NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

77

EVALUATION OF PAVEMENT MAINTENANCE STRATEGIES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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EVALUATION OF PAVEMENT MAINTENANCE STRATEGIES

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AREAS OF INTEREST

MAINTENANCE
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. SEPTEMBER 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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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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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 to maintenance engineers and others seeking information on strategies for pavement maintenance. Detailed information is presented on the selection of alternative treatments within the context of a pavement management system.

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.

Pavement maintenance is intended to upgrade or preserve the condition of a highway segment above some minimum requirement. Various strategies are used to minimize the total costs of repair, rehabilitation, and restoration. This report of the Transportation Research Board reviews factors that need to be considered in deciding on alternative treatments. Recommendations are included for the application of pavement maintenance strategies as part of a pavement management system.

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.

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This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Technical Activities Division. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Nancy A. Ackerman.

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Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the Project 20-5 Staff and Topic Panel.

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

EVALUATION OF PAVEMENT MAINTENANCE STRATEGIES

SUMMARY

Performance of a pavement is greatly affected by the type, timeliness, and quality of maintenance it receives. Regular maintenance can slow the rate at which a pavement deteriorates from traffic loads and climatic conditions. Nationally, pavements are deteriorating faster than they are being restored because maintenance funds have not been sufficient to take care of the needs.

Delays in pavement repairs generally lead to increased severity of defects and higher maintenance costs. Delay of maintenance and rehabilitation can increase the life-cycle costs of providing a good level of pavement performance and may mean that years later the entire pavement will have to be rebuilt.

Maintenance as used in this synthesis is broadly defined as anything done to the pavement after original construction until complete reconstruction, excluding shoulders and bridges. As such, pavement maintenance includes rehabilitation and restoration. Pavement maintenance strategies are defined as plans of action embodying the continuing application of pavement maintenance techniques that are designed to improve or maintain the condition of a pavement segment above some predetermined minimum requirement. The strategy consists of the type of maintenance, its time for enactment, its design life, and various constraints. The optimum strategy is the alternative that minimizes the expected present value of total costs and maximizes benefits within the constraints imposed.

Pavement maintenance strategies are closely related to and a component of pavement management systems. In recent years a significant amount of work has focused on developing such systems. Pavement management in a broad sense includes all the activities contained in the planning, design, construction, maintenance, and rehabilitation of a pavement. The information required to properly manage pavement maintenance and develop optimum pavement maintenance strategies comes from several subsystems or components of a pavement management system.

The proper identification of pavement deficiencies and their causes is very important in the process of selecting proper treatments and strategies. Pavement condition or performance is generally determined by some rating procedure, which usually considers one or more of the following: surface distress, roughness of ride, surface friction or skid resistance, or structural capacity. Pavement maintenance cost data are considered to be a most desirable addition to the other data, even though they are difficult to obtain.

Pavements deteriorate at various rates because of such factors as traffic loads, pavement age, weather, materials, design, and construction quality. Generally, pavement deterioration becomes more rapid with use and age. It is important to

understand the rate of change or the trend in pavement performance for various conditions. A number of agencies identify and classify pavement deficiencies; in some cases they also identify the causes.

The most common factor that triggers maintenance on a pavement segment is the need to correct deficiencies. Other factors that prompt corrective action are (a) protecting the investment, (b) responding to complaints from users, and (c) acting on observations of maintenance personnel.

Pavement maintenance techniques are the methods used to accomplish a strategy or correct some deficiency in a pavement segment. Maintenance techniques are generally classified according to their function; they are either corrective or preventive. Some techniques serve both functions.

The most common method for classifying pavement maintenance techniques is by surface type, which may be further broken down into treatment type. Listings of techniques provide additional detail on such items as cost, use, and life of each technique.

Several agencies have developed matrices relating pavement deficiencies to applicable maintenance techniques. These are valuable as quick references for identifying the most likely solutions for a specific pavement defect.

A questionnaire identified the most frequently used strategy as the correction of failures or deficiencies; next in frequency was maintenance of the pavements above some minimum performance level. The majority of respondents based their strategies on rational engineering concepts; the next most common base was cost-effectiveness. The methodology most frequently used to develop the process for selecting strategies was use of road condition surveys; next in frequency were use of historical data or experience and use of maintenance management systems or quality standards.

When considering alternative treatments, agencies should take into account required life, costs, effects on road user, and probable performance. Taking no action also has its costs. Because funds are generally limited, it is necessary in many cases to select priorities for making pavement improvements; pavement condition data and the expected rate of change in performance are important items of information in this process.

Research needs include identifying (a) operating costs for various levels of pavement quality, (b) the effect of maintenance funding levels on the agency's long-term costs, (c) the types of cost data needed, and (d) the relative costs of preventive and corrective maintenance.

Recommendations of this synthesis include the following:

- Selection of alternative treatments should consider present serviceability of the pavement, probable performance of alternative treatments, required life of improvement, costs, effects on traffic flow, effects on road user, appearance, and availability of resources.
- Each agency should have a maintenance manual that covers major pavement defects, alternative strategies of correction, cost or resources required for each strategy, and life of each strategy.
- A pavement management system is desirable for effective development of pavement maintenance strategies. Each agency should consider implementation of a pavement management system to the level that would satisfy its needs.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The performance of any pavement is greatly affected by the type, timeliness, and quality of maintenance it receives. Low maintenance efforts generally lead to accelerated pavement deterioration and therefore higher user costs and higher future maintenance costs. Nationwide there has been a reduction in pavement quality, as pointed out in a 1977 report to the United States Congress prepared by the secretary of transportation (*1*). This report states:

> a. While there was no apparent increase in the amount of pavement in poor or deficient condition, there was evidence of a shift of mileage from good condition to fair condition. Nationally, it is evident that in general the quality of pavement declined from 1970 to 1975. . . .
>
> f. In order to avert deterioration in the quality of pavements and bridges, and to maintain a satisfactory level of operating performance, commitments by Federal, State, and local governments to highway preservation are necessary. Postponing rehabilitation can only increase the long-run costs of maintaining good performance due to the progressive nature of deterioration and the predicted growth in price inflation. . . .
>
> Finally, it is important that all levels of government continue to make periodic assessments of the physical conditions and performance of the highway transportation system. Using this study as a point of departure, transportation agencies are urged to improve their information on the performance of the system in order that sound rationale may be employed in the determination of appropriate program levels, structures, and priorities. . . .
>
> The NHIPS results indicated that State and local highway agencies have been able to stabilize the proportion of poor pavement over the 6-year period. However, with the increased percentage of pavement in fair condition, it appears that pavement improvement must be accelerated in the years immediately ahead if the proportion of poor pavement is not to increase.

The national summary of "Disbursements for State-Administered Highways—1978" (*2*) showed that in the United States nearly 15 percent, or $2.5 billion, of the $17.2 billion total available funds went for physical maintenance in 1978. Road construction accounted for 40 percent of the funds expended. The Federal Highway Administration (FHWA) estimated in 1975 that the annual cost of highway maintenance was nearly $6 billion and was increasing at the rate of nearly $300 million per year. This represented at that time about one-third of all highway expenditures (*3, 4*). This trend is shown in Figure 1.

PROBLEM

A concern of many agencies is that needed pavement repairs require more funds than are available. This need for repairs came about not because of inferior construction but because over the years pavements slowly and continuously wear out. Automobile and truck traffic and climatic factors contribute to the gradual deterioration of pavements. Timely maintenance or rehabilitation has not always been possible because of higher costs, limited funds, materials shortages, environmental restrictions, and so forth. The problem has become so acute in some areas that pavement maintenance must take priority over other essential highway programs. The situation has been of considerable concern to many highway and transportation administrators. Delays in pavement repair cause increased severity of defects, higher maintenance costs, and higher rehabilitation costs.

Even with the seemingly large expenditure of funds for maintenance—and more particularly for pavement maintenance—there is not enough to take care of the needs. Nationally pavements are deteriorating faster than they are being restored. General money shortages have arisen from declines in gas tax revenue; people are traveling less and using more fuel-efficient vehicles. Maintenance has not been able to keep pace with the needs.

It is obvious that something needs to be done to a pavement when it is no longer performing its function adequately. If an agency does not take corrective action on a badly deteriorated pavement, users will complain until something is done. Complaints are a common basis for taking corrective action, as are routine observations by maintenance personnel. A trained observer, for example, might determine the impending failure of a pavement, and many agencies attempt to prevent serious failure by doing preventive maintanance work on pavements that are likely to fail in the near future. It has been shown that in some cases preventive maintenance may be far more cost effective than corrective maintenance (*5–7*). When maintenance funds are limited, agencies find themselves doing increasingly more corrective maintenance and less preventive maintenance. These items were subjects of discussion at the Sixteenth World Road Congress (*7*), where the following statement was made:

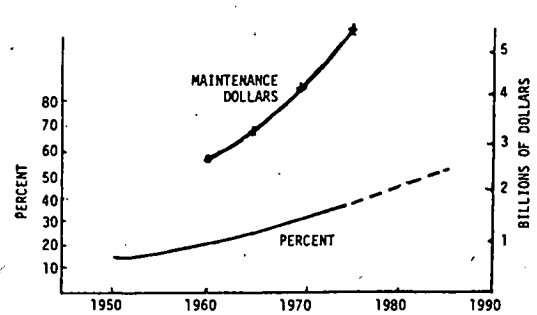


FIGURE 1 Maintenance cost as a percentage of total highway expenditures (*3*).

MAINTENANCE IS OFTEN SACRIFICED

As already expressed and according to the present convictions of every specialist, a chronic insufficiency of funds for maintenance actually costs more than the savings imagined.

For those in charge of road network management, the present issue is one of contributing to the search for a solution which is the most rational one possible from the social and economic points of view. Indeed, what is in fact happening generally speaking, or rather, more specifically, what has happened over the past twenty years?

Under the pressure of the needs, new roads have been built and existing road networks have been re-adapted, widened, complemented. There have been insufficient funds, or none at all, available for maintenance: its financing expenses must be minimised. In addition, maintenance is considered to be a less "noble" task than building new roads.

With the increase in traffic, and in particular heavy traffic, pavements have become more vulnerable and/or deformed. As a result, there is a growing need to plan for traffic restrictions during thaw periods, which raise growing objections; care must also be taken to maintain a minimum level of safety. There has been an increase in the amount of funds spent in maintenance covering emergency road work, performed under bad conditions without proper programming and with rudimentary techniques.

The result is a road network in poor condition where traffic is dangerous and increasingly uncomfortable, thereby entailing a constant increase in the amount of funds allotted to maintenance in the form of local repairs which are often of a temporary nature.

Moreover, on insufficiently maintained roads, wearing processes accelerate and the aggressiveness of heavy axle loads is rapidly growing. At a late stage of deterioration, a few heavy vehicles using the road in winter-time (humidity, frost-thaw) may ruin the pavement. In particular, under such conditions over-loaded vehicles are especially damaging.

When confronted with such risks and pressures exerted by road users as well as public opinion, a restoration policy, which actually consists of recovering from the state created by the postponement of proper maintenance for years, becomes a necessity.

Such a policy is costly. It can be questioned at any time, for example, after a harsh winter which entails unavoidable heavy expenditures on emergency repairs which are frequently executed on a provisional basis.

To avoid repeating past mistakes a coherent maintenance policy, justified in terms of cost, is essential.

Indeed, what is the advantage of neglecting repair work on a surface pavement if the repairs are transformed, a few years later, into an obligatory rebuilding of the entire pavement?

OBJECTIVES

The objectives of this synthesis are to evaluate each of the many pavement maintenance techniques; to report methodologies used to determine the most cost-effective strategies; and to suggest areas for research that would provide the necessary information for making management decisions regarding pavement maintenance strategies. Maintenance as used in this synthesis is broadly defined as anything done to the pavement after original construction until complete reconstruction, excluding shoulders and bridges. As such, pavement maintenance includes rehabilitation and restoration. Some agencies differentiate between maintenance and rehabilitation; other agencies include them under one general classification.

Pavement maintenance strategies are defined as plans of action embodying the continuing application of pavement maintenance techniques that are designed to improve or maintain the condition of a pavement segment above some predetermined minimum requirement. The strategy consists of the type of maintenance, its time for enactment, the design life, and various physical, environmental, and economic constraints. Pavement maintenance strategies can be applied to an entire network, to individual projects, or to pavement segments. The reasons for selecting the optimum pavement maintenance strategy are of prime importance to this synthesis. The basis for optimization may include costs, benefits, safety, and so forth. The "do nothing" alternative is also considered a strategy; this may be referred to as the present level of maintenance. Life-cycle costs are the most important basis for optimization of maintenance strategy selection.

A glossary of terms used in this synthesis is given in Appendix A.

RESEARCH APPROACH

To obtain information for this synthesis, literature searches were conducted, personal contacts were made, and a questionnaire was sent to all states, selected Canadian provinces, and selected toll roads. Questionnaire responses came from 35 states, 3 Canadian provinces, and 8 toll roads.

It is not always obvious from the appearance of a pavement surface what the optimum treatment should be. To establish a strategy, an agency should consider the present pavement condition, the rate of change in condition, maintenance costs, future traffic volume and loads, available funds, and the minimum acceptable performance level. These factors and others were considered in the development of this synthesis. Pavement maintenance techniques (i.e., methods used to accomplish a strategy or correct some deficiency in a pavement segment) were identified and evaluated.

PAVEMENT MANAGEMENT

The subject matter of this synthesis is very closely related to the broad area of pavement management. In recent years considerable activity has focused on pavement management, pavement management systems, and pavement management information systems (*8–13*). Pavement management was the subject of a recent NCHRP report (*8*), which defined it as follows:

> Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design construction, maintenance, and rehabilitation of the pavement portion of a public works program. A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and

ensure the consistency of decisions made at different management levels within the same organization. . . .

It is convenient to describe pavement management in terms of two generalized levels: (1) the network management level, sometimes called the program level, where key administrative decisions that affect programs for road networks are made, and (2) the project management level where technical management decisions are made for specific projects. Historically, most formal pavement management system development has occurred at the project level. More recently, extensive development in maintenance management and data management methodologies has added to the pressure for development of a total pavement management system; one where all activities are included and explicitly interfaced with each other.

The framework and major subsystems for a total pavement management system are illustrated in Figure 2. As may be noted, many of the subsystems or components interact and influence each other. For example, pavement design and construction influence pavement performance and, therefore, the need for maintenance. Quality and timeliness of maintenance influence the time and need for reconstruction. Costs to the responsible agency and to the user are a function of what happens in all the subsystems. The information required to manage pavement maintenance and develop optimum pavement maintenance strategies comes from several of the subsystems in the total framework.

MAINTENANCE POLICIES

Many agencies have developed formal written maintenance policies to define responsibilities, levels of effort, and so on (*14–17*). The Nebraska Department of Roads policy (*14*) includes the following statement:

> 1. Maintenance Program Objectives
>
> The Maintenance Division of the Nebraska Department of Roads is responsible for economically maintaining all highway structures and facilities on the State Highway System.
>
> The objectives of the maintenance operations are as follows:
>
> 1. To preserve the investment made in the roadways, structures and facilities.
> 2. To provide reasonable levels of safety and convenience to highway users.
> 3. To ensure effective and economical utilization of labor, equipment, materials and financial resources in the accomplishment of maintenance programs.
>
> These objectives will be accomplished through the effective management of maintenance operations and resources.

The Arizona Department of Transportation's Highway

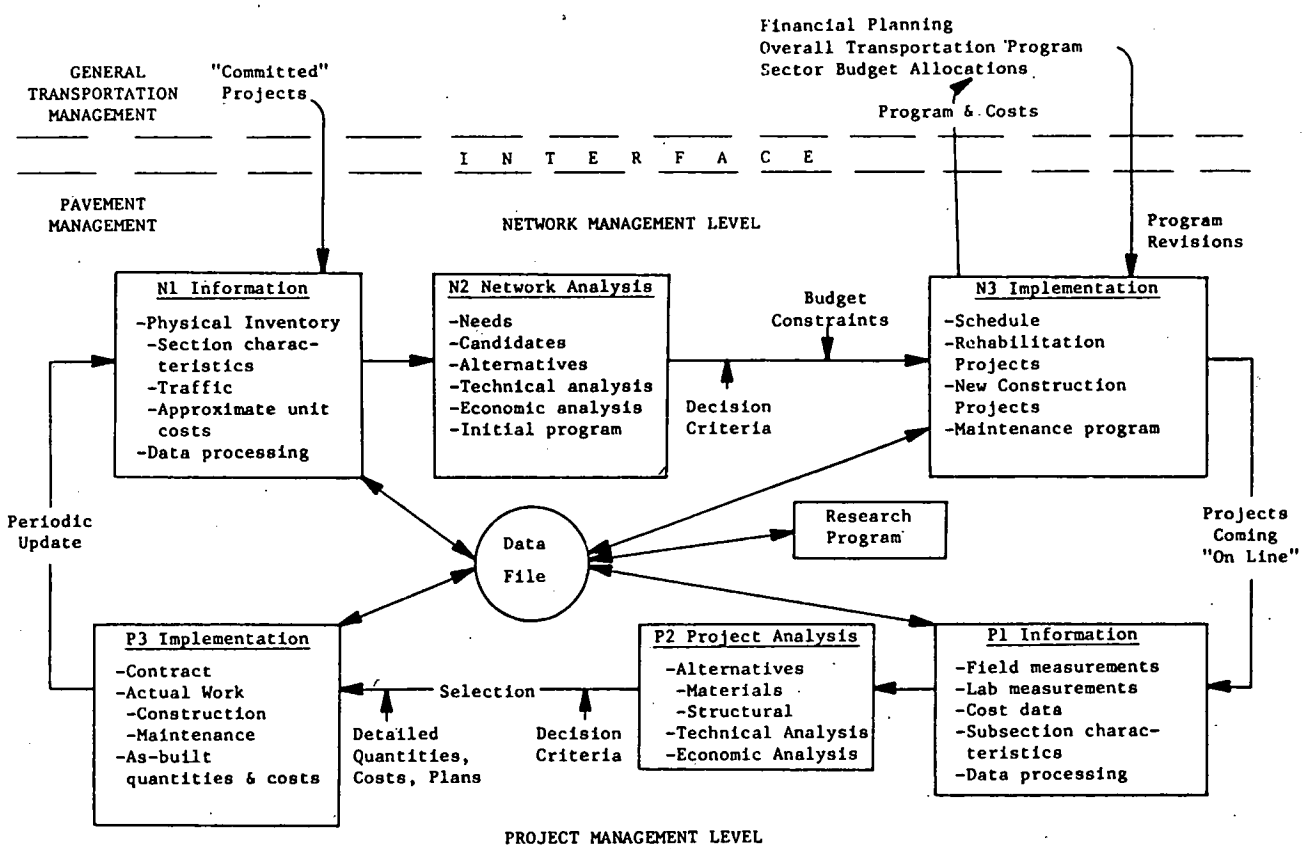


FIGURE 2 Framework and major subsystems for a total pavement management system (*8*).

