construction) — [✓ Low,] Normal, High
   b. Short-term period (1 year) — Low, Normal, [✓ High]
4. Distress Evaluation
   a. Cause
      [✓ Load Associated Distress 58] percent deduct values
      Climate/Durability Associated 36 percent deduct values
      Other(Fault)Associated Distress 6 percent deduct values
   b. Moisture Accelerated Distress — Minor, [✓ Moderate,] Major
5. Load Carrying Capacity Deficiency — No, [✓ Yes]
6. Surface Roughness — Minor, [✓ Moderate,] Major
7. Skid Resistance/Hydroplaning (runways only)
   a. Mu-Meter
      No hydroplaning problems are expected
      Transitional
      Potentional for hydroplaning
      Very high probability
   b. Stopping Distance Ratio
      No hydroplaning anticipated
      Potential not well defined
      Potential for hydroplaning
      Very high hydroplaning potential
   c. Transverse Slope — Poor, Fair, [✓ Good, Excellent]
8. Previous Maintenance — Low, Normal, [✓ High]

FIGURE G-4 Airfield pavement condition evaluation summary (*39*). Note: Circled items refer to the field case study.

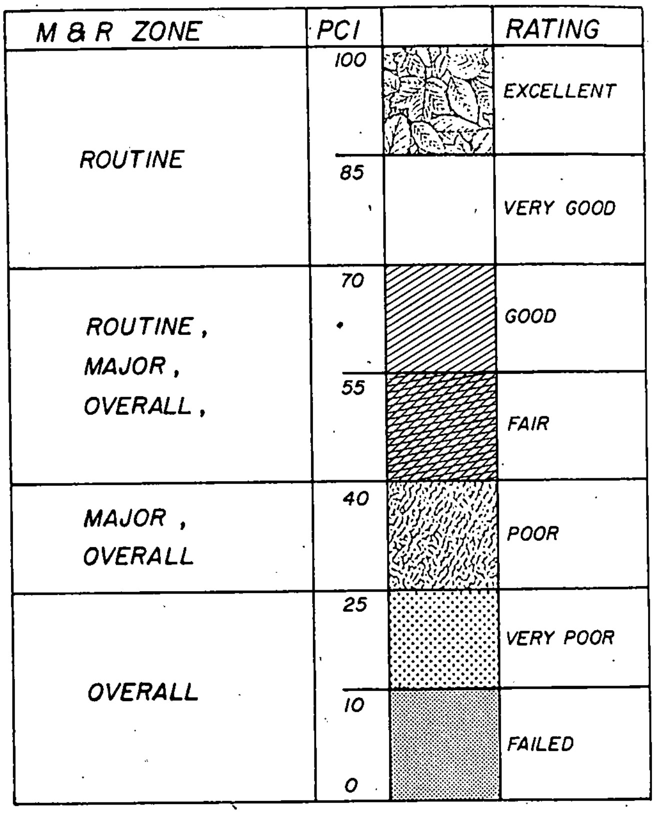


FIGURE G-5 Correlation of M & R zones with the PCI and condition rating (*39*).

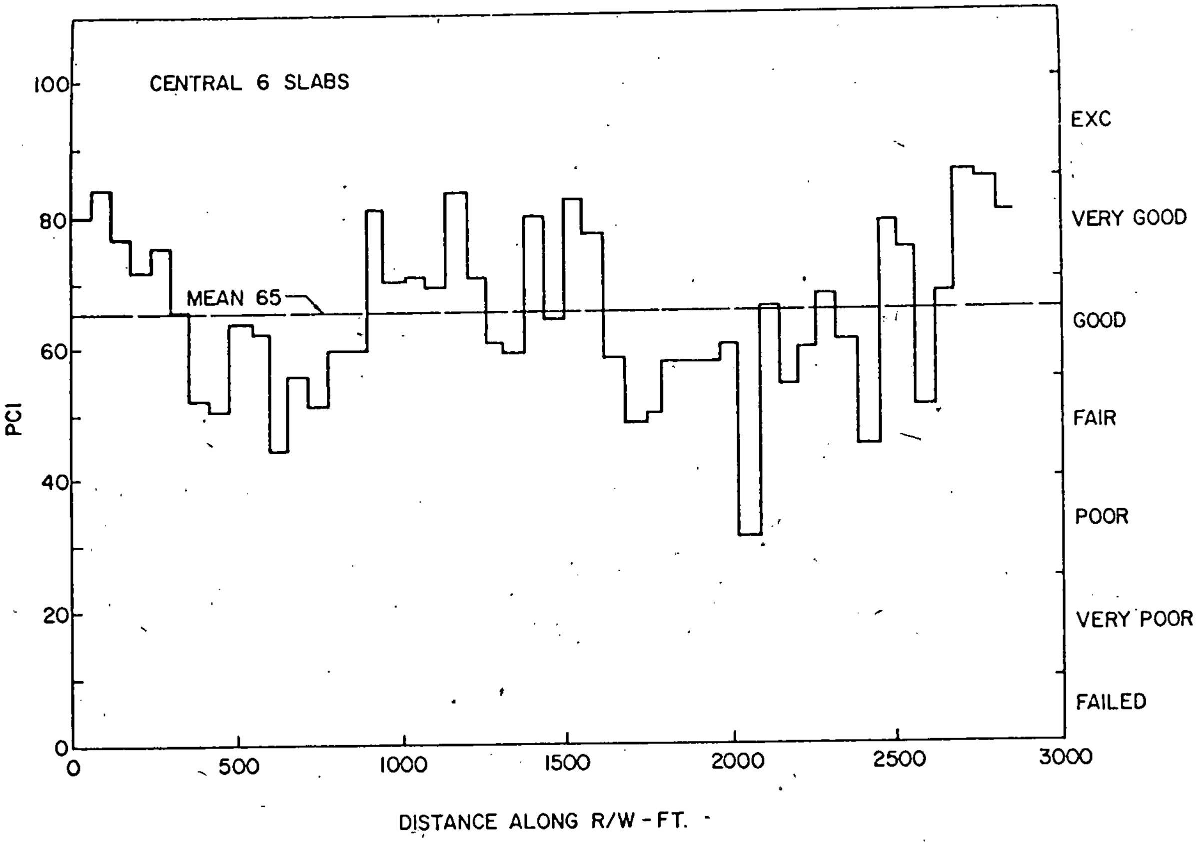


FIGURE G-6 PCI profile along runway feature (*39*).

TABLE G-1

RECOMMENDED PREVENTIVE AND LOCALIZED M & R METHODS FOR JOINTED-CONCRETE-SURFACED AIRFIELD PAVEMENTS (*39*)

Type of Distress	Doing Nothing	Crack Sealing	Joint Sealing	Partial-Depth Patching (bonded)	Full-Depth Patching	Slab Replacement	Slab Undersealing	Slab Grinding	Slab Jacking Grouting
Blowup				L or M[a]	H[a]	H[a]			
Cornerbreak	L	L, M, or H			M or H				
Longitudinal, transverse, or diagonal cracking	L	L, M, or H		H[b]	H	H			
D-cracking	L	L[c]	L[c]	M or H	M or H	H			
Joint-seal damage	L		M or H[d]						
Small patches (<0.46 m²)	L	M		M or H[e]	H[e]				
Large patches (>0.46 m²)	L	M		M or H[e]	H[e]	H			
Pop-outs	A								
Pumping		A	A				A		
Crazing and sealing	L			M or H		H			
Settlement and faulting	L					H		M or H	M or H
Divided slab		L, M, or H				M or H			
Shrinkage cracking	A								
Joint spalling	L		L or M	L, M, or H	M or H[f]	M or H[f]			
Corner spalling	L		L or M	M or H					

Notes: 1 m² = 10.8 ft².