Maintenance Management System (*15*) makes the following statement:

> The goal is to establish and maintain a more effective and efficient highway maintenance program. Specific objectives are:
>
> a. To establish acceptable levels of maintenance service and insure that they are applied uniformly throughout the State,
> b. To provide an objective basis upon which the maintenance program can be planned and executed,
> c. To utilize labor, equipment, material and financial resources in the most efficient and economical manner,
> d. To provide the means by which management can measure actual performance against planned performance and take corrective action if required, and
> e. To utilize a Planned Program Budgeting System as a means of communicating the fiscal requirements for highway maintenance.

The following statement reflects the general policy for highway maintenance of the Pennsylvania Department of Transportation (*16*).

> The Department of Transportation was created by action of the Legislature of the Commonwealth of Pennsylvania and entrusted with the planning, design, construction, reconstruction, maintenance, and operation of the State Highway System. This trust includes: (1) the preservation and upkeep of the State Highway System in its constructed or its subsequently improved condition; and (2) the operation of the highway facility, and related incidental services to provide safe, convenient, and economical highway transportation.
>
> The Bureau of Maintenance is responsible for managing the statewide highway maintenance program within the Department of Transportation. The Bureau of Maintenance shall recommend the allocation of budgeted funds; staffing requirements; procurement and assignment of motorized equipment; and the material requirements to perform the maintenance function. Each Engineering District and Maintenance District is responsible for the execution of their maintenance program within the framework of the statewide highway maintenance program. The Bureau of Maintenance is responsible for providing functional guidance and assistance to each Engineering District and other Department units in all matters pertaining to maintenance. In carrying out this responsibility, the Bureau of Maintenance will consult with the Bureaus of Construction, Design, Traffic, and Materials, Testing and Research for program support.
>
> The Director, Bureau of Maintenance, is responsible for the development and establishment of highway maintenance operating policies and procedures within the framework of the basic objectives of the Department of Transportation.

Two of these policy statements specifically mention the preservation of the investment in the roadways. This is an important aspect of maintenance and will be expanded in the following chapters.

At the Sixteenth World Road Congress in Vienna (*7*), the following statement was made regarding maintenance policy:

> What is actually needed is thus to prove that the maintenance policy selected optimizes road user advantages. In particular, those responsible for roads should become aware of the extent of waste inflicted upon the national community due to inadequate maintenance of road networks on a long term basis, and should make those who deal out the funds as well as the general public aware of this factor.

CHAPTER TWO

PAVEMENT PERFORMANCE AND DEFICIENCIES

To identify maintenance strategies for a given pavement, one must know both the present and the expected deficiencies of the pavement—and their causes, if possible. Pavement condition or performance is generally determined by some formal rating system whose complexity varies with the needs and experience of the agency using the information. Various model categories for pavement performance have been developed; submodels of these were identified and evaluated as part of a San Francisco workshop on pavement rehabilitation (*10*). The submodels are summarized in Table 1.

PAVEMENT EVALUATION

A pavement management workshop with invited participants was held in Olympia, Washington, in November 1977 (*9*). The participating agencies presented information on their pavement evaluation programs. This information was grouped into four categories:

1. Surface distress evaluations.
2. Roughness or ride evaluation.

TABLE 1
SUMMARY OF EXISTING PAVEMENT PERFORMANCE SUBMODELS (*10*)

Category	Model	Function of Model	Advantages	Disadvantages	Implementation	Research Needs
Safety	Skid Number	To predict decay in skid resistance with traffic	Permits designer to utilize minimum skid numbers as decision criteria	Does not completely recognize the complex interaction of tires, surface, and water	Numerous States Air Force (3)	Prediction of SN Decay with Mt'l. Prop.
	Accident Data	Tie accident data to safety characteristics		Difficult to ascertain causes of accidents	(1)	Better accident identification
	Maintenance Safety Index	Relate maintenance activities exposure with the probability of an accident	Permit criteria as to the strategy and the degree of exposure by maintenance employees		Concept in California (1)	Develop the concept
Structural	Elastic Layered	Predict stresses in pvt. structure due to load	Provide better criteria for design of the layers	Lack of adequate transformation between stress and aerial distress	Used for guidance in design (2)	Transformation between stress and perf.
	Deflection	Ties deflection of pvt. structure to performance	Easy to implement and in place evaluation of an existing pvt. structure	Material properties can influence the deflection-perf. relationship	Used as design criteria by many agencies (3)	Transformation between deflection and perf.
	Thermal Fracture	Predict stresses developed in pvt. by shrinkage forces due to thermal changes	Provides a way to design against low temp. cracking	Lack of adequate transformation between stress and aerial cracking	Canadian Provinces (2)	Transformation between cracking and perf.
	Reflection Fracture	Predict stresses (cracking) that occure in overlay due discontinuities in lower layers	Prevent reflection cracking		All State Highway Depts. (2)	Transformation between cracking and perf.
	Structural Number	Predicts performance history of pvt. structure as function of mixed traffic	Provides a transformation between input and aerial distress	Problems in establishing coefficients for materials other than AASHO Road Test	AASHO Interim Guides (3)	Quantify, structural coefficients
Cost	Construction	Compute present worth of all const. and routine maint. costs incurred during life	Permits designer to examine total expenditure during design life		Records available (2)	Procedures for translating present to future
	User	Compiles direct and indirect costs to user resulting from level of service and various activities on pvt. structure	Permits user costs to be considered in decision process	Data required is difficult to obtain and evaluate	Used in SAMP, FPS, and RPS computer programs (2)	Better information
	Noise	Relate noise from surface to a cost item	Permits noise costs to be considered in decision process	Data required is difficult to obtain and evaluate	Only in subjective manner (1)	Relating noise to a composite noise rating
Maintenance	Level of Service	Relates quantity and distribution of traffic to the available resources	Optimum expenditure of funds	Area of political decisions	Subjective only (1)	Develop models
	Performance	Relates the effect of maintenance activities on the pvt. struct. performance	Permits a more reliable comparison of alternate strategies	Many types of activities therefore difficult to encompass	AASHO Interim Guides and other related procedures (3)	Long term observations
	Drainage	Relate drainage characteristics with pvt. performance	Permits an evaluation of the drainage characteristics of an existing pvt. structure	See above	Indirectly in material characterization (2)	Quantify effect on performance
Traffic	EWL	Converts mixed traffic applications to an objective value	Permits the designer to design for fatigue	Equivalency functions will vary depending on mode of obtaining	Numerous design methods (3)	Better traffic prediction techniques
	Traffic Flow	Computes the capacity of a facility for various methods of handling traffic	Permits the optimization of traffic handling		Basis for developing User Cost	Develop models
Optimization		Combines effects of all other models into one basis of comparison	Permits better basis for decision making		Only in component parts (1)	Practical methods to reduce computation time

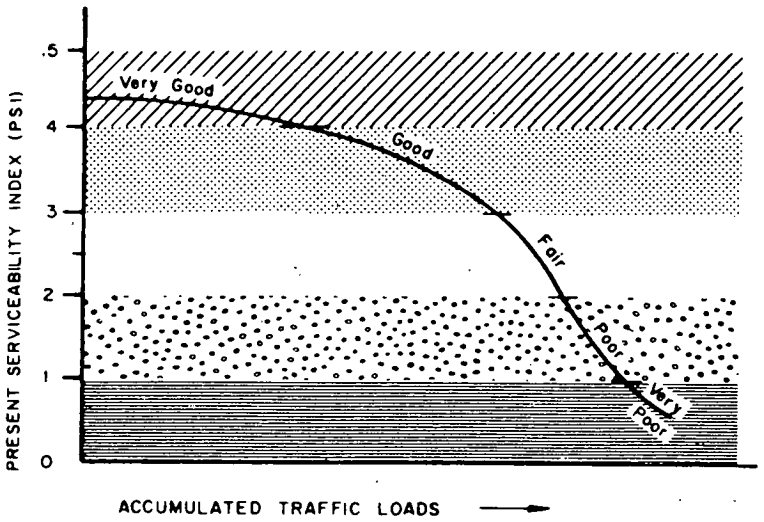


FIGURE 3 Typical pavement performance curve (*6*).

3. Surface friction or skid resistance.
4. Structural capacity evaluation.

The workshop consultants prepared summary tables describing what each participating agency was doing in each area; the information for nine agencies was updated for *NCHRP Synthesis 76* (*18*) and is presented in Table 2–5. The various agencies felt that full automation of data collection and processing is desirable. It was also concluded that a pavement management system should have some means of assisting in the evaluation of maintenance operations and providing feedback. Pavement maintenance cost data are considered very desirable, as they enable one to understand and develop a maintenance strategy as well as a pavement management system. The cost data are difficult to obtain, but every effort should be made to obtain them.

Pavements deteriorate at different rates, depending on such factors as traffic loads, pavement age, weather, materials, design, and construction quality. Generally, deterioration of a pavement increases exponentially as loads are applied to it. A pavement may show little or no apparent change in performance levels the first few years of its life, whereas the rate of deterioration will be very noticeable as it becomes older. It is necessary to know the performance characteristics for a given set of conditions to determine the most cost-effective maintenance schedule. A typical performance curve for pavement serviceability is shown in Figure 3. Another important factor in predicting pavement performance is an understanding of the probable effect of a given corrective treatment on future performance and thus on costs. Figure 4 shows two performance curves for a pavement using two specific maintenance strategies. Other strategies would have different effects on the shape of the curve.

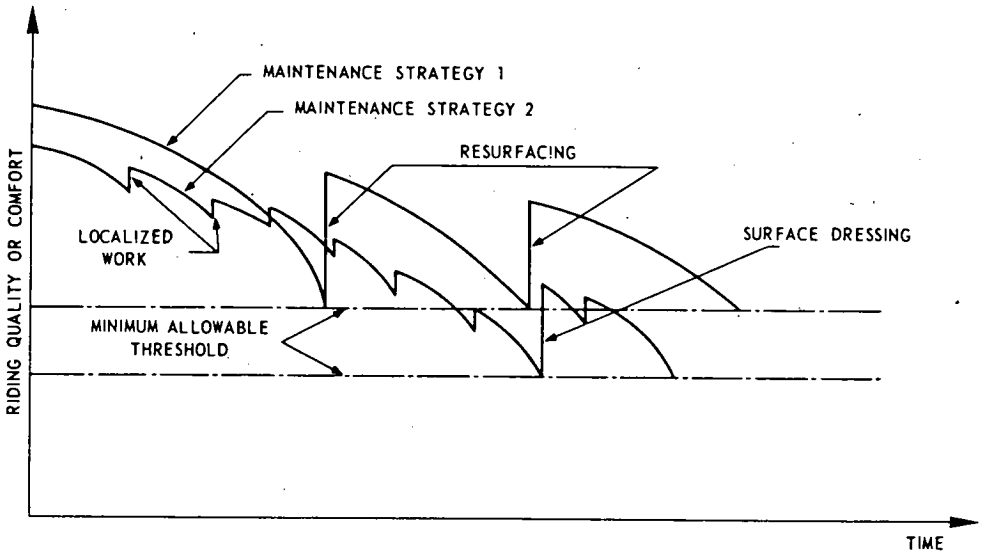


FIGURE 4 Performance curve illustrating the effect of different improvements (*33*).

TABLE 2
CURRENT PRACTICE FOR SURFACE DISTRESS EVALUATION (*18*)

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 representative 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.

TABLE 3
CURRENT PRACTICE FOR RIDE EVALUATION (*18*)

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.

TABLE 4
CURRENT PRACTICE FOR SKID RESISTANCE (*18*)

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.

TABLE 5
CURRENT PRACTICE FOR STRUCTURAL EVALUATION (SURFACE DEFLECTION) (*18*)

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.

TABLE 6
PAVEMENT DEFICIENCIES[a]

Pavement Type	Deficiency		
Flexible	1. Settlement	13. Wheel track cracking	25. Glaze
	2. Subsidence	14. Pavement edge crack	26. Polished aggregates
	3. Bump	15. Meandering crack	27. Bleeding of binder, flushing
	4. Wave	16. Contraction crack, shrinkage crack, transverse crack	28. Pothole, chuckhole
	5. Rippling, wash board corrugation	17. Reflection crack	29. Bleeding of water, water retention, wet spot
	6. Depression, bird bath	18. Slippage, crescent, parabolic, tearing crack	30. Migration of mud to the surface
	7. Distortion	19. Hair-line cracks	31. Inadequate drainage
	8. Rutting	20. Imprint, indentation, scarring	32. Peeling
	9. Shoving	21. Loss of surface aggregates	33. Blistering
	10. Alligator cracking, chicken wire cracking, fish net cracking	22. Stripping	34. Streaking of surface treatment
	11. Block cracking, map cracking	23. Ravelling, weathering	
	12. Centreline crack, longitudinal crack	24. Protrusion of aggregates	
Rigid	35. Inadequate skid resistance	43. Joint sealant extrusion	52. Block cracking, random cracking, third stage crack
	36. Inadequate drainage	44. Longitudinal joint opening	53. Spalling
	37. Wheel track wear (rutting)	45. Transverse crack, diagonal crack	54. Pop-outs
	38. Settlement	46. Long longitudinal crack	55. Pothole, chuckhole
	39. Plumbing	47. Short longitudinal crack	56. Crazing, alligator cracking
	40. Slab rocking	48. Corner crack, corner break	57. Scaling
	41. Stepping, step off, step faulting	49. D cracking	58. Peeling
	42. Loss of waterproofing of joint, loss of seal, joint stripping	50. Buckling, blow up	
		51. Expansion joint failure, shattering	
Gravel	59. Pothole	61. Corrugation	63. Loose verges
	60. Bare spots	62. Dusting	64. Rutting

[a] Based on Catalogue of Road Surface Deficiencies (23).

PAVEMENT DEFICIENCIES

A number of agencies have developed lists of pavement deficiencies, and in some cases they have also identified the causes (*11, 19–31*). The Organisation for Economic Co-operation and Development (OECD) (*23*) has developed a comprehensive list of deficiencies for various pavements (see Table 6).

The OECD report also presents photographs, descriptions, and probable causes for each deficiency listed. California (*24*), Ontario (*22*), the Construction Engineering Research Laboratory (*20*), the Federal Highway Administration (*29*), the American Association of State Highway and Transportation Officials (AASHTO) (*30*), the Highway Research Board (now the Transportation Research Board) (*31*), and many other highway agencies have generated similar lists of deficiencies with descriptions and possible causes.

INITIATING PAVEMENT MAINTENANCE

The first question on the questionnaire was: "What initiates or triggers maintenance on a pavement segment?" The responses by agency are detailed in Appendix B and summarized in Table 7. (Most agencies gave two or more reasons for initiating maintenance, so the totals exceed the number of agencies.) Some of the toll roads also indicated a need to protect revenues as part of protecting their investment. They generally felt that it was essential to avoid all complaints by maintaining their roads at high performance levels and thereby keeping users satisfied.

TABLE 7
FACTORS THAT TRIGGER MAINTENANCE ON A PAVEMENT SEGMENT

	Number of Respondents		
Factor	States	Provinces	Toll Roads
Correct deficiencies	30	2	3
Protect investment, including preventive maintenance	25	3	5
Complaints	14	3	--
Needs from observation	11	--	3
Eliminate hazards	7	2	1
Routine scheduled planned program activities	4	--	--
Maintenance management systems	2	--	--
Pavement management system	2[a]	--	--
Reduce maintenance costs	1	--	--
Fulfill public trust	--	2	--
Convenience of users	--	2	--
Obligation to maintain in good repair	--	--	1
Aesthetic values	--	2	--
Total responding	35	3	8

[a] Future.

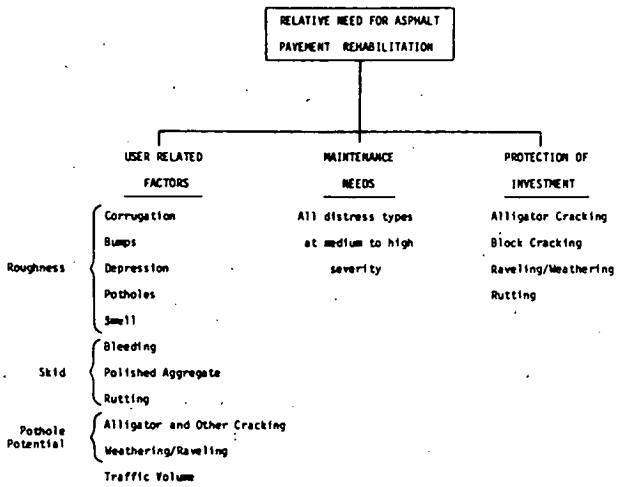


FIGURE 5 Distress types having major influence on need for asphalt pavement rehabilitation (*32*).

Darter and Shahin (*32*) identified what they considered key factors in determining the relative need for the rehabilitation of a given pavement. The major factors they identified are user-related factors, maintenance needs, and protection of the investment. These factors are illustrated in Figure 5 for asphalt pavement rehabilitation and in Figure 6 for concrete pavement rehabilitation.

The *AASHTO Maintenance Manual* (*30*) contains the following statement related to pavement surface maintenance:

> Many surface failures are due to either improper construction or design. A knowledge of the cause of these failures is essential to proper maintenance and repair. Failures caused by design and those due to increasingly heavy traffic should be referred to design engineers for construction by construction projects. Surface failures that are attributed to poor construction usually require increasing amounts of corrective action by maintenance over the life span of the pavement.

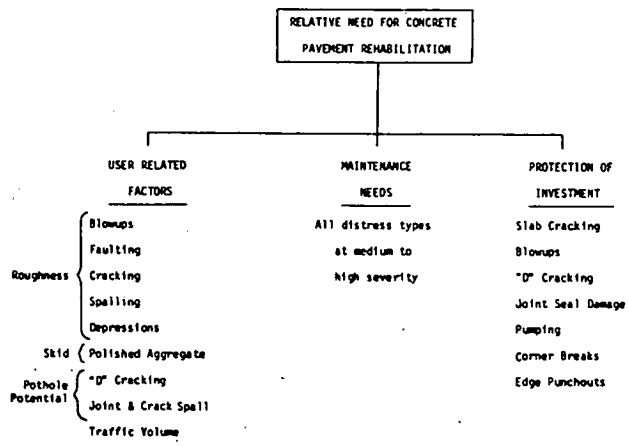


FIGURE 6 Distress types having major influence on need for concrete pavement rehabilitation (*32*).

CHAPTER THREE

PAVEMENT MAINTENANCE TECHNIQUES

Pavement maintenance techniques are the methods used to accomplish a strategy or to correct some deficiency in a pavement segment. Techniques include the use of overlays, seal coats, pothole repair, crack sealing, and so on. Maintenance techniques are classified according to their purpose or function as either corrective or preventive.

- Corrective maintenance is used to take care of day-by-day emergencies and to repair deficiencies as they develop. It may include both temporary and permanent repairs.

- Preventive maintenance is intended to keep the pavement above some minimum acceptable level at all times and is used as a means of preventing further pavement deterioration that would require corrective maintenance. It may include either structural or nonstructural improvements to a pavement surface.

Some maintenance techniques may serve a dual function in that they are both corrective and preventive. For example, crack sealing is intended to correct an existing deficiency of the crack and may also prevent further deterioration of the pavement structure by sealing out water. A chip seal coat can correct a skid problem and also prevent surface deterioration due to water and weathering.

This synthesis covers maintenance techniques for the following surface types:

- *Rigid pavement:* Portland cement concrete pavements in which the concrete slabs provide both the main structural layer and the riding surface.

- *Flexible pavement:* Bituminous or similar pavements that depend on aggregate interlock, particle friction, and cohesion for stability.

- *Unpaved:* Roadways where the surface course is an unbound material.

MAINTENANCE STANDARDS

Many agencies have developed and use standards for maintenance (*7, 14–17, 22, 33–50*). The most common types of standards used by the states are performance, quantity, and quality. The *AASHTO Maintenance Manual* (*30*) provides descriptions of quality standards and time and production standards for use by various agencies in developing their own standards. The purpose for quality standards as described by AASHTO is to:

> Define the physical conditions that indicate a need for maintenance and repair activities and prescribe the character or workmanship and the properties of the completed product. . . .
>
> Quality standards should assure that statewide maintenance is uniform, timely and demonstrates good workmanship. . . .
>
> Quality standards should specify the conditions or repetitive intervals that will cause maintenance actions and prescribe the actions that will be taken. Specifications for the completed product should be identified in enough detail to assure the adequacy of the result.

AASHTO describes time and production standards, or work standards, as follows:

> Time and production standards are essential to effective planning, budgeting, and scheduling. Nearly all maintenance functions are performed as repetitive operations. Some are performed frequently; others are repeated only a few times a year. Some functions are very involved requiring many operational steps with large crews; others are simple operations done by one man. . . .
>
> Accurate time and production standards and maintenance procedures are essential to manpower and equipment use planning, work scheduling and fiscal budgeting. With increased emphasis on operating within prescribed fund allocations, time and production standards can become a primary measurement tool to determine priorities for use of available resources.

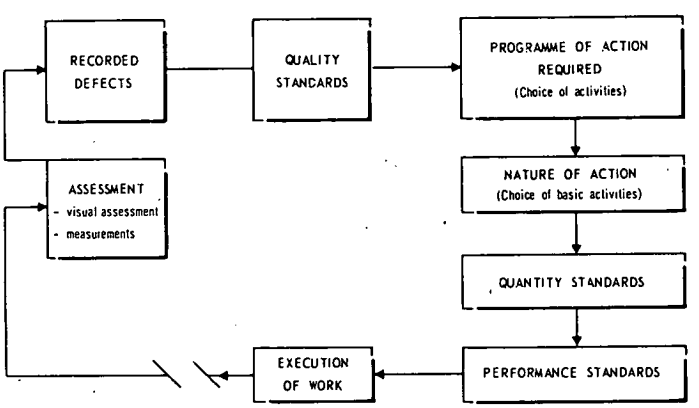


FIGURE 7 Functional relationships between various maintenance standards (*34*).

AASHTO also emphasizes the importance of reports and records. Entries should be kept simple and easy, and direct terms should be used.

OECD (*34*) prepared a diagram illustrating the functional relationships between various types of standards. This diagram is shown in Figure 7.

PAVEMENT MAINTENANCE TECHNIQUES CATEGORIES

Pavement maintenance techniques can be subdivided into major groupings according to what needs to be corrected—for example, a breakdown into the categories of surface evenness, impermeability, skid resistance, and surface water drainage (*33*). Another way of breaking down treatments is by type of treatment, such as the method that includes overlay, recycle, surface treatment, localized correction or treatment, and surface planing (*13*). The most common method is to classify pavement maintenance techniques according to surface type. California uses the breakdown presented in Tables 8 and 9 for pavement rehabilitation (*35*). These tables also present some basic information about each repair strategy concerning use, life, and cost.

Monismith (*51*) developed the diagram illustrated in Figure 8 to identify maintenance and rehabilitation alternatives; some agencies use a similar division. The diagram also differentiates between preventive and corrective surface maintenance alternatives. The *AASHTO Maintenance Manual* (*30*) summarizes the distinction between construction and maintenance for the traveled way as presented in Table 10.

PAVEMENT MAINTENANCE TECHNIQUES IDENTIFIED THROUGH THE QUESTIONNAIRE

The fifth question on the survey was: "What pavement maintenance techniques are used and how effective is each in satisfying the requirements of the strategies? Identify whether the technique is used for preventive or corrective maintenance or both." The responses to this question varied considerably in detail from agency to agency. The responses are presented in Appendix B; Tables 11 and 12 summarize them.

Some agencies also identified maintenance techniques for unpaved surfaces. The techniques included blading, dust treatment, stabilizers, addition of aggregate, and spot recondition. However, the effectiveness of these techniques was not established.

MAINTENANCE TECHNIQUES VERSUS PAVEMENT DEFICIENCIES

Some agencies have developed matrices relating pavement deficiencies to maintenance techniques. This type of system is helpful as a quick reference to identify the most likely solutions for a specific pavement problem and is useful as one step in selecting alternatives or strategies. Tables 13–16 present matrices that were included in an OECD report (*33*) and were based on results of inquiries to OECD countries. Tables 17 and 18 present summaries of repair methods for flexible and rigid pavement as prepared by the U.S. Army Construction Engineering Research Laboratory (*20*).

FHWA regularly updates a list of new products or materials in the AASHTO-FHWA Special Product Evaluation List. Information provided by state highway materials engineers is combined and published biennially by FHWA.

FHWA and the National Cooperative Highway Research Program prepared and published a number of reports that provide valuable assistance in the evaluation of many techniques. Areas covered by these reports include continuously reinforced concrete pavements (*52–54*), bituminous patching (*55, 56*), concrete patching (*57*), reconditioning high-volume freeways in urban areas (*58, 59*), and recycling (*60*). This is only a partial list of available material that can help identify and evaluate maintenance techniques.

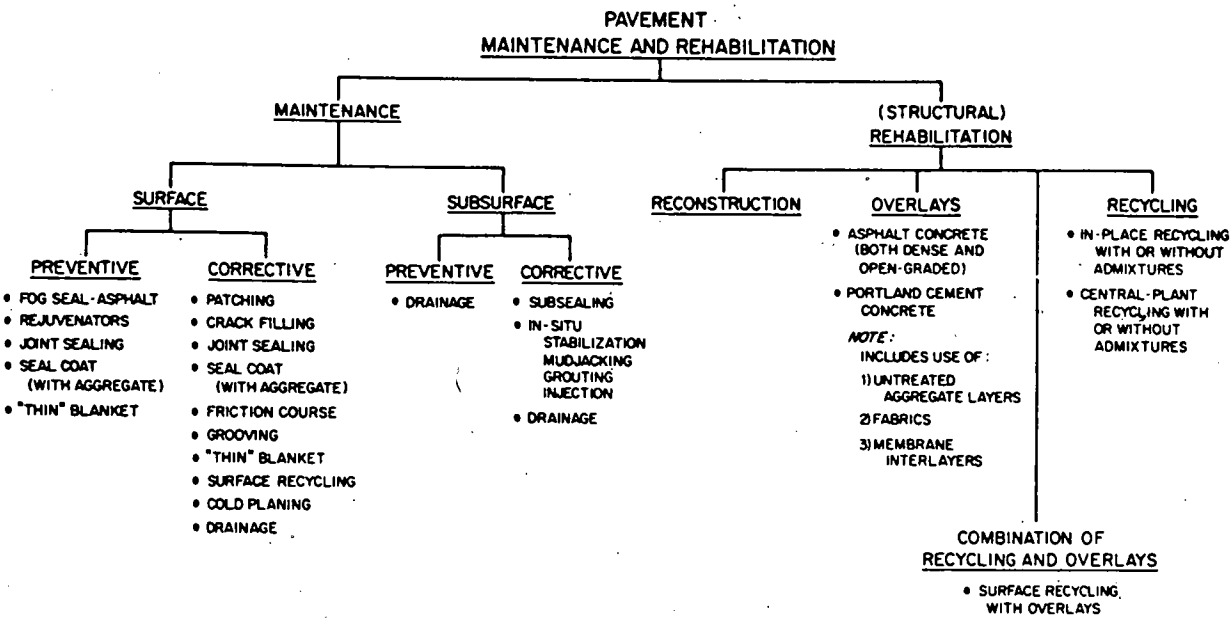


FIGURE 8 Maintenance and rehabilitation alternatives (*51*).

TABLE 8
CALTRANS FLEXIBLE PAVEMENT REPAIR STRATEGY INFORMATION (35)

REPAIR STRATEGY	FUNCTION (OBJECTIVE)	PROPER USE	IMPROPER USE	SERVICE LIFE	*1976/77 COST PER LANE MILE	CALIFORNIA'S EXPERIENCE
1. LANE RECONSTRUCTION	RESTORE STRUCTURAL ADEQUACY	A. WHERE MORE COST EFFECTIVE THAN ALTERNATES B. RIDE SCORE >45 C. VERTICAL GRADE CONSTRAINTS		20 YR	$90,000 (1)	EXTENSIVE
2. PCC OVERLAYS	RESTORE STRUCTURAL ADEQUACY	WHERE MORE COST EFFECTIVE THAN ALTERNATES (0.55' MINIMUM THICKNESS)	A. UNSTABLE TERRAIN B. VERTICAL GRADE CONSTRAINTS	10 YR	$65,000 (2)	LIMITED
3. AC OVERLAYS	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY	A. LOAD ASSOCIATED CRACKING B. RIDE SCORE >45 C. RUT DEPTH > 3/4" D. COARSE AGGREGATE RAVEL	A. VERTICAL GRADE CONSTRAINTS	10 YR	$12,500/0.10'	EXTENSIVE
4. INVERTED OVERLAYS	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY	A. WHERE MORE COST EFFECTIVE THAN CONVENTIONAL OVERLAY B. PROVIDE DRAINAGE BLANKET	FREEZE-THAW AREAS	10 YR TARGET	$35,000 (3)	LIMITED EXPERIMENTAL INSTALLATIONS
5. PAVEMENT REINFORCING FABRIC & OVERLAY	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY E. WATER RESISTANT MEMBRANE	A. WHERE MORE COST EFFECTIVE THAN CONVENTIONAL OVERLAY B. VERTICAL GRADE CONSTRAINTS		10 YR TARGET	$35,000 (4)	LIMITED EXPERIMENTAL INSTALLATIONS
6. RUBBERIZED ASPHALT INTERLAYER & OVERLAY	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY E. WATER RESISTANT MEMBRANE	A. WHERE MORE COST EFFECTIVE THAN CONVENTIONAL OVERLAYS B. VERTICAL GRADE CONSTRAINTS		10 YR TARGET	$35,000 (5)	LIMITED EXPERIMENTAL INSTALLATIONS
7. HOT RECYCLING	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. CONSERVE NATURAL RESOURCES	A. WHERE MORE COST EFFECTIVE THAN ALTERNATES B. VERTICAL GRADE CONSTRAINTS	AIR QUALITY CONSTRAINT AT PLANT	10 YR	$24,000/0.10	NONE TO DATE
8A. HEATER REMIX 8B. CUTLER PROCESS	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE	A. WHERE MORE COST EFFECTIVE THAN ALTERNATES B. VERTICAL GRADE CONSTRAINTS	AIR QUALITY CONSTRAINT AT SITE	5-10 YR	$25,000 (6)	HEATER REMIX-EXTENSIVE CUTLER PROCESS-NONE TO DATE
9. COLD PLANING	A. CONFORM TO ELEVATION CONTROL B. REMOVE DETERIORATED AND/OR CONTAMINATED LAYER	A. WHERE MORE COST EFFECTIVE THAN ALTERNATIVES B. PREPARE FOR OVERLAY C. AIR QUALITY CONTROLS PRECLUDE HOT PLANING D. VERTICAL GRADE CONTROLS		NOT APPLICABLE	$15,000 (7)	MODERATE

TABLE 8 (continued)

REPAIR STRATEGY	FUNCTION (OBJECTIVE)	PROPER USE	IMPROPER USE	SERVICE LIFE	*1976-77 COST PER LANE MILE	CALIFORNIA'S EXPERIENCE
10. RUBBERIZED ASPHALT CHIP SEAL COAT	A. WATERPROOF PAVEMENT B. DECREASE CRACK SPALLING	A. SEAL DRIED OUT PAVEMENT B. STAGE CONSTRUCTION PRECEDING A PLANNED OVERLAY C. FINE AGGREGATE RAVEL	A. HIGH DEGREE OF ROAD CURVATURE B. HIGH VOLUME TURNING MOVES C. HEAL CRACKS D. > HAIRLINE CRACKS UNLESS FILLED E. RIDE SCORE > 45	UNKNOWN ESTIMATE 2-5YR	$10,000	LIMITED EXPERIMENTAL INSTALLATIONS
11. ROCK SEAL COAT	A. WATERPROOF PAVEMENT B. DECREASE CRACK SPALLING C. TEXTURE SURFACE	A. SEAL DRIED OUT PAVEMENT B. FINE AGGREGATE RAVEL C. SKID RESISTANCE CORRECTION	A. HIGH DEGREE OF ROAD CURVATURE B. HIGH VOLUME TURNING MOVES C. HEAL CRACKS D. > HAIRLINE CRACKS UNLESS FILLED E. RIDE SCORE > 45	1-3 YR	$ 3,000	EXTENSIVE
12. OPEN GRADED SEAL COAT	A. DECREASE CRACK SPALLING B. TEXTURE SURFACE C. CORRECT BLEEDING	A. SEAL DRIED OUT PAVEMENT B. COARSE AGGREGATE RAVEL C. SKID RESISTANCE CORRECTION D. CORRECT BLEEDING	A. HEAL CRACKS B. > HAIRLINE CRACKS UNLESS FILLED C. RIDE SCORE > 45 D. FREQUENT TIRE CHAIN USE REQUIRED	5 YR	$ 5,000	EXTENSIVE
13. SLURRY SEALS	A. STOP RAVEL B. WATERPROOF PAVEMENT C. DECREASE CRACK SPALLING D. TEXTURE SURFACE	A. SEAL DRIED OUT PAVEMENT B. FINE OR COARSE AGGREGATE RAVEL	A. HEAL CRACKS B. RIDE SCORE > 45 C. > HAIRLINE CRACKS UNLESS FILLED D. FREQUENT TIRE CHAIN USE REQUIRED	4 YR	$ 4,000	LIMITED
14. SEAL COAT WITH (SAND) COVER	A. WATERPROOF PAVEMENT B. DECREASE CRACK SPALLING C. STOP RAVEL D. RESTORE BINDER FLEXIBILITY	A. SEAL DRIED OUT PAVEMENT B. FINE AGGREGATE RAVEL	A. HEAL CRACKS B. COARSE RAVEL C. RIDE SCORE > 45 D. LOW TO MODERATE SKID NUMBER E. RUTTING F. HIGH. IMPER. PVMT.	1-3 YR	$ 1,500	EXTENSIVE
15. LIQUID SEAL COAT	A. WATERPROOF PAVEMENT B. DECREASE CRACK SPALLING C. STOP RAVEL D. RESTORE BINDER FLEXIBILITY	A. SEAL DRIED OUT PAVEMENT B. FINE AGGREGATE RAVEL	A. HEAL CRACKS B. COARSE RAVEL C. RIDE SCORE > 45 D. LOW TO MODERATE SKID NUMBER E. RUTTING F. HIGH. IMPER. PVMT.	1-3 YR	$ 300	EXTENSIVE
16. BINDER MODIFIERS (REJUVENATING AGENT)	A. WATERPROOF PAVEMENT B. DECREASE CRACK SPALLING C. STOP RAVEL D. RESTORE BINDER FLEXIBILITY	A. SEAL DRIED OUT PAVEMENT B. FINE AGGREGATE RAVEL	A. HEAL CRACKS B. COARSE RAVEL C. RIDE SCORE > 45 D. LOW TO MODERATE SKID NUMBER E. RUTTING F. HIGHLY IMPERMEABLE PAVEMENT	1-3 YR	$ 500	EXTENSIVE

TABLE 8 (continued)

REPAIR STRATEGY	FUNCTION (OBJECTIVE)	PROPER USE	IMPROPER USE	SERVICE LIFE	*1976-77 COST PER LANE MILE	CALIFORNIA'S EXPERIENCE
17. CRACK FILLING	WATERPROOF PAVEMENT	A. CLEAN CRACK ≥ ¼" WIDE B. APPROPRIATE SEALANT	A. DIRTY CRACKS B. < ¼" WIDE CRACKS	1-2 YR	$ 200	EXTENSIVE
18. MISCELLANEOUS (STONE DUST, METAL PLATES, EXPANDED METAL, CHICKEN WIRE, WELDED WIRE FABRIC)	REDUCE REFLECTION CRACKING	NOT WARRENTED	THESE EXPERIMENTAL MATERIALS DID NOT PERFORM BETTER OR AS WELL AS ADJACENT UNTREATED SECTIONS	POOR	N/A	LIMITED EXPERIMENTAL USE

* COSTS DO NOT INCLUDE TRAFFIC HANDLING

ASSUMPTIONS FOR FLEXIBLE PAVEMENT COST ESTIMATES

1. 0.35' AC OVER 0.70' CLASS A CTB
2. 0.55' PCC
3. 0.08' O.G. with 0.20' AC
4. REINFORCING FABRIC WITH 0.20' AC
5. RUBBERIZED CHIP SEAL WITH 0.20' AC
6. SCARIFY, ADD REJUVENATOR AND 0.08' AC
7. 0.10' DEPTH

TABLE 9
CALTRANS RIGID PAVEMENT REPAIR STRATEGY INFORMATION (35)