A = type of distress that has only one severity level; L = low-severity distress; M = medium-severity distress; and H = high-severity distress.

[a] Must provide expansion joint.

[b] Allow crack to continue through patch except when using asphalt concrete.

[c] Seal all joints and cracks.

[d] Joint seal local areas.

[e] Replace patch.

[f] Only when surface is unacceptable.

[g] If caused by keyway failure, provide load transfer.

TABLE G-2

RECOMMENDED PREVENTIVE AND LOCALIZED M & R METHODS FOR ASPHALT- OR TAR-SURFACED AIRFIELD PAVEMENTS (*39*)

Type of Distress	Doing Nothing	Crack Sealing	Partial-, Depth Patching	Full-Depth Patching	Skin Patching	Heating and Sand Rolling	Fog Sealing[a] (emulsion)	Application of Rejuvenator	Application of Aggregate Sealing Coat
Alligator cracking			M or H	M or H				L or M	
Bleeding	A					A			
Block cracking	L	L, M, or H						L	L or M
Corrugation	L	M or H	M or H						
Depression	L	M or H	M or H	M or H					
Jet blast	A		A		A		A		A
Joint reflection cracking	L	L, M, or H	H						
Longitudinal and transverse cracking	L	L, M, or H	H					L	L or M
Oil spillage	A		A	A					
Patching	L	M	M[b]	H[b]					
Polished aggregates	A								A
Raveling and weathering	L	H					L or M	L	M or H
Rutting	L		M or H	M or H	M or H				
Shoving	L	M or H							
Slippage cracking	A		A						
Swelling	L			M or H					

Note: A = type of distress that has only one severity level; L = low-severity distress; M = medium-severity distress; and H = high-severity distress.

[a] Requires prior approval by command pavement engineer.

[b] Replace patch.

APPENDIX H

UTAH—CURRENT PRACTICE

The following information is based on a meeting with Dale Peterson, Douglas Anderson, and Dale Davenport in December 1978, and was reviewed by Douglas Anderson in April 1981.

TYPES OF DATA COLLECTED

Pavement condition data are collected on both a subjective and objective basis, and include: ride, distress, deflection, and skid resistance.

Ride

The Cox meter is used to measure roughness data. The meter is mounted in an automobile to measure the relative vertical movements of the rear axle. The data are used to determine the present serviceability index (PSI):

$$PSI = 4.18 - 0.007(RC)^{0.658} - 0.01\sqrt{C + P} - 1.34RD^2$$

where

RC = summation of roughness count/mile,
C = ft^2 of cracked area/1,000 ft^2 of paved surface,
P = ft^2 of patched area/1,000 ft^2 of paved surface, and
RD = average rut depth in inches measured at the deepest part of the rut.

Ride evaluations are made in one direction on primary and secondary highways and in both directions (outer lane) on freeways.

The data are coded on forms, analyzed, and then listed in order from the roughest to the smoothest highway sections on the basis of the average PSI along the section (Figure H-1). A list of sections ranked by minimum PSI within each highway section is also provided by the program (Figure H-2). This list pinpoints short, rough areas, such as patched areas. Finally, a serviceability listing is generated to identify those sections that have reached the terminal serviceability index (TSI) specified for that section (2.5 for highways, 2.0 for low-volume roads) (Figure H-3).

Surface Distress

Subjective evaluation of pavement distress is performed by pavement evaluation crews. A visual inspection of 500 ft in each mile is conducted. The pavement parameters that are surveyed and the rating scales used are shown in Figure H-4.

From the field survey a combined distress index is computed as follows:

$$\text{Distress index} = \frac{(2A + 2M + L + T)}{36}$$

where

A = alligator crack rating,
M = map crack rating,
L = longitudinal crack rating, and
T = transverse crack rating.

Based on this analysis, a list of pavements in each maintenance district, from the most distressed to those with no apparent distress, is provided annually (Figure H-5). As indicated above, pavement cracking alone is considered in the listing; emphasis is placed on alligator and map cracking, as these distress types are usually associated with a more advanced state of deterioration.

Deflection

Structural adequacy is evaluated by measuring deflection with a Dynaflect. Two Dynaflects are used for the annual deflection inventory, which consists of measuring deflection

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	1.9
2	6	106	0.35	Jct. SR-131	4.38	4th No. Bouniful	4.73	2.3
3	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	2.7
4	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	2.7
5	18	186	1.00	East End US-40	0.00	2500 West	1.00	2.9
6	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	3.0
7	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	3.0
8	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	3.0
9	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	3.1
10	18	071	1.00	Draper West	2.82	11,400 South	3.82	3.1

FIGURE H-1 PSI average (*42*).

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	1.2
2	6	106	0.35	Jct. SR-131	4.38	4th No. Bountiful	4.73	2.3
3	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	2.4
4	18	171	5.30	Jct. SR-111	5.30	4000 West	5.30	2.5
5	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	2.7
6	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	2.8
7	18	186	1.00	East End US-40	0.00	2500 West	1.00	2.9
8	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	3.0
9	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	3.0
10	18	071	1.00	Draper West	2.82	11,400 South	3.82	3.1

FIGURE H-2 PSI minimum (*42*).

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M.P.	P.S.I.	T.S.I.
1	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	1.9	2.0

FIGURE H-3 PSI failures (*42*).

Transverse Cracking	Longitudinal Cracking	Map Cracking	Slipperness & Bleeding	Polishing	Rutting	Spalling	Roughness	Patching
5=None	5=None (0-50 Ft. Per Mile)	5=None	5.0=Good, Coarse	5.0=Good, Coarse Angular	5=None or Slight	5=None	5=Very Smooth	5=None
4=Slight (Less than 10 Cracks Per Mile)	4=Slight (50-500 Ft. Per Mile)	4=1 to 4% of the Surface Cracked	4.0=Fair, Granular	4.0=Fair, Rounded	4=1/16" to 1/8"	4=Slight	4=Smooth	4=Slight
3=Moderate (100 to 500 Ft. Between Cracks)	3=Moderate (500-2000 Ft. Per Mile)	3=5 to 10% of the Surface Cracked	3.0=Slight Bleeding	3.0=Aggregate Slightly Polished	3=1/8" to 1/4"	3=Moderate, Some Aggregate Removed	3=Fair	3=Moderate
2=Severe (30 to 100 Ft. Between Cracks)	2=Severe (2000-3500 Ft. Per Mile)	2=11 to 40% of the Surface Cracked	2.0= Moderate Bleeding	2.0= Aggregate Polished Moderately	2=¼ to ½"	2=Poor, Aggregate Eroded ½ Way Through Material	2=Rough	2=Severe
1=Very Severe (Less than 30 Ft. Between Cracks)	1=Very Severe (More than 3500 Ft.)	1=More than 40% of the Surface Cracked	1.0= Bleeding Badly	1.0= Aggregate Polished Severely	1=More than ½"	1=Eroded Completely Through Material	1=Very Rough	1=Very Severe

CONDITION OF CRACKS

OPENING	ABRASION	MULTIPLICITY
5- HAIRLINE OR FILLED	5- NONE	5- NONE
4- 1/16 to 1/8 inch	4- Slight Wear at Edge	4- Few Assoc. Hairline Cracks
3- 1/8 to 1/4 inch	3- Some Aggregate Removed	3- Map Cracks with Trans. Cracks
2- 1/4 to 1/2 inch	2- Eroded 1/2 Way Through Mat.	2- Alligator Cracks with Trans. Cracks
1- greater 1/2 inch	1- Eroded Through Mat.	1- Associated Cracks Dishing Out