REPAIR STRATEGY	FUNCTION (OBJECTIVE)	PROPER USE	IMPROPER USE	SERVICE LIFE	*1976-66 COST PER LANE MILE	CALIFORNIA'S EXPERIENCE
1. LANE RECONSTRUCTION	RESTORE STRUCTURAL ADEQUACY	A. > 10% THIRD STAGE CRACKING B. WHERE MORE COST EFFECTIVE THAN ALTERNATES. C. VERTICAL GRADE CONSTRAINTS D. RIDE SCORE > 45		20 YR.	$100,000	LIMITED
2. PCC OVERLAYS	RESTORE STRUCTURAL ADEQUACY	A. > 10% THIRD STAGE CRACKING B. WHERE MORE COST EFFECTIVE THAN ALTERNATES. C. NO VERTICAL GRADE CONSTRAINTS D. WHEN TRAFFIC HANDLING PERMITS E. RIDE SCORE > 45		20 YR.	$ 65,000 (1)	LIMITED
3. AC OVERLAYS	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY	A. > 10% THIRD STAGE CRACKING B. WHERE MORE COST EFFECTIVE THAN ALTERNATES. C. FAULTING IF SLABS STABILIZED D. NO VERTICAL GRADE CONSTRAINTS E. RIDE SCORE > 45	ROCKING SLABS	10 YR.	$ 12,500/0.10'	MODERATE
4. INVERTED OVERLAYS	A. RESTORE STRUCTURAL ADEQUACY B. REPAIR CRACKED PAVEMENT C. RESTORE SURFACE TEXTURE D. IMPROVE RIDE QUALITY	A. > 10% THIRD STAGE CRACKING B. WHERE MORE COST EFFECTIVE THAN ALTERNATES. C. FAULTING IF SLABS STABILIZED D. NO VERTICAL GRADE CONSTRAINTS E. RIDE SCORE > 45 F. PROVIDE DRAINAGE BLANKET	FREEZE-THAW AREAS	10 YR.	$ 40,000 (2)	LIMITED
5. PAVEMENT REINFORCING FABRIC & OVERLAY	A. REPAIR BADLY CRACKED PAVEMENT B. WATER RESISTANT MEMBRANE	A. WHERE MORE COST EFFECTIVE THAN ALTERNATES. B. VERTICAL GRADE CONSTRAINTS		10 YR.	$ 35,000 (3)	ONE EXPERIMENTAL INSTALLATION
6. SLAB REPLACEMENT	REPLACE RANDOM SLABS WHICH ARE SEVERELY DISTRESSED	A. LESS THAN 35 SLABS PER MILE B. WHERE MORE COST EFFECTIVE THAN OVERLAY OR RECONSTRUCTION C. SEVERE CRACK SPALLING D. RIDE SCORE > 45		5 YRS.	$ 15,000 (4)	MODERATE

TABLE 9 (continued)

REPAIR STRATEGY	FUNCTION (OBJECTIVE)	PROPER USE	IMPROPER USE	SERVICE LIFE	*1976-77 COST PER LANE MILE	CALIFORNIA'S EXPERIENCE
7. MUDJACKING	A. FILL CAVITIES UNDER PAVEMENT B. RESTORE PAVEMENT GRADELINE	A. IMPROVE RIDE SCORE B. FAULTED OR VERTICALLY DISPLACED SLABS C. WHERE MORE COST EFFECTIVE THAN ALTERNATES	BADLY CRACKED	5-10 YR.	$ 55,000 (5)	EXTENSIVE
8. SUBSEALING	FILL CAVITIES UNDER PAVEMENT	FAULTED PAVEMENT	BADLY CRACKED SLABS	5-10 YR.	$55,000	NO RECENT EXPERIENCE
9. GRINDING	A. RELIEVE FAULTING B. IMPROVE RIDE QUALITY	A. FAULTING > 1/4" B. RIDE SCORE > 45	> 10% THIRD STAGE CRACKING	MORE THAN 5 YR.	$20,000	EXTENSIVE
10. PAVEMENT SUBDRAINAGE	DEWATER STRUCTURAL SECTION	A. AT LOWER PAVEMENT EDGE B. IN WET CLIMATE C. INDICATIONS OF FAULTING AND/OR PUMPING		UNKNOWN EST 10-15 YR.	$20,000/MILE	LIMITED EXPERIMENTAL INSTALLATIONS
11. CRACK FILLING	WATERPROOF PAVEMENT	A. CLEAN CRACKS ≥ 1/4" WIDE B. APPROPRIATE SEALANT	A. DIRTY CRACKS B. < 1/4" CRACKS	1-2 YR.	$ 200	EXTENSIVE
12. GROOVING	A. REDUCE HYDROPLANING B. IMPROVE VEHICLE TRACKING	A. ABNORMAL RATE OF WET PAVEMENT ACCIDENTS DUE TO HYDROPLANING	BADLY CRACKED PAVEMENT	10-15 YR.	$ 5,000	EXTENSIVE

* COSTS DO NOT INCLUDE TRAFFIC HANDLING

ASSUMPTIONS FOR RIGID PAVEMENT REPAIR COST ESTIMATES

(1) 0.60' PCC
(2) 0.08' O.G PLUS 0.25' AC
(3) REINFORCING FABRIC WITH 0.20' AC
(4) 30 SLABS/MILE @ $500 EACH (12" DEPTH PCC)
(5) $8 PER SQUARE YARD

TABLE 10
AASHTO DISTINCTION BETWEEN CONSTRUCTION AND MAINTENANCE (*30*)

CONSTRUCTION		MAINTENANCE	
Construction and Reconstruction	Betterment	Physical Maintenance	Traffic Services
Traveled Way			
All operations on new location or where considerable reconstruction to modern standards for 500' or more. Widening sufficient to change geometric type, as from a 2-lane to a 3- or 4-, from a 3- to a 4-, or from a 4- to a 6-lane highway, with all lanes not less than 11'. Addition of 500' or more of frontage road in any one mile.	Placing new loose material on roads suf. to substan. increase thickness of surfacing beyond that orig. built for 500 or more contin. feet. Imp. of surface to a higher type for 500' or more. Resurf. of hard surfaces with bit. material ¼" thick or more for a length of 500 contin. feet or more. Replace. of exist. pavement with higher standard for 500' or more. Widening with no change in number of lanes. Addition of less than 500' of frontage road in any one mile.	Scarifying, reshaping, applying dust palliatives, and restoring material losses; patching, mudjacking, joint filling, surface treating, etc. Resurfacing of hard surfaces with bit. material less than ¼" thick. Replacement of traveled way in kind for less than 500 continuous feet. Replacement of unsuitable base materials in patching operations.	Removal of snow and ice, and related operations as sanding, chemical applications, etc. Painting pavement stripes and markings.

TABLE 11
FLEXIBLE PAVEMENT MAINTENANCE TECHNIQUES

Treatment Type	Techniques	Corrective or Preventive	Effectiveness	Remarks
Patching	Temporary Permanent Spot seal (spray) Cold mix Hot mix Level	All patching is considered corrective. Some agencies said patching could be preventive in some cases when preventing more serious deterioration.	When properly done, patching is considered to be effective and to serve purpose. Temporary patching is considered moderately effective to serve short period until permanent repairs can be made.	There is a wide range of materials that can be used for patching. See NCHRP Synthesis 64 (56).
Surface Treatments	Seal coating with cover aggregate, chips, etc. Sand seal coat Flush coating (black seal, liquid asphalt, etc.) Dilute sealing (fog seal) Slurry seal Rejuvenators (binder modifiers, Reclamite, etc.) Hot-weather sanding Open-graded seal coat	Approximately 70% of replies indicated that surface treatments were preventive. Others indicated that surface treatments were corrective for skid resistance, etc. Some said surface treatments serve dual function.	Most of those providing ratings said surface treatments are effective for purpose intended. Several agencies have a schedule of every so many years for placing a surface treatment.	There is a considerable variation in materials and techniques used by various agencies for surface treatments. Local conditions vary extensively (climate, traffic, etc.) and must be considered for each treatment used.
Crack Maintenance	Crack cleaning Crack sealing Crack filling	Crack sealing is used as a preventive technique about 2/3 of the time. It is used 1/3 of the time as a corrective technique. Some consider it to serve a dual function.	Crack sealing is considered to be relatively effective. It has a fairly short life (1 to 2 yr) and so must be repeated often.	There are several different materials that can be used for crack sealing. Rubber asphalt appears to be the most cost-effective if properly used.
Surface Planing	Burn/plane Cold plane	Corrective	Generally effective in correcting corrugations and in reducing effect of high asphalt content or soft mix. May excessively harden asphalt.	There are different types of equipment that can be used. See NCHRP Synthesis 54 (60).
Other Localized Repairs	Blankets Base repair Remove and replace	Corrective	No evaluation given.	None
Recycling	Plant recycling In-place recycling (cold) In-place recycling (hot)	Corrective	Very few agencies identified this technique. Those that did considered it effective.	A relatively new technique that uses different softening agents, different equipment, etc.
Overlays	Thick overlays Thin overlays Pavement reinforcing Fabric and overlay Rubberized asphalt interlayer and overlayer Inverted overlays	Most agencies (69%) consider overlays to be a corrective technique. Thirty-one percent considered them to be preventive. Some believe they serve a dual function.	All agencies rating overlays said they were effective.	The timing of when an overlay is placed determines whether it is preventive or corrective. If the overlay is placed after failure, then it becomes corrective. Some agencies consider overlays to be rehabilitation rather than maintenance.

TABLE 12
RIGID PAVEMENT MAINTENANCE TECHNIQUES

Treatment Type	Techniques	Corrective or Preventive	Effectiveness	Remarks
Patching	Temporary patching Permanent patching PCC patching	Corrective	Temporary patching considered fair to poor. Permanent patching rated good.	There are numerous patching materials available. NCHRP Synthesis 45 (57) gives data on some.
Crack Maintenance	Crack cleaning Crack sealing	Classed as preventive and/or corrective	Rated as generally effective.	There was limited input on crack maintenance in rigid pavements.
Joints	Pressure relief joints	Corrective and/or preventive	Rated as effective in helping maintain rigid pavement and in protecting pavement and bridges.	Limited input.
	Repair joints	Corrective	Effective	Limited input.
	Cleaning joints Sealing joints	Mostly classed corrective; some considered preventive	Generally effective depending on materials and workmanship	There are a number of different materials that can be used.
Faulting Repair	Grinding (planing)	Corrective	Effective	The most common repair method identified was mudjacking.
	Mudjacking (pressure grouting)	Mostly corrective, some preventive	Moderately effective	
	Subsealing	Preventive	Not rated	
Blowup Repair	Temporary	Corrective	Temporary	There was minimal input in this area.
	Remove and replace	Corrective	Effective	
Surface Planing	Grinding	Corrective	Effective for correcting ride but may not solve basic problem creating roughness.	Limited input from agencies.
	Grooving	Corrective	Effective for correcting skid resistance.	
Other Localized Repairs	Drainage Correction Underdrain installation	Preventive	Rated effective	It was felt by some agencies that water was serious problem and that proper drainage of system would extend performance.
	Remove and replace Surface/base replacement	Corrective	Effective	Limited input.
Overlays	Thick bituminous overlay Thin bituminous overlay Thick PCC overlay Thin PCC overlay Pavement reinforcing fabric and overlap Rubberized asphalt interlayer and overlay	Corrective	Generally effective; thicker overlays considered more effective.	There was limited input on overlays over portland cement concrete pavement.

TABLE 13
EXAMPLES OF MAINTENANCE TREATMENTS IN RELATION TO CERTAIN TYPES OF DEFICIENCIES FOR FLEXIBLE PAVEMENTS (*33*)

Selected deficiencies (See Catalogue of Road Surface Deficiencies, OECD, Paris 1978) / Treatments	Planing**	Patching	Sealing	Surface dressing	Thin overlays	Recycling
see sub-chapter	8.1	8.2	8.2 and 8.6	8.3	8.4	8.5
3. Bump	X	XX			ϵ	ϵ
4. Wave	XX	X		ϵ	XX	
5. Rippling, washboard, corrugation	XX				XX	
6. Depression, bird bath		XX	ϵ	ϵ		ϵ
7. Distortion	ϵ	XX			XX	X
8. Rutting	XX	X		ϵ	XX	X
9. Shoving	X	ϵ		ϵ	XX	ϵ
10. Alligator cracking, chicken wire cracking		X	ϵ	XX	XX	ϵ
11. Block cracking, map cracking	ϵ	X	X	X	XX	
12. Centreline crack, longitudinal crack	ϵ	ϵ	XX	ϵ	ϵ	ϵ
13. Wheel track cracking*		ϵ	X	X	X	ϵ
14. Pavement edge crack		ϵ	X	X	ϵ	
15. Meandering crack		ϵ	X	ϵ	X	
16. Contraction crack, shrinkage crack, transverse crack		X	ϵ	ϵ	X	
17. Reflection crack		ϵ	X	ϵ	X	ϵ
18. Slippage, crescent, parabolic, tearing crack		ϵ		ϵ	ϵ	
20. Imprint, indentation, scarring	ϵ	X	ϵ	X	X	ϵ
21. Loss of surface aggregates		ϵ		X	XX	
23. Ravelling, weathering		X	ϵ	XX	XX	ϵ
26. Polished aggregates	ϵ			X	X	
27. Bleeding of binder, flushing	X			ϵ	X	ϵ
28. Pothole, chuckhole		XX	ϵ	ϵ	X	
29. Bleeding of water, water retention, wet spot***		ϵ	ϵ	ϵ		
31. Inadequate drainage***					X	
Inadequate skid resistance	ϵ			X	XX	ϵ

* = Strengthening would be preferred.
** = Can also be used as preparatory measure for other treatments.
*** = Drainage system must first be improved.
ϵ = Seldom used.
X = Used in some countries for some types of road.
XX = Used in almost all countries.

TABLE 14
LIST OF DEFICIENCIES AND APPROPRIATE REMEDIAL TECHNIQUES FOR RIGID PAVEMENTS (*33*)

DEFICIENCIES			Restoring micro- and macro-texture	Grooving	Re-sealing of joints	Concrete patching or layer	Repair of spalled joint and crack edges	Milling and sealing of cracks	Impregnation	Pressure grouting	Partial or total reconstruction	Dowelling and tying cracks
CLASS	Nr*	TYPE See Chapter	7.1	7.2	10.2	10.3	10.4 & 10.6	10.5	10.7	10.8	10.9	10.10
Surface defects	35	Inadequate skid resistance	X									
	36	Inadequate surface drainage		X		X						
	37	Wheel track wear (rutting)		X		X						
	42	Loss of waterproofing of joint			X		X					
	43	Joint sealant extrusion			X		X					
	51	Expansion joint failure, shattering					X					
	53	Spalling					X					
	54	Pop-outs				X						
	55	Potholes, chuck holes, etc.				X						
	56	Crazing, alligator cracking							X			
	57	Scaling				X			X			
	58	Peeling				X						
Structural defects	38	Settlement								X		
	39	Pumping								X		
	40	Slabrocking								X		X
	41	Stepping				X				X		
	44	Longitudinal joint opening			X							X
	45	Transverse or diagonal crack						X			X	X
	46	Long longitudinal crack						X				X
	47	Short longitudinal crack						X			X	X
	48	Corner cracking, corner break						X			X	
	49	D-cracking									X	
	50	Buckling, blow up									X	
	52	Block, random or third stage cracking								X	X	

* See: Catalogue of road surface deficiencies, OECD, Paris, 1978.

TABLE 15
FLEXIBLE ROADS: PAVEMENT CHARACTERISTICS, DEFICIENCIES, AND TREATMENT (*33*)

Pavement Characteristic	Effects if allowed to deteriorate	Deficiencies which cause deterioration	Examples of possible treatment
IMPERMEABILITY	Ingress of water to structure. Possible weakening of structure and subgrade. Stripping of binder. Loss of adhesion between layers.	Surface crazing. Surface cracking. Surface ravelling. Surface disintegration.	Individual crack sealing. Spray patching. Patching. Surface dressing. Surfacing.
SKID RESISTANCE	Safety: Reduced vehicle control.	Loss of texture. Polishing of surface aggregates.	Surface dressing. Surfacing.
SURFACE EVENNESS	Safety: Reduced vehicle control. Comfort: Physical discomfort.	Deformation. Distortion. Surface ravelling. Surface disintegration. Rutting (all types). Potholes.	Patch - if local. Surface - if general. Patch ruts or surface road. Patch.
SURFACE WATER DRAINAGE	Safety: Aquaplaning. Safety and Driving Comfort: Loss of visibility from excessive spray.	Loss of texture. Deformation. Distortion. Rutting (all types). Inadequate camber or cross-fall. Impediments to free flow of water from surface: - blocked grips or ditches - raised shoulders.	Surface dress or surface. Patch or surface. Patch ruts or surface road. Surface. Clean out grips or ditches. Reduce shoulder levels.

TABLE 16
RIGID ROADS: PAVEMENT CHARACTERISTICS, DEFICIENCIES, AND TREATMENTS (*33*)

Pavement Characteristic	Effects if allowed to deteriorate	Deficiencies which cause deterioration	Examples of possible treatment
IMPERMEABILITY	Ingress of water. Weakening of supporting layers. and subgrade.	Defective joint/crack seals. Defective edge/shoulder seals.	Seal.
SKID RESISTANCE	As for flexible roads.	Loss of texture. Polishing of surface aggregate.	Grooving. Roughening. Surface dressing. Surfacing.
SURFACE EVENNESS	As for flexible roads.	Settlement. Differential settlement at joints or cracks. Surface scaling. Spalling along joints or cracks. Protruding joint sealant. Blowups. Shattering at joints. Rutting (wear)	Pressure grout. Patch.* Patch. Remove excess sealant. Reconstruct as necessary.* Patch.
SURFACE WATER	As for flexible roads.	Loss of texture. Rutting (wear) Impediments to free flow of water from surface: - blocked grips or ditches. - raised shoulders.	Groove, roughen, surface dress. Patch. Clean out grips or ditches. Reduce shoulder levels.

* Applicable also to composite pavements.