CONDITION OF SURFACE

WEAR	WEATHERING
5- NONE - Mat. Uniform	5- NONE - Mat. Original Dark Color
4- Slight Agg. Showing in Wheel Path	4- Slight - Mat. is Color of the Agg. (not protuding)
3- Moderate Agg. Showing Protruding up to 1/16 inch.	3- Moderate - Agg. Protrudes Across Whole Mat.
2- Severe Agg. Showing Protruding one 1/16 inch.	2- Cracks Due to Weathering
1- Abrasion More Then 20% Agg. Kicked out in W. P.	1- Agg. Kicked out 20% Uniformly Across Pavement

POPOUTS	UNIFORMITY
5- Less Than 1 per 3 Sq. Ft.	5- Good
4- 1 to 5 per Sq. Ft.	4- Streaked
3- 6 to 10 per Sq. Ft.	3- Cracks Sealed
2- 11 to 15 per Sq. Ft.	2- Blotchy
1- More than 15 per Sq. Ft.	1- Non-uniform

FIGURE H-4 Field sheet for surface rating systems.

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	186	1.00	East End US-40	0.00	2500 West	1.00	1.0
2	18	071	1.00	Draper West	2.82	11,400 South	3.82	1.0
3	6	106	0.35	Jct. SR-131	4.38	4th. N. Bountiful	4.73	1.0
4	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	3.0
5	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	3.3
6	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	3.6
7	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	3.7
8	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	3.8
9	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	4.2
10	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	5.0

FIGURE H-5 Distress analysis (*42*).

on one segment of each mile. A maintenance engineer may request a second analysis to obtain more extensive data in weak areas. Deflection parameters used to estimate the strength of the surface and base layers are the Dynaflect maximum deflection (DMD), the surface curvature index (SCI), and the base curvature index (BCI). The data are used to estimate years to failure. For comparison purposes, the remaining life prediction has been converted to a 1 to 5 rating similar to that used in the PSI and distress analysis:

Years to Failure	*Structural Rating*
>10	5.0
8–10	4.5
6–7	4.0
5	3.5
4	3.0
3	2.5
2	2.0
1	1.5
0	1.0

An example of the structural analysis output for a given district is shown in Figure H-6.

Skid Resistance

The Mu-Meter is used to estimate the friction number by pivoting the testing wheels to an angle with the line of movement at 40 mph and measuring the resulting friction force generated. The friction numbers range from 0 to 100. Values below 35 are considered to indicate a need for pavement surface improvement.

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	1.0
2	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	1.0
3	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	1.5
4	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	1.5
5	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	3.5
6	18	171	1.75	Redwood Road	8.18	Jct. SR I-15	9.91	4.5
7	6	106	0.35	Jct. SR-131	4.38	4th. N. Bountiful	4:73	4.5
8	18	186	1.00	East End US-40	0.00	2500 West	1.00	4.5
9	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	5.0
10	18	071	1.00	Draper West	2.82	11,400 South	3.82	5.0

FIGURE H-6 Structural analysis (*42*).

Areas 0.10-mi long are tested every mile in each section. Any areas that appear to be slippery are also tested. Two lists are provided to the maintenance people: the average friction numbers in each section (Figure H-7); and the minimum values in each section (Figure H-8). The minimum ranking can identify a slippery area, such as a bleeding patch, that might otherwise be lost in the average.

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	071	1.00	Draper West	2.82	11,400 South	3.82	29
2	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	33
3	18	186	1.00	East End US-40	0.00	2500 West	1.00	35
4	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	43
5	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	49
6	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	51
7	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	56
8	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	58
9	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	63
10	6	106	0.35	Jct. SR-131	4.38	4th. N. Bountiful	4.73	70

FIGURE H-7 Skid average (*42*).

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M. P.	Index
1	18	071	1.00	Draper West	2.82	11,400 South	3.82	29
2	18	270	0.75	East End I-15	0.00	1st. W. Railroad	0.75	30
3	18	186	1.00	East End US-40	0.00	2500 West	1.00	33
4	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	33
5	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	41
6	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	49
7	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	49
8	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	50
9	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	53
10	6	106	0.35	Jct. SR-131	4.38	4th. N. Bountiful	4.73	62

FIGURE H-8 Skid minimum (*42*).

Overall Rating

A combined rating, calculated by using the PSI, structural index, and distress index, is used in establishing maintenance priorities. The friction number is a surface problem and thus is not directly related to the other forms of distress.

A final index (FI) is calculated as follows:

$$FI = 0.47 \, [F_1 \, (PSI)^{1.5} + F_2 \, (SI)^{1.5} + F_3 \, (DI)^{1.5}]$$

where

PSI = present serviceability index,
SI = structural index,
DI = distress index, and
F_1, F_2, F_3 = weighting functions (Table H-1).

The overall rating (FI) obtained by this method is shown in Figure H-9 along with the other ratings.

TABLE H-1

WEIGHTING FUNCTIONS USED TO ESTABLISH FINAL INDEX[a]

FUNCTIONAL CLASS	LOW AADT[b]			MEDIUM AADT			HIGH AADT		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
1	0.45	0.25	0.30	0.50	0.20	0.30	0.55	0.15	0.30
2	0.40	0.30	0.30	0.45	0.25	0.30	0.50	0.20	0.30
3	0.35	0.35	0.30	0.40	0.30	0.30	0.45	0.25	0.30
4	0.30	0.40	0.30	0.35	0.35	0.30	0.40	0.30	0.30
5	0.25	0.45	0.30	0.20	0.40	0.30	0.35	0.35	0.30

[a] If speed limit is greater than 40 mph, F1 is increased by 0.05 and F2 is reduced by 0.05. If percent heavy trucks is greater than 5%, F2 is increased by 0.1, and F1 and F3 are reduced by 0.05.

[b] Annual average daily traffic.

Detailed Data Sheet

For each pavement section tested, a printout is generated showing the condition of each mile with respect to ride, distress, structural adequacy, and skid resistance (Figure H-10). This printout provides detailed condition information related to each type of data, furnishes a profile of condition for use by design and maintenance personnel, and predicts the remaining life of the section.

DATA REDUCTION AND STORAGE

The pavement inventory data are hand-reduced on the coding forms by milepost, keypunched, and edited before filing in the computer. The computer system (Univac 1160) sorts, merges, records, and analyzes incoming field data. The system combines these data with traffic information, and, by means of statistical and empirical methods and equations, lists based on structural adequacy, surface friction, serviceability, and surface distress are developed.

The estimated costs for data collection and reduction are summarized in Table H-2. The costs are calculated to be about $15 to $20 per mile for monitoring 4,130 center-line mi of primary and secondary roads and 940 center-line mi of Interstate highway.