TABLE 17
SUMMARY OF REPAIR METHODS FOR FLEXIBLE PAVEMENT DISTRESS (*20*)

	Repair Methods											
	Seal Coat	Spray Patching	Spread Blotting Material	Remove with Blade or Heater-Planer	Removal and Replacement of Surface Course	Asphaltic Concrete Leveling and Surfacing	Temporary Hole Filling	Permanent Patching	Scarifying and Mixing	Crack Filling	Crack Filling with Slurry	Asphalt Emulsion Slurry Seal
Distress	1	1	1	1	2	3	4	4	5	6	7	8
Abrasion	MT					BP			BP			
Bleeding			MB		SP							
Char		MB			SP							
Indentation				MB		SP						
Loss of Cover Agg.	BB		MT	SP		SP						
Polished Aggregates	BT			BB		BP						
Pothole		MT					BT	BP				
Raveling	BB			SP								
Streaking				BB	SP	SP						
Weathering	BB											MT
Corrugation				MB		MB			BP			
Alligator Cracking					MT			SP	SP			
Contraction Cracking					SP				SP	BT	BT	BT
Edge Cracking						SP				MT	BT	
Edge Joint Cracking						SP		SP		MT		
Lane Joint Cracking					SP				SP	MT	MT	MT
Reflection Cracking										BT		
Shrinkage Cracking	MT				SP						SB	
Slippage Cracking		MT			SP			SP				
Depression						SP						
Butting					SP	MB	MT	SP				
Shoving						MT		SP				
Upheaval					MT			SP				
Utility Cut Depression						MB		SP				

Severity of Distress: (M) moderate, (S) severe, (B) both
Permanency of Repair: (T) temporary, (P) permanent, (B) both

TABLE 18
SUMMARY OF REPAIR METHODS FOR RIGID PAVEMENT DISTRESS (*20*)

	Repair Methods					
	Asphalt Emulsion Slurry Seal	Joint Filling	Thin Asphaltic Concrete Overlay	Concrete Patching Shallow	Concrete Patching Deep	Slab Jacking
Distress	8	9	10	11	11	12
Crazing	MT				SP	
Joint Filler Extrusion/Stripping		BB				
Scaling	MT		BP	SP	SP	
Buckling Blow-Up					BP	
Shattering Blow-Up					BP	
Corner Cracking		MT			BP	MP
Diagonal Cracking		MT			BP	BP
Longitudinal Cracking		MT			SP	BP
Transverse Cracking		MT			SP	BP
2nd Stage Cracking		MT			SP	BP
Progressive Cracking		MT			SP	SP
Random Cracking	MT	ST			SP	
"D" Cracking	MT		BP	MP		
Faulting		BT				BP
Joint Failure		BT		BP	BP	
Pumping						BP
Spalling			MT	MP	BP	

Severity of Distress: (M) moderate, (S) severe, (B) both
Permanency of Repair: (T) temporary, (P) permanent, (B) both.

CHAPTER FOUR

PAVEMENT MAINTENANCE STRATEGIES

WHAT ARE PAVEMENT MAINTENANCE STRATEGIES?

For the purpose of this synthesis, pavement maintenance strategies are defined as plans of action embodying the continuing application of pavement maintenance techniques that are designed to improve or maintain the condition of pavement segments above some predetermined minimum requirement. The strategy consists of the type of maintenance technique, its design life, and its time for enactment, along with various economic, physical, and environmental constraints. Some of the general categories of maintenance are maintaining the pavement above some minimum serviceability level, correcting failures or deficiencies as they develop, performing maintenance at some predetermined time interval, restoring pavements to an as-built condition, protecting the investment, and conducting maintenance on a priority basis.

Maintenance strategies were defined by Lu and Lytton (*61*) as "different activities to be selected for each highway segment in the analysis to increase the pavement rating above specified minimum requirement." Smith and Monismith (*62*) stated that "the optimal maintenance strategy defined by the PMMS [pavement maintenance management system] is the alternative that minimizes the expected present value of total costs for each pavement condition state." They identified two components of pavement cost: (a) the highway department costs, which are the funds actually spent to maintain the pavement and (b) the highway user costs, which are those incurred by the pavement users as related to the pavement condition. They reached the following conclusions:

> 1. Optimal maintenance strategy was dependent on the value placed on excess user costs as measured by the excess user cost scale factor.
> 2. Level of maintenance in an optimal maintenance strategy increased as the value placed on excess costs increased.
> 3. For a given excess user cost scale factor, the level of maintenance that was optimal increased as the condition of a pavement deteriorated.

Strategies are defined in *NCHRP Report 215* (*8*) as "a plan or method for dealing with all aspects of a particular problem." For example, a rehabilitation strategy is a plan for maintaining a pavement in a serviceable condition for a specified period of time. An optimum strategy is defined as "that strategy among the alternatives considered which is expected to maximize the realization of management goals subject to the constraints imposed."

QUESTIONNAIRE RESPONSES ON PAVEMENT MAINTENANCE STRATEGIES

The second question in the survey was: "What pavement maintenance strategies do you use?" The responses are summarized in Table 19; detailed responses are contained in Appendix B. The most frequently identified strategy was to correct failures or deficiencies; 78 percent of the agencies listed this. The next most frequently listed strategy was to maintain the pavement above some minimum serviceability or level of service; 28 percent of the respondents included it.

The third survey question was: "What basis is used for selecting a strategy?" The majority of the respondents (63 percent) indicated that they based their strategies on rational or theoretical engineering concepts. The next most frequent basis was cost-effectiveness, with 57 percent of the agencies identifying it. Several agencies indicated that rational engineering concepts and cost-effectiveness were built into their systems because of research and experience over the years.

The responses to the third question are summarized in Table 20 and detailed in Appendix B. Several states indicated that funding or the lack of it formed the basis for their strate-

TABLE 19
PAVEMENT MAINTENANCE STRAGEGIES USED[a]

Pavement Maintenance Strategies	States	Canadian Provinces	Toll Roads
Correct failures or deficiencies	3 Network[b] 25 Project	2 Project[c]	1 Network 5 Project
Predetermined schedule, routine maintenance	1 Network 2 Project 6 Unident.[d]	0 Network 0 Project 1 Unident.	0
Inspection, pavement condition and survey, priority, need	0 Network 0 Project 9 Unident.	0	0
Maintain above minimum serviceability or level of service	3 Network 3 Project 4 Unident.	1 Project	1 Project 2 Unident.
Maintenance management system, performance and quality standards	1 Network 1 Project 3 Unident.	1 Project	0
Maintain pavement in as-built condition, preventive measures	4 Unident.	0	2 Unident.
Restore to as-built condition (skid, ride, etc.)	1 Network	1 Unident.	0
History	2 Unident.	0	0
Long-range pavement maintenance program	0	0	1 Unident.

[a]Responses to the questionnaire were received from 35 states, 3 Canadian provinces, and 8 toll roads.

[b]Network: Network level—usually minor repairs.

[c]Project: Project level—usually major repairs.

[d]Unidentified: Not identified whether project or network level.

TABLE 20
BASIS USED FOR SELECTING STRATEGIES[a]

Bases for Pavement Maintenance Strategies	States[b]	Canadian Provinces[c]	Toll Roads[d]
Rational engineering concepts	21	2	6
Cost-effectiveness	20	2	4
Traditional allocation	13	0	0
Fund availability	10	0	0
Maintenance management system	4	1	0
Visual observations, periodic inspections	5	1	1
Optimal use of existing maintenance personnel and equipment	1	1	1
Experience	1	1	1
Previous budgets, history	2	0	0

[a]Responses to the questionnaire were received from 35 states, 3 Canadian provinces, and 8 toll roads.

[b]Other bases identified by states: priority sequence, safety, ridability, cost necessity, protection of investment, sufficiency ratings, management principles, pavement management system, and planning data.

[c]By Canadian provinces: potential energy shortfall, serviceability index.

[d]By toll roads: maintain in good condition at all times, pride in work.

gies. Some of the toll roads said that they depended on users to pay the operating and maintenance costs through fares, which in turn dictated that they maintain their roads in good condition at all times.

The fourth question in the questionnaire was: "What methodologies, if any, were used in developing the process identified in [the previous question]?" The responses to this question are summarized in Table 21 and detailed in Appendix B. The most frequently used methodology was identified as road condition surveys and similar approaches; 22 percent of the agencies listed it. The next two were historical data (including experience) and maintenance management systems (including quality standards); 20 percent of the respondents identified each one.

ECONOMIC CONSIDERATIONS AND PRIORITY SETTING

Economic analysis and choice of priorities was one of the subject areas covered at the Sixteenth World Road Congress (7), where it was pointed out that maintenance costs are increasing rapidly and that the effect of increased damage from heavy commercial vehicles and the increased cost of materials used is significant. The report further states:

> At present, there appears to be a general concern for the economic assessment of the effectiveness of highway maintenance but very few, if any, countries appear to have yet progressed very far with the complex problems involved.
>
> The Economics and Finance Committee have discussed these problems in some depth. For the purpose of this Conference-Discussion, it is sufficient to observe that an economic analysis incorporating the variety of significant parameters involved must be concerned with the best solution and not necessarily the cheapest one. It must take account of the potential results of a decision to commit, or not to commit, resources as the case may be, and weigh the outcome. . . .
>
> A certain amount of subjective judgement in the decision making process seems almost inevitable whatever the depth of analysis. Engineering assessments of condition and economic evaluation are two essential aids to decision making, but neither is complete in themselves.

The factors considered by various countries in selecting priorities and making decisions based on economics are summarized in Table 22. Table 23 presents similar information for a number of states. The report further points out the

TABLE 21
METHODOLOGIES USED IN DEVELOPING THE PROCESS FOR SELECTING STRATEGIES[a]

Methodologies	States	Canadian Provinces	Toll Roads
Road condition survey, etc.	9	0	1
Historical data, experience	8	1	0
Maintenance management system, quality standards	8	1	0
None identified	6	0	2
Area supervisors	5	0	0
Funding availability, budget restrictions	3	0	0
Experimental trial, review, modification	1	0	1
Developed by group or committee effort	2	1	0
Self-supporting nature of toll roads	0	0	2
Research activities	1	1	0
Routine maintenance costs	1	0	0
Current maintenance practices	1	0	0
Pavement management system	1	0	0
Program continuity	1	0	0
Level of service	1	0	0
Subjectivity	1	0	0
Trade-offs between two or three alternatives	1	0	0
Service life curves	0	0	1
Pride in work, confidence	0	0	1

[a]Responses to the questionnaire were received from 35 states, 3 Canadian provinces, and 8 toll roads.

TABLE 22
ECONOMIC ASPECTS OF DECISION-MAKING IN VARIOUS COUNTRIES (7)

	Australia	Austria	Belgium	Canada (1)	Czecho-slovakia	Fed. Rep. of Germany	Finland	France	Italy	Japan	The Netherlands	Spain	UK	USA (2)	USSR
Inadequate annual maintenance funds	X	X	X	X	X		X	X	X	X	X Not always	X	X	X 70%	
Priority given to pavement maintenance	X	X	X			X	X	X		X	X			X 60%	
Priority by Route importance	X	2X	X	2	X	X	X			X			X	X 55%	
by Traffic safety		1X	X	1		X	X		X				X	X 70%	X
by degree of deterioration		3X		2		X			X	X			X	X 55%	
by cost		4X		3									X	X 12%	
by target values and PSI			X							X					
by engineers decision	X			X		X		X	X		X		X	X 14%	
by accident statistics			X	X		X			X			X for black spots	X	X 75 %	
by Inspection	X													X 40%	
Cost benefit analysis for maintenance treatments		X		X	X		X	X		X			X	X 50%	X
Reconstruction costs	X	X		X	X	X	X	Rate	X	3X	X	X	X	X 75%	
Delay costs				X				of		2X			X	X 53%	
Accident costs considered when selecting alternatives				X		X		return	X	1X	X(3)		X	X 65%	
Procedure for optimising costs		X		X	X				X Proposed	X			X	X 35%	X
Variation of costs in different areas/regions/districts	X	X (slight)	X	X	X		X	X	X	X	X	X (by budget)	X	X 70%	

(1) Not all Highway Departments
(2) Expressed as % of information from 28 states
(3) Incidentally

TABLE 23
MAINTENANCE PRIORITIES AND ECONOMICS (USA) (7)

	ALABAMA	ARIZONA	ARKANSAS	CALIFORNIA	DELAWARE	FLORIDA	GEORGIA	HAWAII	ILLINOIS	IOWA	KANSAS	LOUISIANA	MARYLAND	MASSA-CHUSETTS	MISSOURI	NEVADA	NEW JERSEY	NEW YORK	OHIO	OKLAHOMA	PENNSYL-VANIA	SOUTH DAKOTA	TENNESSEE	TEXAS	VIRGINIA	WASHINGTON	WEST VIRGINIA	WISCONSIN	WYOMING
Inadequate annual maintenance funds	X		X		X		X		X	X		X		X (50%)		X	X	X	X	X	X	X	X	X	X	X			
Priority given to pavement maintenance		X	X	X	X				X	X		X		50%		X	X	XW	X	X	W	X	J	PI/E	.X			X	
Priority by route importance		X	X	X		X	X		X					XD	X				X	X	X	X	X	X		X	X		
by traffic safety	X	X	X	X		X	X	TV	X	X		X			X	X	XR	X	X	X				X	X	X			
by degree of deterioration	X		X	X		X			X	X					X	X	XR		X			X		X	X	X	X		
by cost		X				X						PI								X	X								
by target values and PSI																													
by engineers decision							C						X			X HQC					JP		J						
by accident statistics		X	X	X			X		XD	XD			X	X	X	XD	XR	X	X	X	X	X	X	XD	X	XD	XD		
by Inspection		AM		X		X		PC					X	X			XR	X				X				X			X
Attempt at cost benefit analysis for maintenance treatment	X	X	X	X			J			X		X	J	X			X	X		X		X		·	X	X	X		
Reconstruction costs	96%	X	X	X	1		X	1	X	1		X	40%	X	X	75%	1		1	1	1	1	1	1		NM	X	NM	
Delay costs	2%		X	X	3			2	X	2					X	5%	3		3	3	2	3	3			XD			
Accident costs	2%		X	X	2	X		3	X	3			60%		X	20%	2		2	2	3	2	2			F	X		
Chiefly used in selecting best alternative reconstruction method																													
A procedure used for minimising or optimising costs of maintenance policy		X	X	X					X	X			X									X	X			X	X		
Variation in maintenance expenditure rates in different areas/regions/districts	X		X	X	X		X		X	X		X	X	X	X					X	X	X	X	X	X	X	X		X
States offering any additional reason than those quoted above for priority selection	P		S				TV			TV		Budget limit-ation		P			P		A		PI E			PI E	PE	SA			

REFERENCE KEY:

A	AGE	J	JUDGEMENT BY ENGINEER	R	RATING SYSTEM
C	COMPLAINTS	M	TYPE OF MATERIAL	S	SEASON OF YEAR
E	TO A DEGREE	NM	NOT MAINTENANCE	SA	SALVAGE VALUE
F	FREQUENCY	P	POLITICAL, POLICY PUBLIC DEMAND	TV	TRAFFIC VOLUME
HQC	HIGH MANAGEMENT LEVEL	PI	PRESERVATION OF INVESTMENT	W	WINTER MAINTENANCE

desirability of taking into account the social and economic importance of the road as well as the physical condition of the pavement and the damaging effect of traffic.

A report by the OECD (*33*) identifies several factors that need to be considered when evaluating possible alternative treatments:

- Suitability for immediate purposes.
- Subsequent implications (probable performance, future treatment).
- Required life (short-term/long-term).
- Costs (immediate, future).
- Effects on traffic (delays, congestion).
- Effects on road user (safety, comfort, noise).
- Appearance.
- Road-user objections (flying stones, noise).

The OECD report describes a decision-making process that begins with the consideration of each defect and ends with the final adoption of the most economical course of action (Fig. 9). The report discusses the difference between maintenance strategies as the "(1) choice between 'taking action' or 'doing nothing' (in this case it is necessary to compare the costs involved in carrying out maintenance work with the global costs of delaying action (considering each time road-user costs and benefits)) or (2) in the framework of a well defined maintenance policy, choice between the various possible maintenance treatments by comparing global costs."

The do-nothing alternative is the same as the present level of maintenance.

It is not enough simply to know what pavement maintenance is needed and where, because generally many more

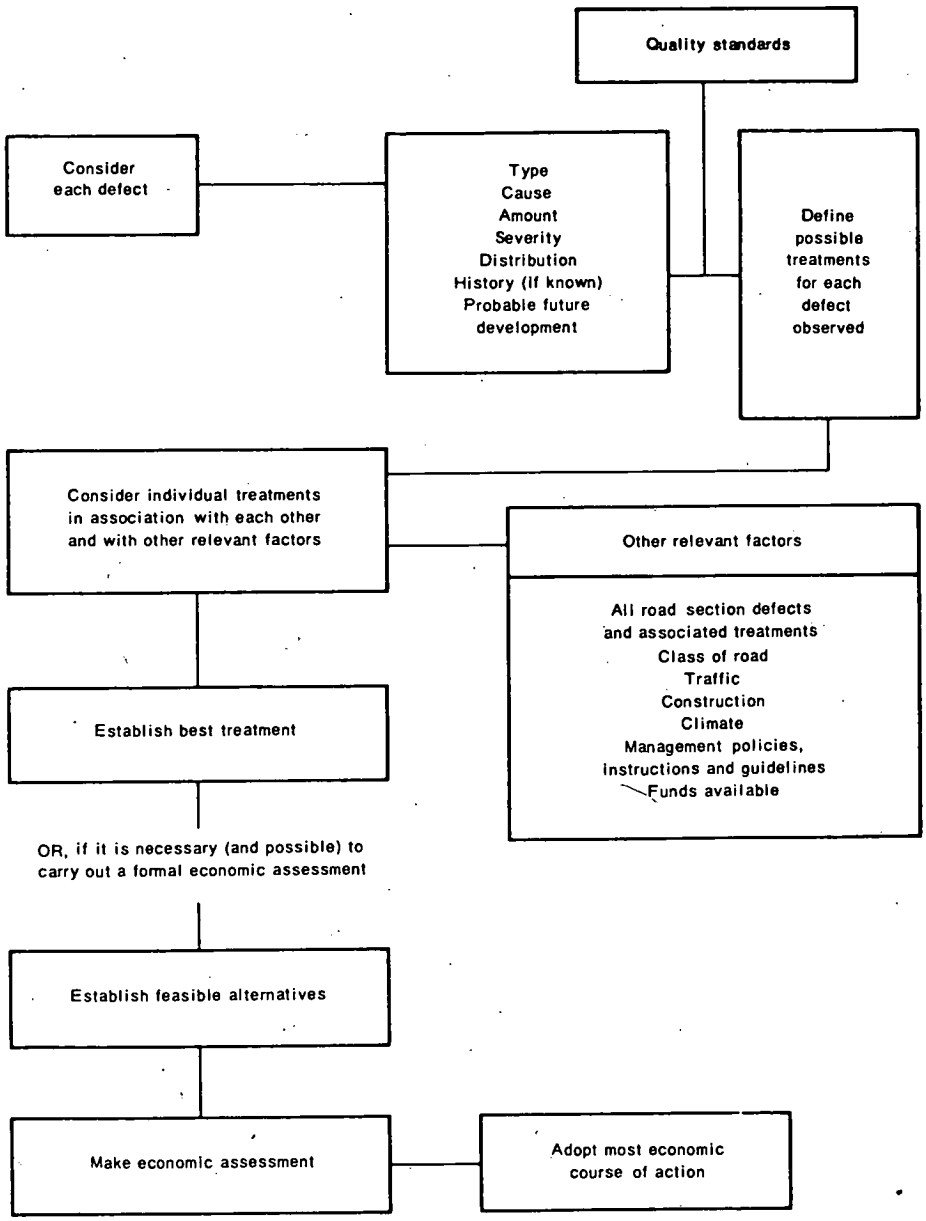
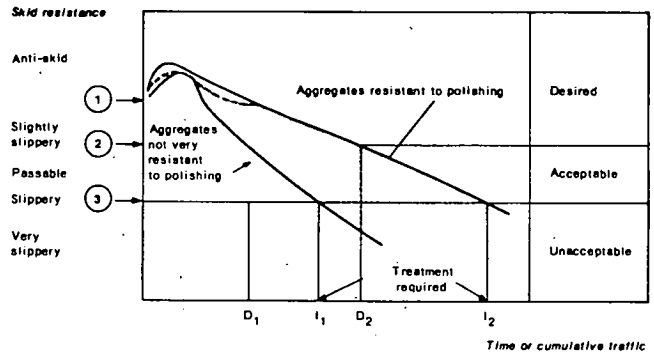


FIGURE 9 Decision-making process for pavement improvements (*33*).

pavement sections are deficient than there are funds available to correct them. It is therefore necessary to establish some form of priority ranking for all the pavement sections where work is required or desired. There are not many formalized methods for establishing priorities because most agencies depend on subjective judgment. Important factors in ranking pavements for maintenance or rehabilitation include the function of the road, the traffic volume, the present condition of the pavement, the rate of change in pavement condition, and the costs. It is usually difficult to ascertain the expected rate of change and the point in time when the pavement condition would be considered unacceptable. Figures 10 and 11 are examples of models for predicting pavement behavior and the evolution of defects with time. Developing such curves requires that pavement condition data be gathered for extended time periods.