The cost breakdown for types of measurement is estimated as follows:

Measurement	*%*
Deflection	30
Distress	30
Ride	20
Skid	20

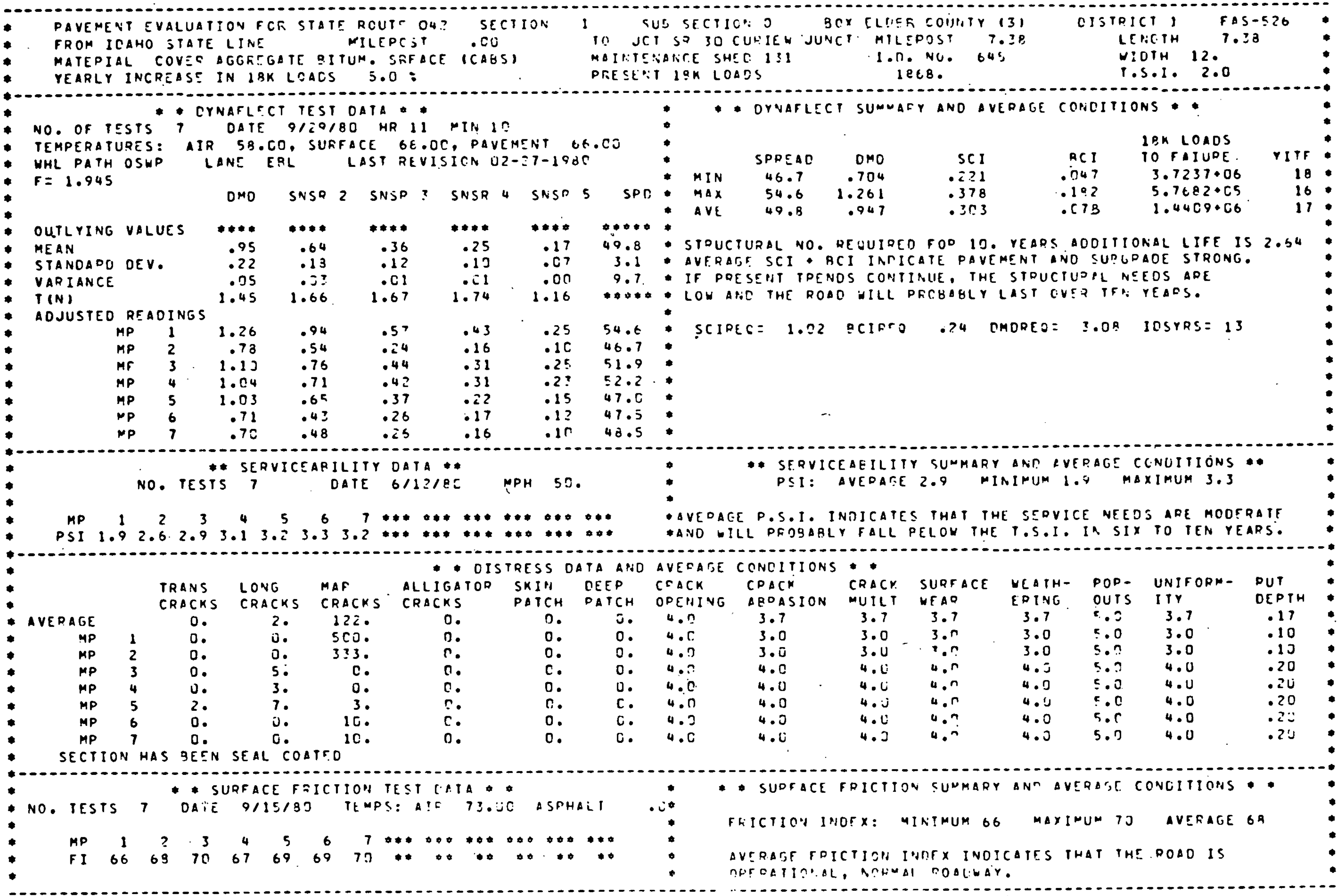
All funds for data collection and analysis processes are derived from the state.

PROBLEMS ENCOUNTERED

1. The teams required to obtain data, particularly distress data, must be well-trained, which requires that the rating scale (Figure H-4) be well-defined and that field personnel undergo training and periodic review.
2. The effects of temperature and/or season of year on ride

No.	Co.	State Route	Length	Beg. Termini	Start M.P.	End Termini	End M.P.	Final Index	Struct.	Distress	P.S.I.	Ave. Skid
1	6	106	0.35	Jct. SR-131	4.38	4th No. Bountiful	4.73	2.4	4.0	1.0	2.3	70
2	18	E02	8.40	Saltair	105.49	SLC Airport	113.89	2.4	1.0	4.2	1.9	58
3	18	201	0.79	Jct. I-15	17.64	Jct. SR-271	18.43	2.4	1.0	3.6	2.7	63
4	18	186	1.00	East End US-40	0.00	2500 W.	1.00	2.5	4.0	1.0	2.9	35
5	18	201	2.03	Redwood Road	15.61	Jct. I-15	17.64	2.6	1.0	3.8	3.1	51
6	18	071	1.00	Draper West	2.82	11,400 South	3.82	2.7	5.0	1.0	3.1	29
7	18	270	0.75	East End I-15	0.75	1st W. Railroad	0.75	2.8	1.0	5.0	3.0	33
8	18	171	1.75	Redwood Road	8.16	Jct. SR I-15	9.91	2.9	4.0	3.0	2.7	49
9	22	E02	3.60	Coalville	167.72	Echo Dam	171.32	3.0	3.0	3.7	3.0	43
10	18	171	5.30	Jct. SR-111	0.00	4000 West	5.30	3.2	5.0	3.3	3.0	56

FIGURE H-9 Final summary table (*42*).