1. Level is the value specified for a new road or a resurfaced or a surface dressed road (Restoration level).
2. The level at which some action is desirable.
3. The level at which action is imperative.

FIGURE 10 Example of a model for predicting pavement behavior with time (*33*).

EXAMPLES OF OPERATIONAL SYSTEMS

California

The California Department of Transportation (Caltrans) has developed a pavement management system that is designed to assist management in making cost-effective decisions regarding pavement maintenance and rehabilitation (*24, 35*). The Caltrans system brings together the following systems approach (*35*):

- Taking inventory of pavement condition.
- Analyzing extent and severity of pavement condition.
- Identifying appropriate repair strategies.
- Identifying cost-effective strategies and reasonable alternatives for candidate projects.
- Relating the repair strategies to the appropriate Caltrans highway program structure.
- Organizing candidate projects for each Caltrans highway program component within each transportation district on a statewide basis, and other required groupings.

Caltrans has rating systems for flexible pavements and rigid pavements. The agency's present condition rating system distinguishes between severity and extent in separate terms that provide useful information for selecting the proper repair strategies.

The flexible pavement condition rating includes alligator and block cracking, longitudinal cracking, transverse cracking, raveling and weathering, rutting, patching, and drip track (ravel). The rigid pavement condition rating includes slab breakup, crack spalling (third stage only), patching (full-lane width), faulting (step-off), lane/shoulder displacement (right edge), right shoulder condition, and bridge approach ride comfort.

Ride quality is measured with a ride meter, and the ride score is used to identify locations that should be considered for improvement of ride quality. Skid resistance (SN-40 ≤ 37) is used by the districts to trigger a more detailed investigation into what course of action, if any, should be taken. The condition survey is scheduled once every 2 years and is done in the late spring.

The primary function of the evaluation system is to correlate pavement problems with feasible repair strategies.

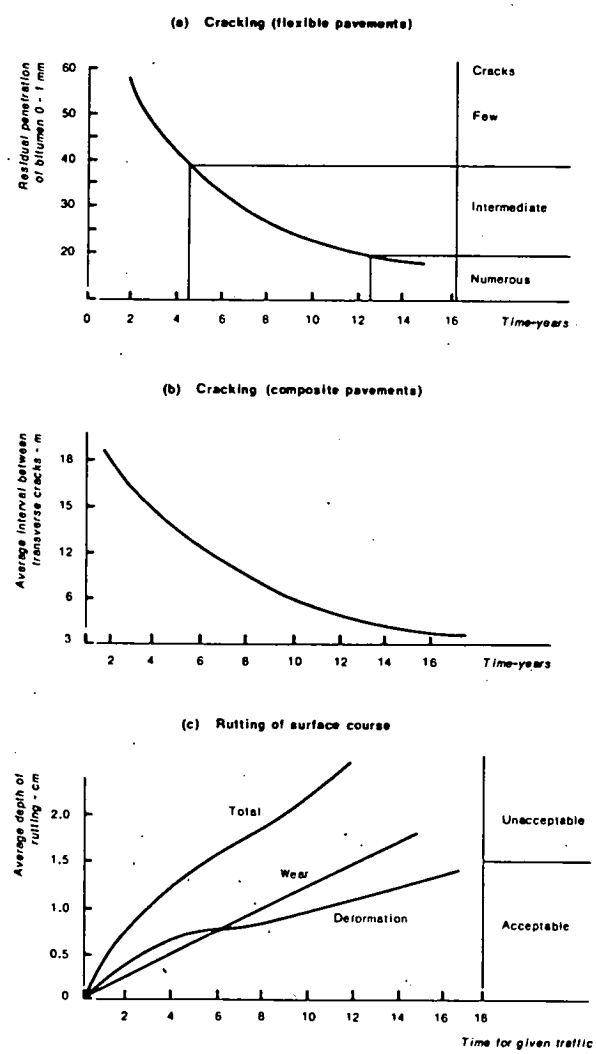


FIGURE 11 Example of models for predicting the evolution of defects with time (*33*).

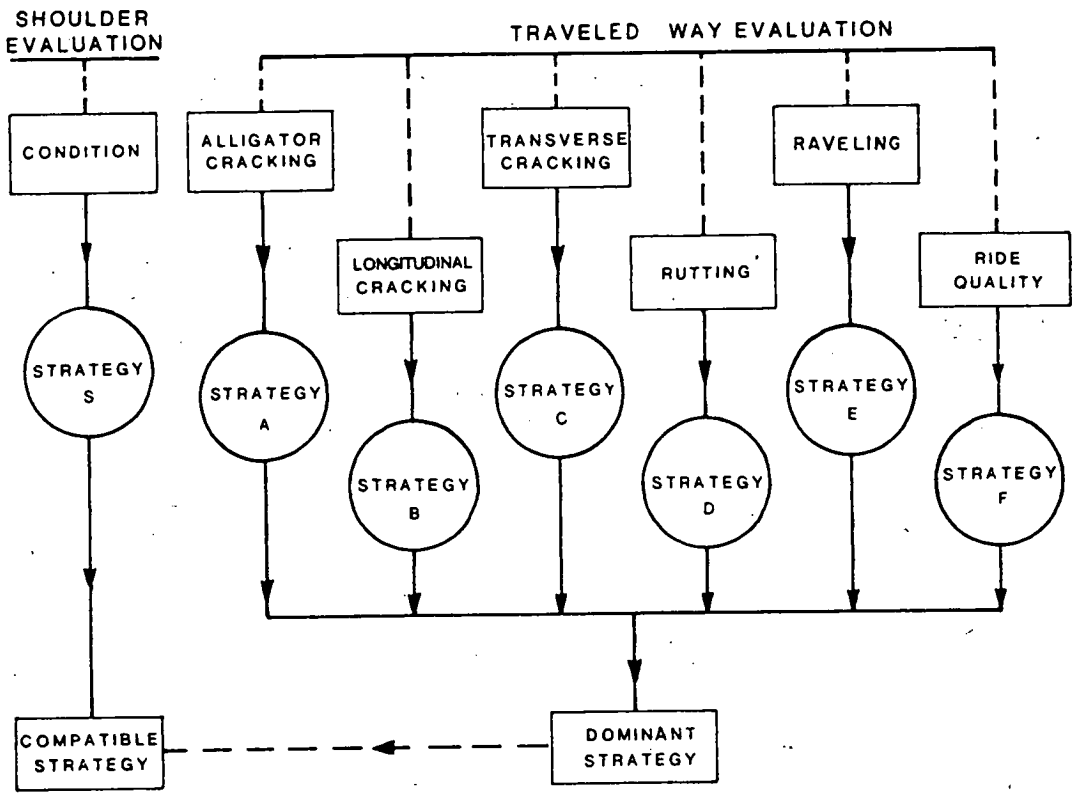


FIGURE 12 Caltrans flexible pavement condition evaluation procedure (*35*).

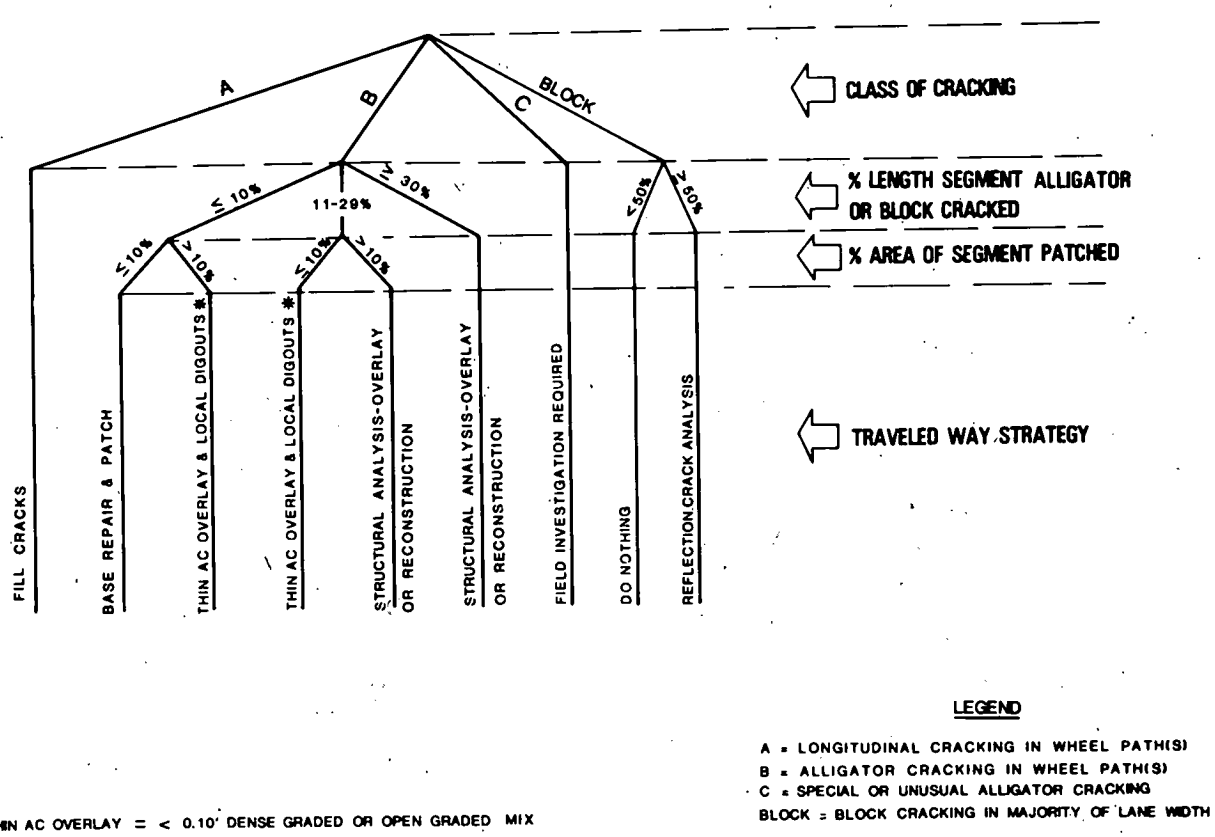


FIGURE 13 Caltrans flexible pavement alligator/block cracking rehabilitation decision tree (*35*).

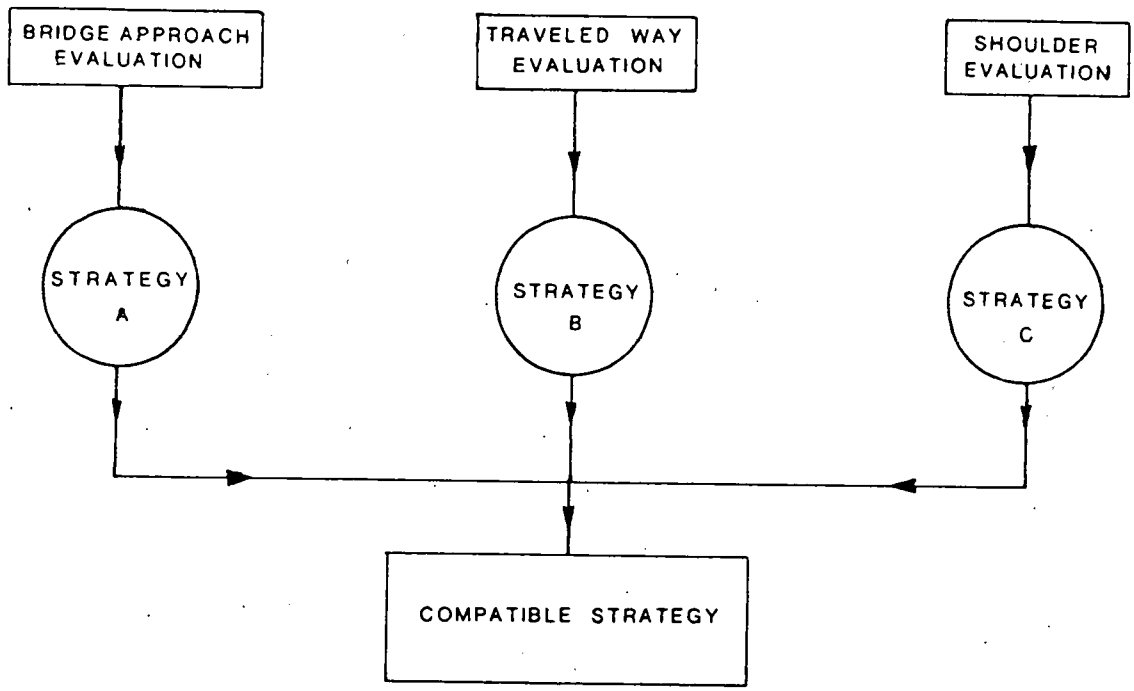


FIGURE 14 Caltrans rigid pavement condition evaluation procedure (*35*).

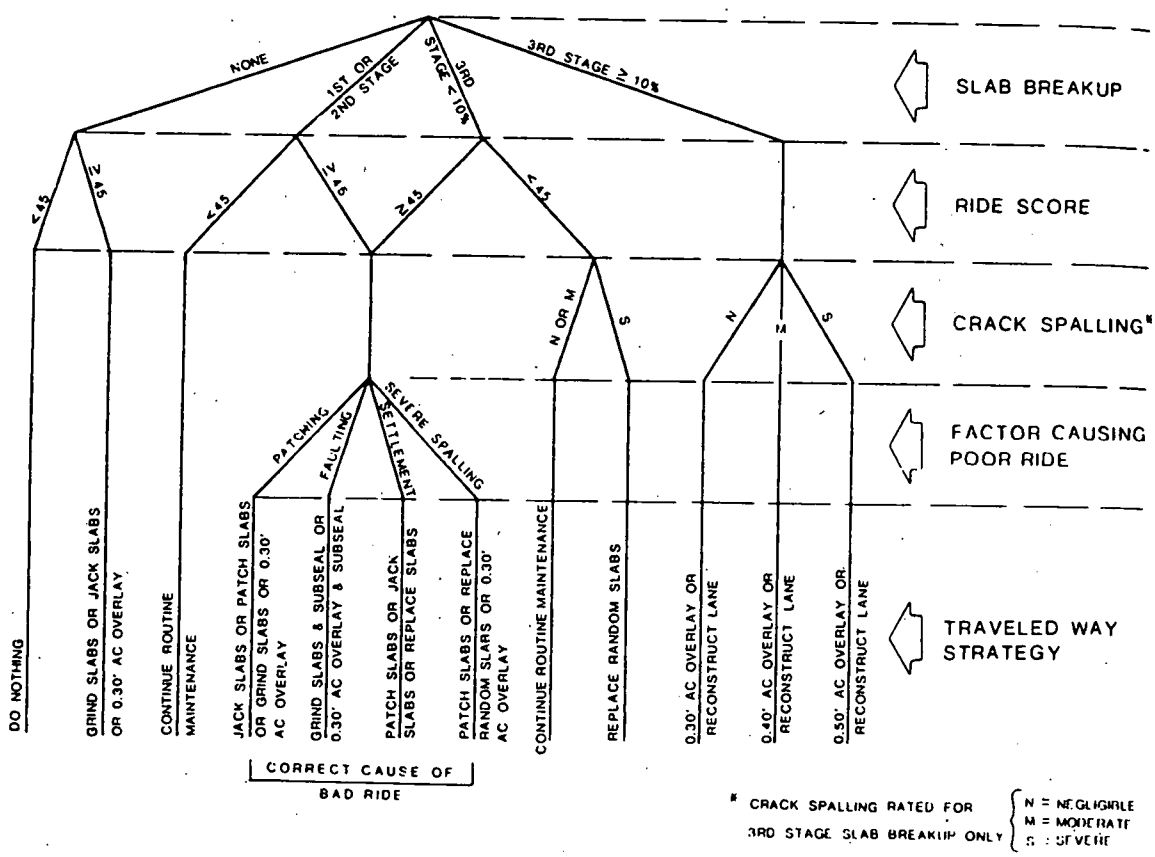


FIGURE 15 Caltrans rigid pavement traveled-way rehabilitation decision tree (*35*).

Levels of service are set for each type of problem that may justify improvement. Several strategies are identified; the one that will correct all problems and provide an acceptable level of service is classed as the dominant strategy. The evaluation procedure used in selecting the dominant strategy is illustrated in Figure 12. Decision trees, such as the one shown in Figure 13 for flexible pavement alligator/block cracking, are used to select the appropriate strategy based on pavement condition and problems. There are also decision trees for other cracking types, rutting, raveling and weathering, and ride quality. The rigid pavement condition evaluation procedure is illustrated in Figure 14, and the traveled way evaluation process for selecting a strategy is shown in Figure 15. Alternative selections are based on an engineering evaluation of field conditions, traffic volume, allowable work shift, materials availability funds, and so on.

Caltrans identified a number of maintenance and rehabilitation strategies for its own use. Each repair strategy has different functions, costs, and service life. Tables 8 and 9 in Chapter 3 provide detailed information for the California flexible and rigid pavement strategies.

Guidelines developed for the design of overlays on flexible pavements are presented in Figure 16.