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*    PAVEMENT EVALUATION FOR STATE ROUTE 042   SECTION   1       SUB SECTION 0     BOX ELDER COUNTY (3)     DISTRICT 1     FAS-526  *
*    FROM IDAHO STATE LINE           MILEPOST    .00         TO  JCT SR 30 CURIEW JUNCT  MILEPOST    7.38          LENGTH     7.38    *
*    MATERIAL  COVER AGGREGATE BITUM. SRFACE (CABS)          MAINTENANCE SHED 131          I.D. NO.  645           WIDTH  12.         *
*    YEARLY INCREASE IN 18K LOADS   5.0 %                    PRESENT 18K LOADS              1868.                  T.S.I.  2.0        *
*----------------------------------------------------------------------------------------------------------------------------------*
*                 * * DYNAFLECT TEST DATA * *                            *     * * DYNAFLECT SUMMARY AND AVERAGE CONDITIONS * *      *
*  NO. OF TESTS  7     DATE  9/29/80  HR 11  MIN 10                      *                                                           *
*  TEMPERATURES:  AIR  58.00, SURFACE  66.00, PAVEMENT  66.00            *                                          18K LOADS        *
*  WHL PATH OSWP    LANE  ERL      LAST REVISION 02-27-1980              *        SPREAD     DMD        SCI        BCI  TO FAIURE  YITF *
*  F= 1.945                                                              *  MIN    46.7     .704       .221       .047  3.7237+06   18 *
*                      DMD    SNSR 2   SNSR 3   SNSR 4   SNSR 5    SPD   *  MAX    54.6    1.261       .378       .192  5.7682+05   16 *
*                                                                        *  AVE    49.8     .947       .303       .078  1.4409+06   17 *
*  OUTLYING VALUES     ****    ****     ****     ****     ****    *****  *                                                           *
*  MEAN                 .95     .64      .36      .25      .17    49.8   * STRUCTURAL NO. REQUIRED FOR 10. YEARS ADDITIONAL LIFE IS 2.64 *
*  STANDARD DEV.        .22     .13      .12      .10      .07     3.1   * AVERAGE SCI + BCI INDICATE PAVEMENT AND SUBGRADE STRONG.   *
*  VARIANCE             .05     .03      .01      .01      .00     9.7   * IF PRESENT TRENDS CONTINUE, THE STRUCTURAL NEEDS ARE       *
*  T(N)                1.45    1.66     1.67     1.74     1.16   *****   * LOW AND THE ROAD WILL PROBABLY LAST OVER TEN YEARS.        *
*  ADJUSTED READINGS                                                     *                                                           *
*           MP   1     1.26     .94      .57      .43      .25    54.6   *  SCIREQ=  1.02  BCIREQ   .24  DMDREQ=  3.08  IDSYRS= 13    *
*           MP   2      .78     .54      .24      .16      .10    46.7   *                                                           *
*           MP   3     1.10     .76      .44      .31      .25    51.9   *                                                           *
*           MP   4     1.04     .71      .42      .31      .23    52.2   *                                                           *
*           MP   5     1.03     .65      .37      .22      .15    47.0   *                                                           *
*           MP   6      .71     .43      .26      .17      .12    47.5   *                                                           *
*           MP   7      .70     .48      .26      .16      .10    48.5   *                                                           *
*----------------------------------------------------------------------------------------------------------------------------------*
*                 ** SERVICEABILITY DATA **                              *     ** SERVICEABILITY SUMMARY AND AVERAGE CONDITIONS **    *
*          NO. TESTS  7       DATE  6/12/80    MPH  50.                  *          PSI:  AVERAGE 2.9   MINIMUM 1.9   MAXIMUM 3.3    *
*                                                                        *                                                           *
*    MP   1   2   3   4   5   6   7 *** *** *** *** *** ***             *AVERAGE P.S.I. INDICATES THAT THE SERVICE NEEDS ARE MODERATE *
*   PSI 1.9 2.6 2.9 3.1 3.2 3.3 3.2 *** *** *** *** *** ***             *AND WILL PROBABLY FALL BELOW THE T.S.I. IN SIX TO TEN YEARS. *
*----------------------------------------------------------------------------------------------------------------------------------*
*                                         * * DISTRESS DATA AND AVERAGE CONDITIONS * *                                              *
*                TRANS   LONG    MAP    ALLIGATOR  SKIN   DEEP   CRACK    CRACK     CRACK  SURFACE  WEATH-  POP-  UNIFORM-   RUT   *
*                CRACKS  CRACKS  CRACKS CRACKS     PATCH  PATCH  OPENING  ABRASION  MUILT  WEAR     ERING   OUTS  ITY        DEPTH *
* AVERAGE          0.      2.    122.      0.        0.     0.    4.0      3.7       3.7    3.7      3.7    5.0   3.7         .17  *
*      MP   1      0.      0.    500.      0.        0.     0.    4.0      3.0       3.0    3.0      3.0    5.0   3.0         .10  *
*      MP   2      0.      0.    333.      0.        0.     0.    4.0      3.0       3.0    3.0      3.0    5.0   3.0         .10  *
*      MP   3      0.      5.      0.      0.        0.     0.    4.0      4.0       4.0    4.0      4.0    5.0   4.0         .20  *
*      MP   4      0.      3.      0.      0.        0.     0.    4.0      4.0       4.0    4.0      4.0    5.0   4.0         .20  *
*      MP   5      2.      7.      3.      0.        0.     0.    4.0      4.0       4.0    4.0      4.0    5.0   4.0         .20  *
*      MP   6      0.      0.     10.      0.        0.     0.    4.0      4.0       4.0    4.0      4.0    5.0   4.0         .20  *
*      MP   7      0.      0.     10.      0.        0.     0.    4.0      4.0       4.0    4.0      4.0    5.0   4.0         .20  *
*    SECTION HAS BEEN SEAL COATED                                                                                                  *
*----------------------------------------------------------------------------------------------------------------------------------*
*             * * SURFACE FRICTION TEST DATA * *                        *     * * SURFACE FRICTION SUMMARY AND AVERAGE CONDITIONS * * *
* NO. TESTS  7   DATE  9/15/80   TEMPS: AIR  73.00  ASPHALT     .0*                                                                  *
*                                                                        *     FRICTION INDEX:  MINIMUM 66   MAXIMUM 70   AVERAGE 68  *
*    MP   1   2   3   4   5   6   7 *** *** *** *** *** ***             *                                                           *
*    FI  66  68  70  67  69  69  70  **  **  **  **  **  **             *     AVERAGE FRICTION INDEX INDICATES THAT THE ROAD IS      *
*                                                                        *     OPERATIONAL, NORMAL ROADWAY.                           *
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FIGURE H-10 Printout showing condition of each mile with respect to ride, distress, structural adequacy, and skid resistance.

TABLE H-2

ESTIMATED COSTS FOR DATA COLLECTION AND ANALYSIS

	1978 - 79	1979 - 80[a]
PERSONNEL	$ 77,000	$ 75,000
TRAVEL	4,500	5,000
EQUIPMENT	7,800	8,000
OTHER	500	800
DATA PROCESSING	1,400	5,600
	$ 91,200	$ 94,400
	$17.99/mi[b]	$18.62/mi[b]

[a] Estimated through June 30, 1980.

[b] Based on 4,130 roadway-miles tested on primary and secondary roads and 940 center-line miles on Interstate highways.

and deflection data must be accounted for to ensure adequate data.

3. Ride and deflection equipment need to be periodically calibrated.
4. The time period for getting out the reports is short. Normally, data collection is started in May in order to produce reports by November.
5. Data processing efforts would be improved if the system were automated.
6. Equipment maintenance is a problem. A ready supply of parts is needed. Equipment maintenance can be reduced by preventive maintenance.
7. Milepost changes lead to difficulties in the comparison of results from one year to another.

SAMPLING PROGRAM

Currently approximately 4,630 mi of primary and secondary roads and 940 mi of Interstate highway are monitored every 2 yr (about 50 percent of the roadways is checked each year). Both portland cement and asphalt concrete pavements are evaluated.

To realize the greatest benefit from the program, the following criteria are used to select projects for evaluation in any given year:

1. Control sections that are tested every year to insure data consistency,
2. Pavements that had an index of below 3.0 for any type of data (deflection, distress, ride, or skid) for the previous year,
3. Sections that are requested for testing by district personnel, and
4. Pavements that have not been tested for 3 yr.

Ride and deflection are evaluated in one direction for primary and secondary roads and in both directions on Interstate highways (outer lane only). Ride is recorded continuously, whereas deflection measurements are taken only once per mile. Distress is evaluated over a 500-ft section in each mile, and friction measurements are taken over a 0.1-mi section in each mile.

The information is coded, keypunched, and stored on the central processor (Univac 1160) for use in establishing maintenance priorities and rehabilitation strategies.

USE OF DATA

The data are used for a variety of activities, including priority programming and establishing rehabilitation strategies, and will eventually be used for pavement management.

Priority Programming

Each year data on serviceability, distress, structural adequacy, and friction number are plotted with previously gathered data to obtain an indication of the change in condition with time (Figure H-11). The data are also used to calculate, at any time, a combined rating or final index (FI), which does not include friction number. The final index and other indexes are shown in Figure H-9, which provides dis-

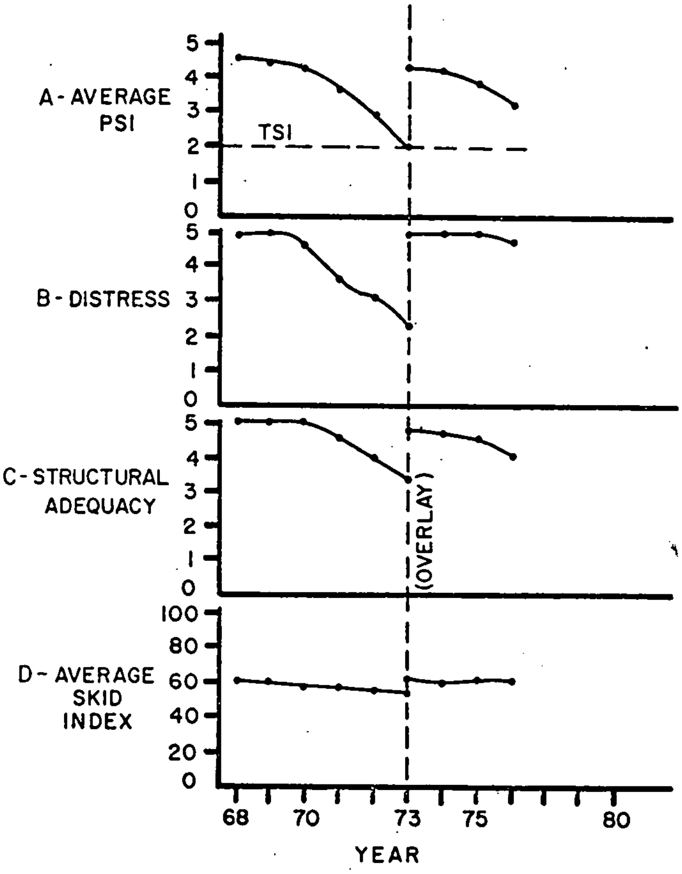

FIGURE H-11 Pavement condition versus time (*42*).