The performance of completed pavement repairs was analyzed to establish the predictability of service life so that values for the various rehabilitation and maintenance strategies could be verified. An example of the service life of crack correction using a rock seal coat is shown in Figure 17.

The Caltrans pavement management system generates, for each district in the state, a list of problem pavement locations, the indicated dominant repair strategies, service life, and estimated project cost (*35*). The cost estimates are used

PAVEMENT PROBLEM	RECOMMEND OVERLAY DESIGN METHOD			
	ENGINEERING JUDGEMENT	GRAVEL EQUIVALENT	DEFLECTION ANALYSIS ①	REFLECTION CRACKING CONTROL ①
NON LOAD ASSOCIATED CRACKING — BLOCK OR SHRINKAGE CRACKING, TRANSVERSE AND/OR LONGITUDINAL CRACKING				
1. NO VERTICAL GRADE CONTROLS				X
2. WITH VERTICAL GRADE CONTROLS		X		X ②
3. COST EFFECTIVENESS INDICATES A COMPOSITE OVERLAY, REWORKING THE EXISTING STRUCTURAL SECTION, OR RECYCLING - (USING R VALUE TEST PROCEDURE)		X		
LOAD ASSOCIATED CRACKING -- ALLIGATOR CRACKING IN THE WHEELPATHS				
1. NO VERTICAL GRADE CONTROLS			X	
2. WITH VERTICAL GRADE CONTROLS		X	X ②	
3. COST EFFECTIVENESS INDICATES A COMPOSITE OVERLAY, REWORKING THE EXISTING STRUCTURAL SECTION, OR RECYCLING - (USING R VALUE TEST PROCEDURE)		X		
PREMATURE STRUCTURAL FAILURE - INVESTIGATION		X		
RIDE ROUGHNESS -- NOT ACCOMPANIED BY ABOVE CRACKING DEFECTS, < 0.10 FOOT PLUS REQUIRED LEVELING COURSE	X			
RAVEL, LOW SKID RESISTANCE, POOR SURFACE TEXTURE, NON LOAD ASSOCIATED HAIRLINE CRACKING ETC. NOT ACCOMPANIED BY ABOVE CRACKING (<0.10 FOOT)	X			

① WITH BOTH NON LOAD ASSOCIATED AND LOAD ASSOCIATED CRACKING, THE GREATER REQUIRED THICKNESS GOVERNS.

② APPLICABLE IF A REINFORCING FABRIC OR RUBBERIZED INTERLAYER WILL REDUCE OVERALL THICKNESS SUFFICIENTLY TO ACCOMMODATE VERTICAL GRADE CONTROLS.

FIGURE 16 Caltrans guidelines for the design of overlays on flexible pavements (*35*).

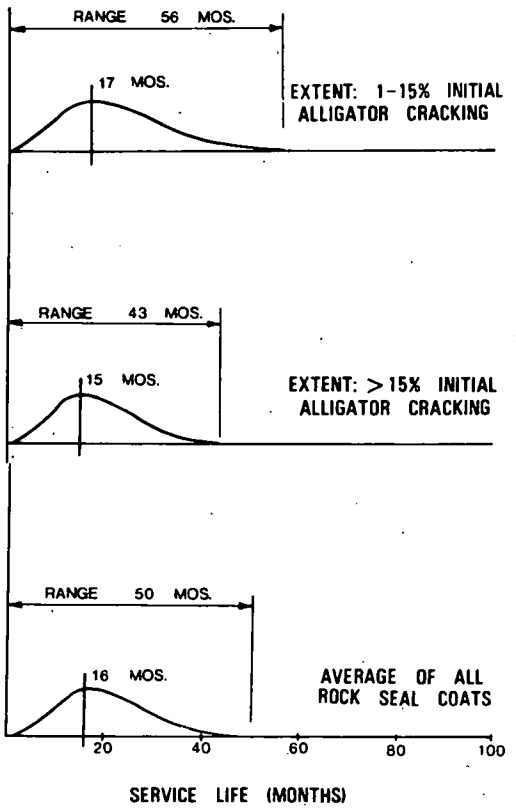


FIGURE 17 Caltrans crack correction service life for rock seal coats (*35*).

for (a) making cost-effectiveness comparison among repair strategies; (b) determining repair costs for all districts; (c) determining relative pavement repair program mix among routine maintenance, major maintenance, resurfacing, and reconstruction; and (d) determining appropriate statewide funding level for maintenance, resurfacing, reconstruction, and other pavement repair programs.

Cost formulas were developed taking into account such items as location, traffic handling, flexible pavement repair, and rigid pavement repair for each candidate for repair strategy. The overall cost-effectiveness addresses several phases in the management decision process, including (a) determining relative program levels based on repair costs, program effectiveness, and sound engineering practice; (b) determining relative project priorities; (c) determining appropriate strategies among alternatives; and (d) reassessing cost-effectiveness.

The California pavement management system has been implemented statewide to manage pavement improvements; the structural process is shown in Figure 18. The three basic user reports generated from the system are Pavement Condition Inventory, Candidate Project Lists (Dominant Strategy), and Corrective Strategies for All Triggered Lanes (*35*).

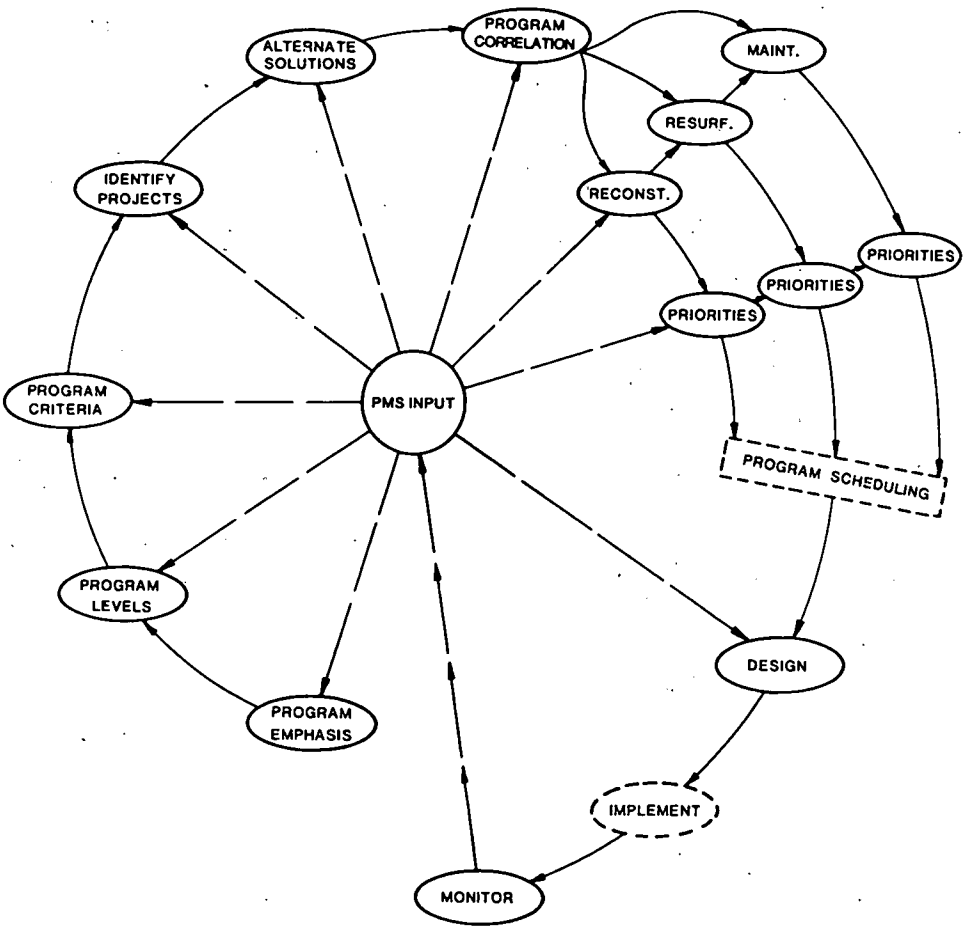


FIGURE 18 Caltrans pavement management systems applications (*35*).

Construction Engineering Research Laboratory

The U.S. Army Construction Engineering Research Laboratory (CERL) has developed an automated pavement maintenance and repair management system called PAVER (*11*). It consists of (a) a data base for storage of relevant pavement information, (b) a set of forms used to collect pavement data and enter them into the data base, and (c) a set of report generator programs to retrieve information from the data base and present it in usable format.

The PAVER data base consists of several data groups, as illustrated in Figure 19. The information is analyzed by computer, and reports are generated to assist pavement engineers in making proper maintenance management decisions. The following reports are prepared by the system:

1. INV provides an inventory of pavement sections in the pavement network. Basic information such as location, surface type, facility use, pavement rank, and pavement area is reported for each pavement section.
2. INSPECT provides the user with results of condition surveys performed on pavement sections, including quantities and severities of distress and overall condition ratings.
3. WORKREQ provides a list of maintenance and repair requirements as determined by the pavement engineer based on the most recent inspection results.
4. WORKHIS provides a list of past maintenance and repair performed on the pavement network.
5. RECORD provides comprehensive information on each pavement section, including section identification and dimensions; shoulder, drainage, and secondary structure identification; work history; pavement structure; layer material properties; results of traffic surveys; and proposed future work for the section.
6. ECON provides an economic analysis of various maintenance and repair alternatives.

Figure 20 is an example of an ECON report generated by PAVER. This report presents a detailed cost comparison of maintenance and repair alternatives. CERL has also published two volumes describing the development of a pavement maintenance management system. Volume 1 covers airfield pavement condition rating and provides detailed descriptions of the procedures for both rigid and flexible pavements (*63*). Volume 2 is an identification manual for airfield pavement distress and includes photographs and descriptions of distress in both flexible and rigid pavements (*64*).

Utah

The Utah Department of Transportation, faced with a serious shortage of funds for rehabilitating failed or nearly failed pavements, decided to find out what level of service or pavement performance would be the most economical for the state and for users. Existing pavement performance data were evaluated to determine what needed to be done to bring the pavements up to some acceptable standard. Cost curves and cost estimates were prepared for upgrading pavements to an acceptable level from various present conditions (*6*). Figure 21 shows the overlay thickness required to bring a pavement to an acceptable level of performance from its present condition. The worse the pavement condition is, the thicker the overlay required to correct it. User costs, maintenance costs, and rehabilitation (overlay) costs were included in the analysis. These costs varied with the condition of the pavement.

Four different strategies were analyzed to determine the

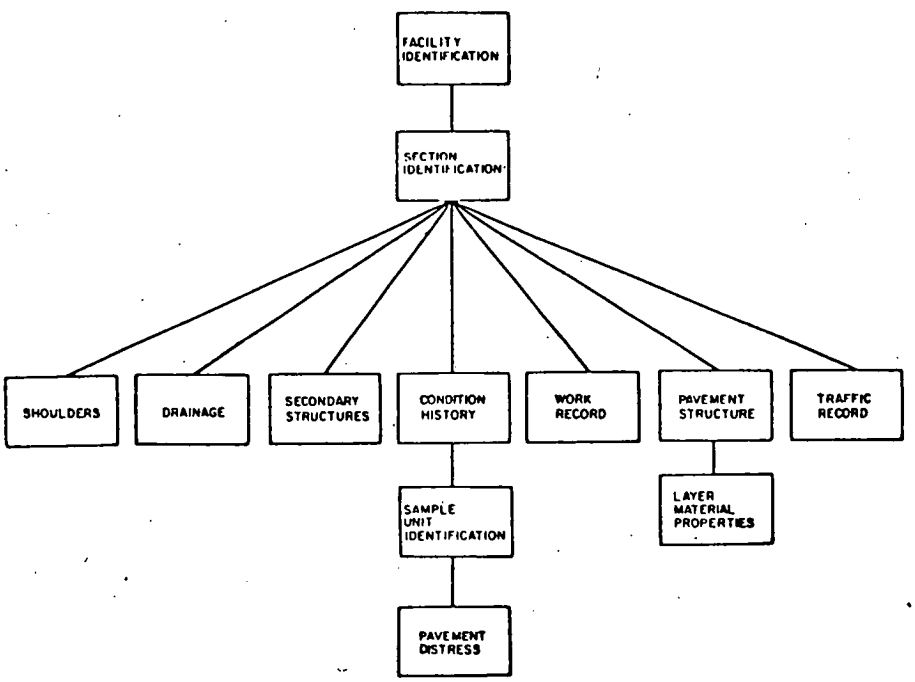


FIGURE 19 PAVER data structure (*11*).

COMPARISON OF M&R ALTERNATIVES
ELM ST
SECTION 3

ANALYSIS PERIOD - 5 YEARS INTEREST RATE 6.00 PERCENT

ALTERNATIVE	DESCRIPTION	TOTAL PRESENT COST
A	LOCALIZED REPAIR EACH YEAR	3048.
B	OVERLAY 1.5 INCH	6827.
D	AC OVERLAY 1 INCH --- YEAR 3	7598.
C	REPROCESS AND AC OVERLAY 1 INCH	7935.

DETAILED COMPARISON OF M&R ALTERNATIVES

YEAR		ALT A COST	ALT A PRES COST	ALT B COST	ALT B PRES COST	ALT C COST	ALT C PRES COST	ALT D COST	ALT D PRES COST
1	FY77	1470	1470	6726	6726	7886	7886	1470	1470
2	FY78	150	141	0	0	0	0	150	141
3	FY79	300	266	0	0	0	0	6726	5986
4	FY80	450	377	50	41	25	20	0	0
5	FY81	1000	792	75	59	35	27	0	0
TOTAL			3048		6827		7934		7597

FIGURE 20 Example of ECON report (*11*).

relative costs and benefits; they are shown in Figure 22. Each strategy is based on normal maintenance, including the placement of a seal coat on the average of once every 7 years. The four basic strategies are described below.

- Strategy A requires that each pavement be rehabilitated when its present serviceability index (PSI) drops to 3.0. This means that for a 20-year design each pavement will be overlaid on the average of once every 17 years rather than once every 20 years.
- Strategy B specifies that each pavement be rehabilitated when its PSI decreases to 2.5, requiring an overlay on the average of once every 20 years; 2.5 is the design level for higher-volume roads.

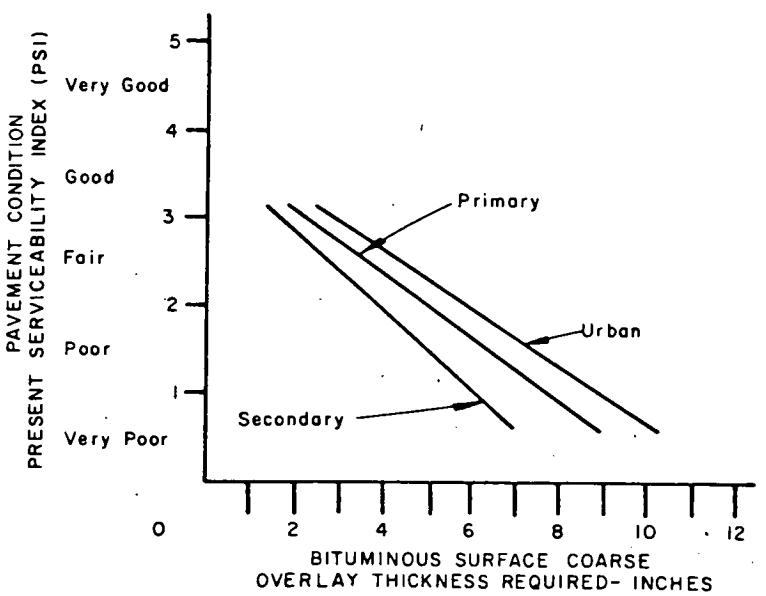


FIGURE 21 Utah-required overlay thickness based on pavement condition—20-yr design (*6*).

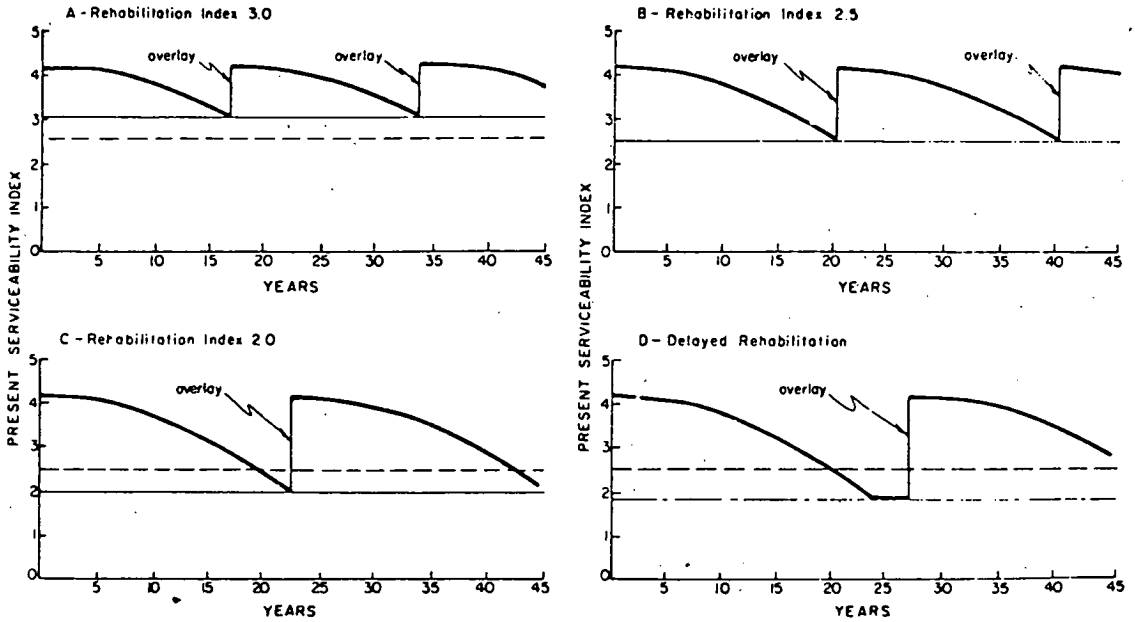


FIGURE 22 Utah's pavement rehabilitation design strategies (*6*).