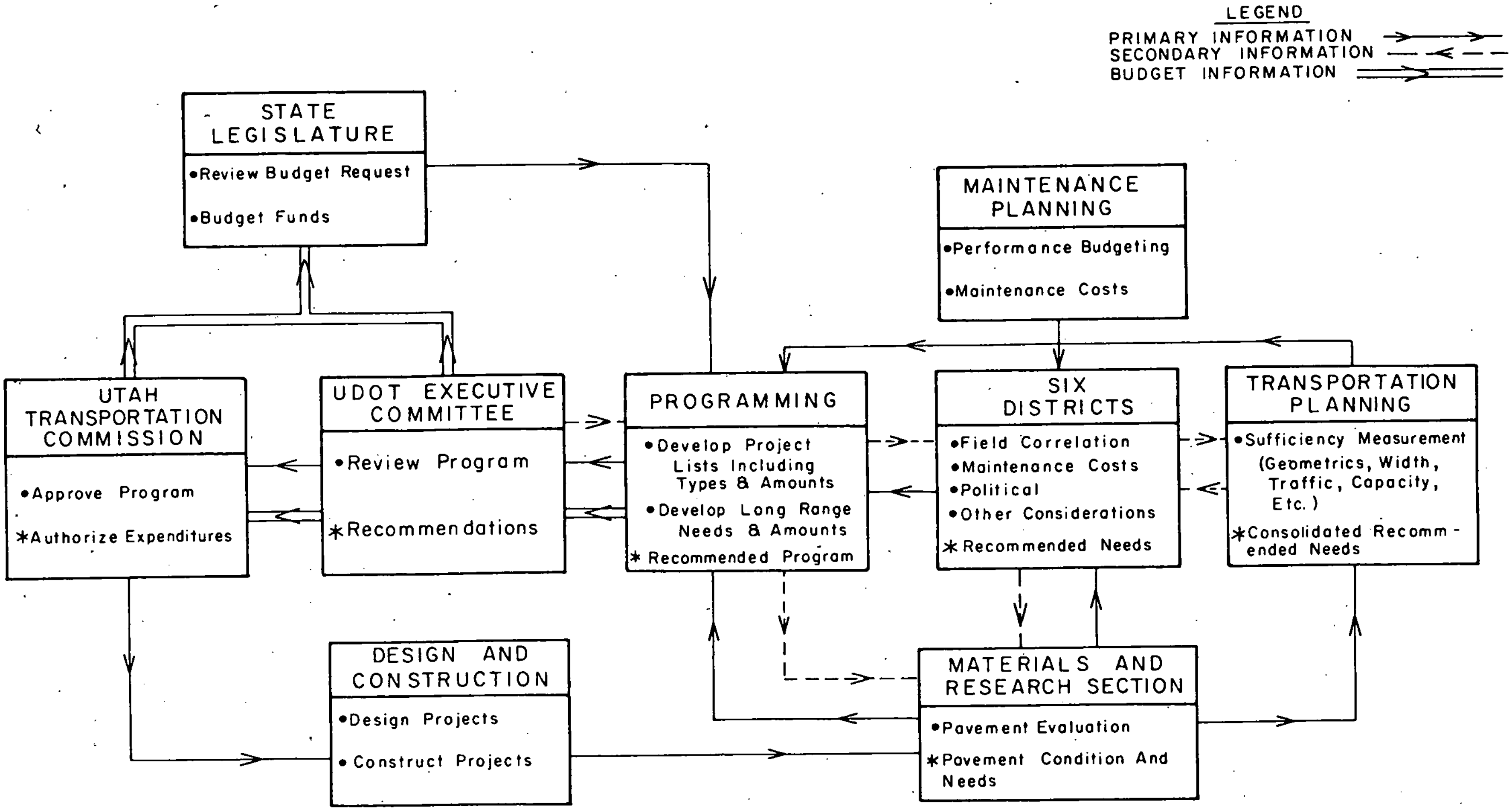

FIGURE H-12 Pavement management and rehabilitation (Utah Department of Transportation).

trict personnel with information on the relative condition of the sections in each category for making decisions regarding needed maintenance.

Establishing Rehabilitation Strategies

The data, along with local experience, are used by district personnel to establish the type of maintenance and rehabilitation (seal, overlay, etc.) required.

Pavement Management

A system is currently being developed that will combine data bases, including traffic volume and accident, maintenance, construction, road life, and pavement evaluation data within a pavement management system. (*43*).

FURTHER OBSERVATIONS

The pavement evaluation system is designed to provide pavement information in the form required by the various districts and divisions for effective management of the pavements. The pavement condition data have application in the following areas:

- Pavement rehabilitation programs,
- Pavement surface maintenance,
- Monitoring pavement performance,
- Improving pavement designs,
- Improving pavement performance,
- Programming funds,
- Planning short- and long-range improvements, and
- Budgeting funds.

The proper management of pavements is expected to produce dividends through savings to the state and the highway user.

The general flow of information related to pavement performance and needs is shown in Figure H-12. The figure also shows the relationship among the various districts and divisions involved with pavement management.

The state is embarking on an extensive pavement rehabilitation program. The pavement evaluation system should be of particular benefit in this area by providing information that can be used in establishing priorities for improvements and in selecting the most promising rehabilitation procedures.

APPENDIX I

WASHINGTON—CURRENT PRACTICE

The following information is based on meetings in November 1978 with R. V. LeClerc, Materials Engineer; Art Peters, Assistant Materials Engineer; Tom Nelson, Pavement Management Engineer; Newton Jackson, Pavement Design Engineer; Bob Gietz, Special Projects Engineer; and Keith W. Anderson, Assistant Special Projects Engineer, of the Washington Department of Transportation.

The information was reviewed by Tom Nelson in March 1980.

TYPES OF DATA COLLECTED

The pavement management system is based on the concept that the present serviceability of a roadway should be a combination of two factors: (a) the quality of the ride provided by the roadway; and (b) the severity of pavement distress or failure. This information has been collected on 8,000 mi of state highway for the past 13 yr.

Ride

The ride score is obtained by objective evaluation. A Cox meter is mounted in a vehicle to measure rear axle deflections along a pavement profile. The ride score (R_8) is based on a scale of 0 to 9 (a score of 0 indicates a "glass" smooth ride and a score of 9 indicates a very rough ride) and is calculated as follows:

$$\text{Asphalt concrete pavement: } R_8 = \left(\frac{\text{CPM}}{30}\right)^{1/2} - 1$$

$$\text{Bituminous surface treatment: } R_8 = \left(\frac{\text{CPM}}{50}\right)^{1/2} - 1$$

$$\text{Portland cement concrete: } R_8 = \left(\frac{\text{CPM}}{40}\right)^{1/2} - 1$$

where

CPM = counts per mile from the meter.

One vehicle is used to evaluate the 8,000 mi of state highway every other year. All roughness data are physically recorded on coding charts for each project and later stored in the main computer for data analysis.

Distress

Distress is evaluated subjectively by judging the severity of pavement distress, and objectively by measuring the actual extent of a distress. Evaluations are performed by two-man teams. Charts displaying the values of defect deductions for flexible and rigid pavements are shown in Figures I-1 and I-2, and the field rating data form is shown in Figure 3 (Chapter 2). The defect deductions are used to determine a structural rating calculated as follows:

$$S_R = 100 - \Sigma D$$

where:

S_R = structural rating, and
ΣD = sum of defect deductions.

To keep the sum of defect deductions on any rated pavement below 100, adjustment values are used as follows.

Total Negative Values	*Adjusted Values*
<90	No adjustment (same value)
91–94	91
95–105	93
106–115	95
116–125	97
126–140	98
>140	99

This adjustment is used because only comparative ratings are desired when pavements have reached the above levels of deterioration and the rankings of roadways for priority programming will not be affected.

Overall Pavement Rating

After completion of the pavement survey, the data are keypunched, audited, corrected, and adjusted to true roadway lengths. The final rating is calculated as follows:

$$\text{Final Rating} = S_R\left(1 - \frac{R_s}{10}\right)^{1/2}.$$

The individual ratings are summarized by pavement type within the length of roadway.

Other Data

Roadway friction data are collected using a K.J. Law test vehicle. The data are not currently used in making pavement management decisions, but will probably be used in the future. Deflection data are infrequently collected with a Benkelman beam, and are used for individual project overlay design; however, the data are not used in making pavement management decisions.

SAMPLING PROGRAM

A ride and pavement condition survey is conducted once every 2 yr on the 8,000 mi of pavement that make up the state highway system. One ride vehicle and four two-man rating teams from the headquarters' Planning and Survey Section make the evaluations. Each team walks the "middle" 200 ft of each subsection (1 mi or less), measures and notes each defect, and then applies the resulting evaluation to the entire subsection.

Uniform recognition and classification of pavement distress are essential. All raters are trained in the recognition of defects and the use of the rating sheets. The teams rate a few preselected sections of roadway. Ratings are compared and a mutual decision is made on the type and extent of the defects noted. Each team spends at least one-half day with a trainer rating the regular sections of roadway to further ensure consistency of evaluation.

TABLE I-1

PROGRAM COSTS (1978–1980)

DATA COLLECTION AND PROCESSING		
Personnel		$ 82,767
Travel		18,884
Equipment rental (including calibration)		29,400
	Subtotal	$ 131,051
Indirect costs @ 20%		26,210
	Total	$ 157,261/8000 mi ≈ $20/mi
PROGRAM DEVELOPMENT		$ 250,000/8000 mi ≈ $31/mi

DATA REDUCTION AND STORAGE

The ride and pavement condition data are hand-recorded on the coding form (see Figure 3 in Chapter 2) by milepost, keypunched, and audited before filing in the computer. The data have been collected since 1967.

The estimated costs for the data collection and data reduction are summarized in Table I-1. Also given are the estimated program development costs.

PROBLEMS ENCOUNTERED

1. Even though raters study color slides of all types of distress, train on actual pavement sections, and work with veteran crews, by far the biggest problem is subjectivity in the evaluations by personnel. Tests given to check consistency of evaluation among the teams produced discouraging results. After the first two surveys were conducted, it was recognized that requiring the efforts of two people from each district for over 3 months was too much of a drain on some offices. Currently, the entire operation is conducted by the headquarters' Planning and Survey Section.
2. Changes or modifications in defect deductions, distress evaluation, equation parameters, or vehicles used to measure roughness result in inconsistencies when previous surveys are compared to the current survey.
3. Milepost updating has created some minor problems. Two types of milepost have been used: control and route mileposts. If either of these are changed because of realignment of routes, the data need to be adjusted. Thus all data banks must be accessible.

USE OF DATA

The data collected have previously been used primarily for priority programming; however, sufficient data have now been acquired for developing performance history for use in pavement management.

Priority Programming

The data from the pavement condition survey are currently used by the Priority Programming Section to prepare recommendations for scheduling future highway construction and maintenance. Pavement condition is one factor used to establish priorities; other factors include bridge conditions, hazardous accident locations, volume-capacity ratio deficiencies, and geometric deficiencies. All projects are assigned a priority ranking related to each factor considered.

Pavement Management

The data are also used in the pavement management system, which is a method of tabulating rehabilitation strategies and their total costs for a system of pavements. The primary function of the system is to provide administrators with the necessary information for planning and budgeting in the overall maintenance of the state roadway system.

A computer program developed to accomplish this task includes the following basic components:

1. Prediction of pavement condition with time.
2. Selection and tabulation of reasonable rehabilitation strategies based on needs shown by predicted performance.
3. Calculation of the cost of each strategy.

Pavement condition data collected over the past 13 yr have been used to develop performance prediction equations. Some typical equations for flexible pavements are given in Table I-2. Prediction models have not yet been developed for portland cement concrete pavements.

As the pavement wears out, the pavement ratings drop

PAVEMENT CONDITION RATING
BITUMINOUS PAVEMENTS
DEFECT DEDUCTIONS

			Negative Values Are Assigned To The Failures By Degree					
			Throughout Rated Section					
			None	1/4-1/2	1/2-3/4	3/4+		
RUTTING PAVEMENT WEAR	Average Depth in Inches	(1) 1/4-1/2"		5				
		(2) 1/2-3/4"			12			Negative Values
		(3) Over 3/4"				20		
			Change Per 10 Feet in Inches					
			None	1/8-2	2-4	4+		
CORRUGATIONS WAVES SAGS HUMPS	Percent of Roadway	(1) 1-25		1	2	3		
		(2) 26-75		2	3	4		Negative Values
		(3) 76+		3	4	5		
			Percent of Wheel Track Per Station					
			None	1-24	25-49	50-74	75+	
ALLIGATOR CRACKING.		(1) Hairline		2	5	10	15	
		(2) Spalling		5	10	15	20	Negative Values
		(3) Spalling & Pumping		10	15	20	25	
				Local-ized	Wheel Paths	Entire Lane		
RAVELING OR FLUSHING		(1) Slight		2	5	10		
		(2) Moderate		5	10	15		Negative Values
		(3) Severe		10	15	20		
			Average Width in Inches					
			None	1/8-1/4	1/4+	Spalled		
LONGITUDINAL CRACKING	Lineal Feet Per Station	(1) 1-99		10	15	20		
		(2) 100-199		15	20	25		Negative Values
		(3) 200+		20	25	30		
			Average Width in Inches					
			None	1/8-1/4	1/4+	Spalled		
TRANSVERSE CRACKING	Number Per Station	(1) 1-4		8	10	15		
		(2) 5-9		9	12	17		Negative Values
		(3) 10+		10	15	20		
			Average Depth in Inches					
			None	0-1/2	1/2-1	1+		
PATCHING	Percent Area Per Station	(1) 1-5		2	5	7		
		(2) 6-25		5	7	10		Negative Values
		(3) 26+		7	10	15		

FIGURE I-1 Defect deductions for use in structural rating for bituminous pavements (*44*).

(Figure I-3) until a level is reached when some type of maintenance *should* be considered (SHUD). If maintenance is not applied at this time, the ratings will continue to drop until some type of maintenance is mandatory (MUST). These levels are constants in the program and can be adjusted by administrators. The rate of decrease is a function of the type of overlay (thin versus thick).

As the pavement wears out, the associated maintenance and user costs increase and the salvage value decreases. The total cost of any alternative is computed by including the following formula:

$$\text{Total cost} = \text{MC} + \text{CALT} + \text{CTI} + \text{UC} - \text{SALV}$$

where

MC = routine maintenance,
CALT = cost of overlay,
CTI = user cost incurred by traffic interruption during rehabilitation,
UC = user cost incurred by traffic as a result of the condition of the road, and
SALV = salvage value of the pavement at the end of the study period.

The program produces a listing including project description and construction history, the performance history with

PAVEMENT CONDITION RATING
CEMENT CONCRETE PAVEMENT
DEFECT DEDUCTIONS

Negative Values Are Assigned
To The Failures By Degree

			Percent of Panels				
			None	1-25	26-50	51+	
CRACKING AVERAGING 1/8+	Units Per Panel Length	(1) 1-2		5	10	20	Negative Values
		(2) 3-4		10	20	35	
		(3) 4+		15	30	50	
			Percent of Area				
			None	1-25	26-75	76+	
RAVELING DISINTEGRATION POPOUTS SCALING		(1) Slight		5	10	20	Negative Values
		(2) Moderate		10	20	35	
		(3) Severe		15	30	50	
			Percent of Joints				
			None	1-15	16-50	51+	
SPALLING AT JOINTS AND CRACKS	Average Width in Inches	¼ (1) 0-1		5	10	20	Negative Values
		(2) 1-3		10	20	35	
		(3) 3+		15	30	50	
			Percent of Panels				
			None	1-15	16-35	36+	
PUMPING BLOWING	Percent of Panel Length	(1) 1-9		5	20	35	Negative Values
		(2) 10-50		10	25	40	
		(3) 51+		15	30	45	
			Blowups Per Mile				
			None	1	2-3	4+	
BLOW-UPS	Number Per Mile	(1) 1		5			Negative Values
		(2) 2-3			10		
		(3) 4+				15	
			Percent of Panels				
			None	1-15	16-35	36+	
FAULTING CURLING WARPING SETTLEMENT	Average Displacement in Inches	½ (1) 0-1/4		0	10	20	Negative Values
		(2) 1/4-1/2		5	15	25	
		(3) 1/2+		10	20	30	
			Percent of Area Per Panel				
			None	1-5	6-25	26+	
PATCHING	Percent of Panels	(1) 1-5		2	5	7	Negative Values
		(2) 6-20		5	7	10	
		(3) 21+		7	10	15	
			Throughout Rated Section				
			None	1/4-1/2	1/2-3/4	3/4+	
RUTTING PAVEMENT WEAR	Average Depth in Inches	(1) 1/4-1/2"		5			Negative Values
		(2) 1/2-3/4"			12		
		(3) Over 3/4"				20	

FIGURE I-2 Defect deductions for use in structural rating for cement concrete pavements (*44*).

TABLE I-2

EXAMPLE OF PERFORMANCE EQUATIONS[a]

ROUTINE MAINTENANCE

$R = 99.85 - 0.21112\ P^{2.25}$

OVERLAYS

0.08 ft $R = 100 - 1.41088\ P^{2.00}$

0.15 ft $R = 100 - 0.13637\ P^{2.50}$

0.25 ft $R = 100 - 0.01615\ P^{3.00}$

where: R = Overall pavement rating

P = Number of years

[a] Separate equations are developed for each project.

developed performance equation, itemized traffic data, a description of certain parameters, and a description of the specific rehabilitation alternatives considered. Results of the analysis are shown at the bottom indicating the optimal timing of each alternative based on least total cost. The selections are provided in order of increasing cost so that the first listing is considered to be optimal from the cost standpoint.

This program is currently being used on a project-by-project basis to evaluate maintenance strategies. However, it is not yet routinely applied to all projects. Future plans are to use this technique to manage the entire state network and develop future budget needs, etc.

FURTHER OBSERVATIONS

1. The inherent weakness of a subjective method for making a comparative ranking is obvious. A system employing objective measurements by mechanical or electronic means will ultimately provide more unbiased results.
2. Improved training of raters is necessary. Inconsistent ratings from year to year is a problem.
3. Selection of a uniform time of year to rate pavements is essential. Ratings can vary with the season of the year.
4. It is important to involve maintenance personnel in the development of management systems.

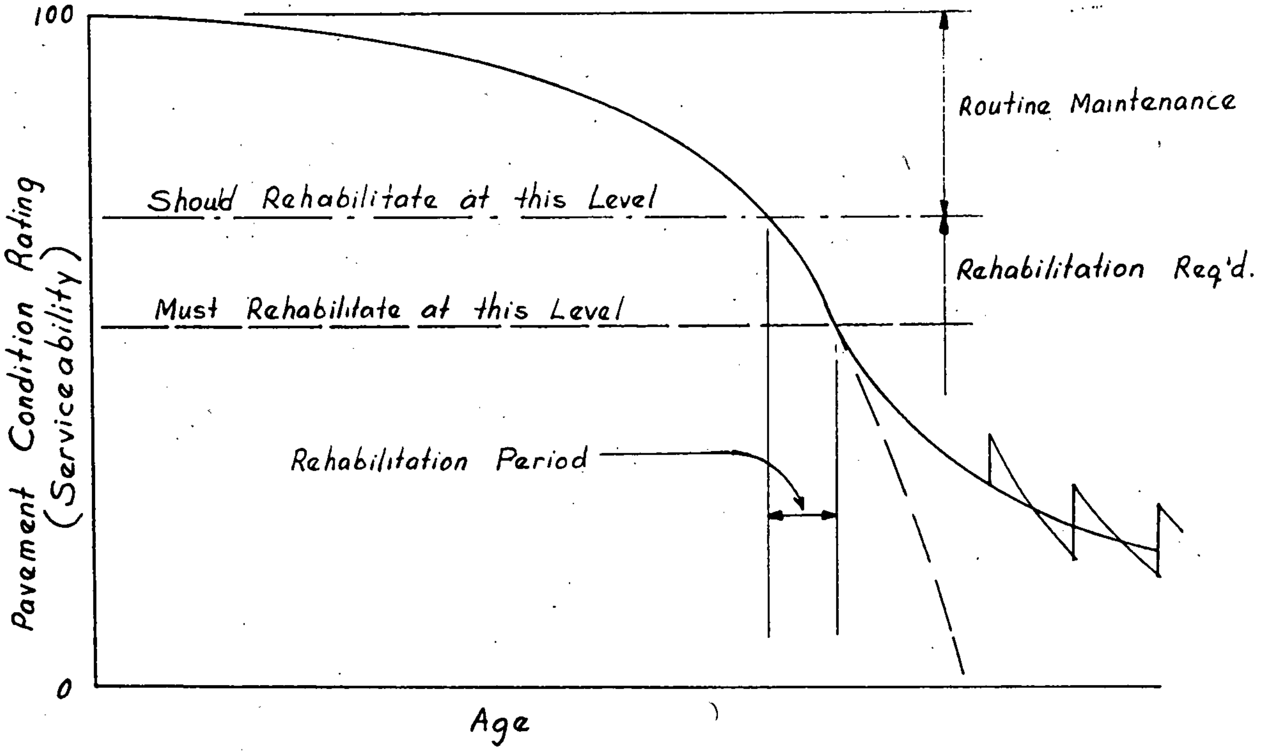

FIGURE I-3 Pavement performance curve.

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