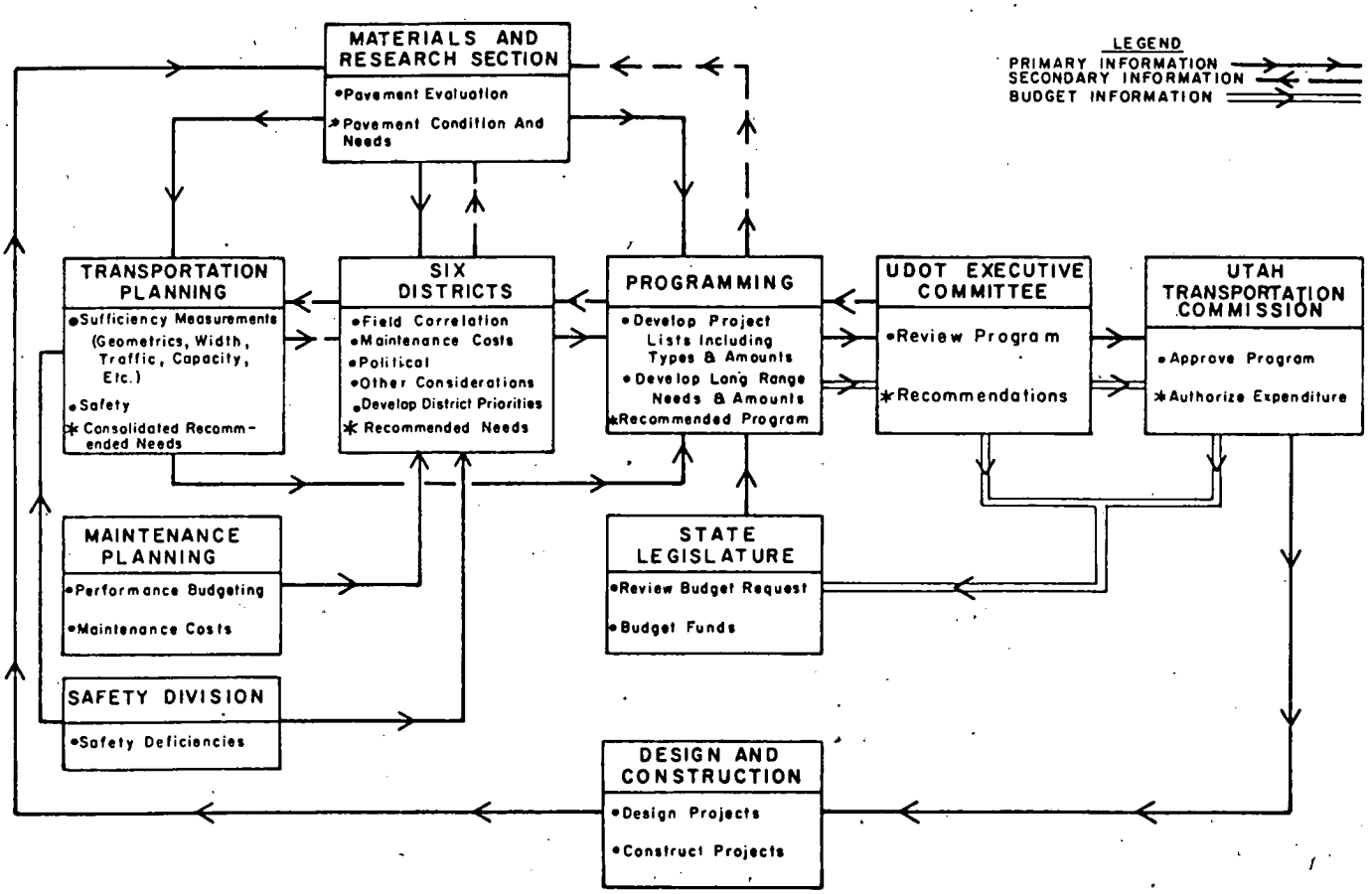


FIGURE 23 Utah's conceptual flowchart for pavement management and rehabilitation (*21*).

TABLE 24
UTAH STRATEGY BENEFIT AND COST SUMMARY (*6*)

STRATEGY	EXISTING PAVEMENT UPGRADING COSTS MILLIONS	TOTAL ANNUAL SURFACING COSTS MILLIONS	TOTAL ANNUAL BENEFITS MILLIONS
A	$128.3	$12.7	$20.4
Combination B-<Primary, Secondary, Urban	68.7	16.0	15.2
B	30.9	17.5	12.9
C	7.8	21.7	5.9
D	0.0	23.6	0.0

- Strategy C requires that each pavement be rehabilitated at a PSI of 2.0; it would be overlaid approximately once every 23 years for a 20-year design.
- Strategy D represents the present status and the level of effort required to maintain it. The Utah Department of Transportation's (DOT's) level of funding and the mileage being overlaid was such that each pavement could be overlaid once every 27 years. As a pavement deteriorates to a poor level of performance, additional maintenance is required to maintain pavement integrity.

Table 24 presents the strategy benefit and cost summary for the four strategies and for a combination of strategies A and B. As a result of this study (*6*) the Utah state legislature increased the gas tax to provide additional funds for starting to catch up on the backlog of needed rehabilitation.

The Utah DOT has developed a conceptual plan for determining pavement improvements; this plan describes the functions of various units and the interrelationship and information flows among them (Fig. 23).

Pennsylvania

The Pennsylvania DOT uses the serviceability index and structural capacity data as part of its pavement maintenance policy (*16*). The agency uses the Mays meter to determine the present serviceability index; if this value falls below the terminal serviceability index, corrective action is initiated to improve the pavement surface. The Road Rater is used to measure deflection on flexible pavements, and these measurements are then analyzed to determine the required overlay thickness. When the structural capacity is adequate for the design loads, a wearing course of appropriate thickness is used to improve the skid resistance and/or riding quality of the pavement.

Ontario

The Ontario Ministry of Transportation and Communications uses pavement condition surveys "to determine the order of priority of rehabilitation needs, to identify problems and thus promote the use of more effective short-term remedial or longer-term rehabilitation alternatives, to allow maintenance staffs to match as closely as possible practical corrective and preventive treatments and ideal solutions, and to increase the effectiveness of maintenance and rehabilitation procedures through timely and cost-effective strategies determined from pavement-management optimization procedures" (*22*). The Ontario procedures are outlined in Figure 24.

Ontario has identified a number of possible solutions for each type of distress. In order to improve the cost-effectiveness of pavement maintenance, pavement distress is coordinated with corresponding sets of suitable maintenance

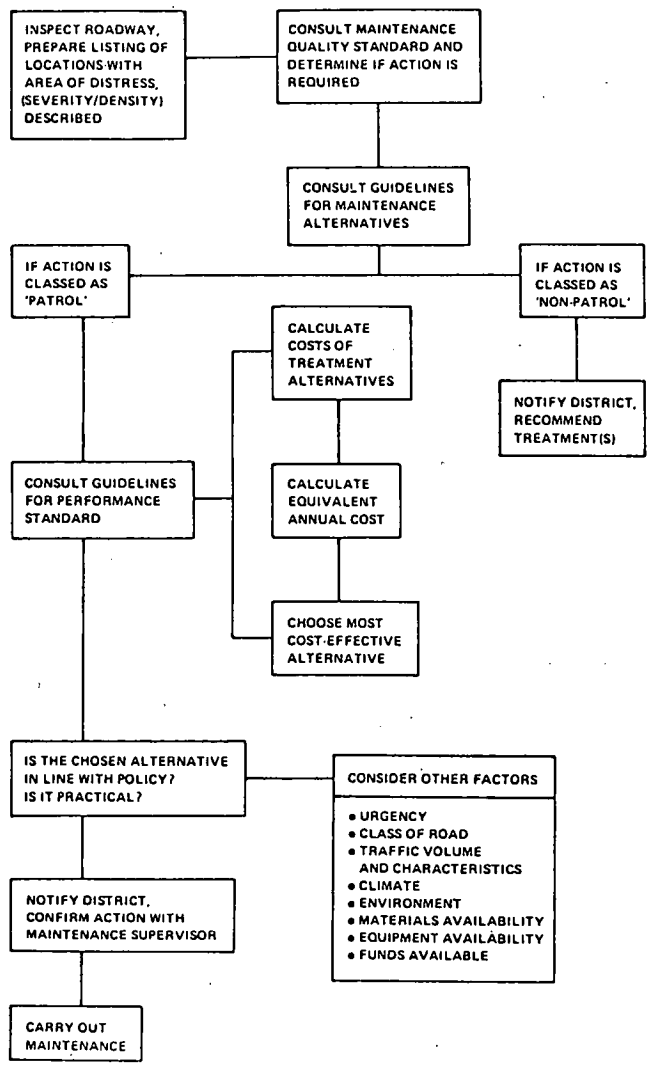


FIGURE 24 Ontario's procedures for maintenance staff (*22*).

POTHOLES

Description: Bowl-shaped holes in pavement surface unrelated to other surface defects, or as a direct result of other defects such as ravelling, alligator cracking, etc.

Possible causes:
(1) Poor construction technique and quality control.
(2) Poor aggregates in pavement.
(3) Result of other defects such as ravelling, cracking, alligator cracking, etc.

Severity: GUIDE FOR DESCRIBING SEVERITY OF POTHOLES

CLASS	GUIDELINES (BASE ON OBSERVATIONS OF APPEARANCE)
Slight	Less than 8 cm in diameter and shallow in depth
Moderate	8 up to 30 cm in diameter and usually greater than 5 cm in depth
Severe	30 cm plus in diameter and usually over 10 cm in depth

Treatments:

EVALUATION		RECOMMENDED MAINTENANCE TREATMENT ALTERNATIVES	MAINTENANCE FUNCTION CLASSIFICATION		EXPECTED EFFECTIVE LIFE IN YEARS
Severity	Density		Routine patrol	Non-patrol	
Slight	Local	Spray Patch	1004		1.5
	General	Spray Patch	1004		1.5
Moderate	Local	Cold Mix Patch	1001		1
		Hot Mix Patch	1001 1002		2
	General	Cold Mix Patch	1001		1
		Hot Mix Patch	1001 1002		2
Severe	Local	Cold Mix Patch	1001		1
		Hot Mix Patch	1001 1002		2
	General	Cold Mix Patch and notify District Office	1001		1
		Cold Mix Patch with Sand Seal (for Highways with AADT < 2000)	1001	1017	1.5
		Cold Mix Patch with surface treatment for highways with AADT < 2000	1001	1017	2
		Mulching over existing highway for highways with AADT < 2000		1014	3.5
		Granular lift and surface treatment for highways with AADT < 2000		x	4
		Hot Mix Patch and notify District Office	1002		2
		Hot Mix Patch and Surface Treatment for highways with AADT < 2000		x	3
		Hot Mix Patch and Single Course Hot Mix Resurfacing for highways with AADT > 2000		x	6

FIGURE 25 Ontario's maintenance alternatives for pothole treatment (*22*).

alternatives from which effective solutions are chosen. The purposes of the Ontario maintenance program are to provide road users with an acceptable level of service and to preserve the investment in the road system.

The expected life of each alternative is based on the experience of Ontario maintenance personnel. More than 50 persons—each with a minimum of 20 years' experience—estimated the life of each alternative. The median value of the estimates was used to establish the expected life in years for each treatment type. Maintenance alternatives are compared on the basis of their equivalent annual costs, which are based on the cost of doing the job and the expected life of the work accomplished. The following relationships (*22*) are used to determine equivalent annual costs:

$$\text{Unit cost} = \frac{\text{Manpower} + \text{Equipment} + \text{Materials}}{\text{Accomplishments per day}}.$$

$$\text{Equivalent annual cost} = \frac{\text{Unit cost}}{\text{Expected life of alternative in years}}.$$

A seven-step procedure is used in Ontario in selecting the treatment process.

Step 1. To assess the pavement conditions, drive over the pavement at or below posted speed. This will establish the prevailing distress or distresses for the surveyor.

Step 2. Using the standardized pavement distress and evaluation terminology, such as "moderate" for severity and "general" for density, identify the prevailing distress or distresses.

Step 3. Assess the identified distress or distresses as to urgency. Urgency in this case is related to potential hazard to the traveling public.

Step 4. Set the identified distress or distresses in order of priority.

Step 5. Using the appropriate distress-treatment table, decide on the most cost-effective maintenance treatment available or, in the case of immediate and short-term needs, the most effective alternative.

Step 6. If more than one treatment is involved due to multiple distresses, decide on the most universal treatment if individual treatment is neither possible nor economically feasible.

Step 7. Decide if the selected treatment or treatments fall within the capability of the patrol; if they do, confirm action with the district maintenance supervisor. If they do not, notify the district office with all the pertinent information available in a Maintenance Needs Report Form.

An example of the description and alternative treatments for potholes is presented in Figure 25. This is similar to the treatment outlined for several other flexible pavement distress types, including slippery surfaces, flushing, raveling/streaking, rippling/shoving, wheel track rutting, distortion, and cracking. There are similar treatment listings for rigid pavement distresses. Maintenance performance standards for carrying out the various maintenance activities are also described.

CHAPTER FIVE

RESEARCH NEEDS, CONCLUSIONS, AND RECOMMENDATIONS

RESEARCH NEEDS

The sixth question in the survey asked: "What problem areas or deficiencies do you have in providing or obtaining the needed information for management decisions in selecting appropriate pavement maintenance strategies?" The responses to this question are summarized in Table 25, and Appendix B contains the complete responses. There was considerable variation in the problems or deficiencies identified. One-third of the respondents, however, indicated that they had no problem areas or deficiencies related to information. Problems associated with funding were the most frequently cited; usually the funding was inadequate to accomplish the needed work. The most common needs associated with data or information are the need for a pavement management system, the need for a priority system, and the need for uniform rating procedures and data.

Following are research needs that have been identified:

- The operating cost for the various levels of pavement quality.
- The effect of maintenance funding levels on the agency's long-term costs.
- The types of cost data needed and the manner in which they can be efficiently and effectively obtained for use in developing pavement maintenance strategies.
- The development of priority rating systems that will produce the most cost-effective maintenance or rehabilitation program, one that includes not only the order of improvements but also the optimum time.
- The relative costs of preventive versus corrective maintenance for a wide range of pavement maintenance activities.

CONCLUSIONS

- Because the quality of pavements in the United States has been declining, pavement improvements should be accelerated. Pavement maintenance has not kept pace with the needs, and the problem is compounded because of the steady increase in maintenance costs.
- The postponement of pavement maintenance or rehabilitation increases the long-run costs for the responsible agency. Research and the experiences of some agencies indicate that preventive maintenance is more cost-effective than corrective maintenance. Further documentation of the relative benefits of corrective versus preventive maintenance is needed.
- The need to maintain minimum levels of performance for the safety of motorists may be the determining factor for corrective action in some cases, rather than the costs associated with delayed or deferred maintenance.
- Pavement maintenance strategies are defined as plans of action embodying the continuing application of pavement maintenance techniques that are designed to improve or maintain the pavement condition above some predetermined minimum requirement. Strategies can be applied to a network, a project, or a pavement segment. Life-cycle costs provide the basis for optimizing strategies.
- It is not obvious from the appearance of the pavement surface what the optimum maintenance strategy should be. The information required in selecting pavement maintenance strategies includes (a) present pavement condition; (b) rate of change in the condition of the pavement, using the present level of maintenance; (c) maintenance cost experience; (d)

TABLE 25
PROBLEM AREAS OR DEFICIENCIES IDENTIFIED[a]

Need Identified[b]	States	Canadian Provinces	Toll Roads
None	9	0	6
Funding	9	1	0
Priority system	5	0	0
Pavement management system	5	0	0
Knowledge that maintenance is done efficiently by standards	1	0	1
Confidence that work undertaken is based on real needs	2	0	0
Accurate, reliable information	3	0	0
Uniform rating procedures and data	4	0	0
Predicting pavement performance	2	0	0
Forecasting needs and allocating funds	2	0	0
Categorize costs and cost-effectiveness of techniques	3	0	0

[a]Responses to the questionnaire were received from 35 states, 3 Canadian provinces, and 8 toll roads.

[b]Other items of need identified from Question 6 were reducing apathy, personnel training, correlations between pavement condition and safety, improve standards for seal coats, timing for seal coats, timetable for contract work based on pavement evaluation, tie construction strategies to maintenance strategies, materials availability, more manpower, coping with cost increases, timing for preventive maintenance, data base, pavement design evaluation, more accurate location and identification of maintenance activities, improved construction quality, crack sealing criteria, identifying maintenance techniques from deflections, effect of excessive moisture, information on load transfer at joints, information on new product performance, and dealing with political process.

expected future maintenance cost; (e) present and future traffic volume and loads; (f) potential techniques for making improvements; (g) performance characteristics of potential improvements; (h) cost of the potential improvements; and (i) effect of a maintenance increase or decrease on the condition of the pavement.

- Several transportation agencies have lists of pavement defects and their causes; these are an essential part of the input needed for selecting strategies. Agencies evaluate pavement condition using evaluation procedures that range from very simple visual observations to involved systems that use measuring equipment and trained observers. Pavement evaluation systems may include one or more of the following: (a) surface distress, (b) roughness or ride measurements, (c) skid resistance measurements, and (d) structural capacity. Techniques vary within and among states.
- Pavement maintenance techniques are generally grouped by either purpose of treatment (preventive or corrective) or type of treatment (overlay, surface treatment, etc.). Some maintenance techniques can serve both corrective and preventive functions.
- The reasons (triggers) for undertaking maintenance on a pavement segment, as obtained from the questionnaire survey, include the need to (a) correct deficiencies, (b) protect investments, and (c) respond to complaints. Several agencies stated that a lack of funds leads to more work in correcting deficiencies and a reduction in preventive maintenance for protecting the investment. Correcting failures or deficiencies was the most common strategy identified in the survey.
- Several matrices relating pavement deficiencies to maintenance techniques or alternatives are available. This type of information is very important in the process of selecting potential repair strategies because it enables correlation of pavement problems with repair strategies.
- Establishing priorities for pavement improvements is essential, especially when available funds for pavement maintenance and/or construction are limited. The priority-ranking process should consider the following information for candidate projects: (a) function of the road, (b) traffic volume, (c) condition of the pavement, (d) projected rate of change in the pavement condition, (e) maintenance costs, and (f) repair costs.
- Pavement maintenance strategies are closely aligned with a complete pavement management system, which is defined, in part, as the finding of optimum strategies. The interfacing of pavement maintenance with all the other elements in a pavement management system is essential to effective pavement management.
- Costs are an integral part of selecting optimum strategies. An optimum strategy should maximize benefits and minimize costs. Cost formulas should include consideration of geographic differences, traffic handling, and pavement repair defects. Unit costs should include manpower, equipment, and materials. Annual costs are obtained by dividing unit costs by the expected life of the proposed alternatives. These costs can be refined by considering rates of inflation and interest. Highway user costs, when included, will significantly affect total costs and can affect the selection of the type of pavement maintenance strategies; they should be imposed with a great deal of caution.
- Many agencies have maintenance policies that include statements regarding the preservation of the investment in highways as a goal or policy. In addition to protecting the interests of the responsible agency, maintenance policies should also include an awareness of user costs and benefits.
- When all the required information is available for developing cost-effective pavement maintenance strategies, the manager then has an effective tool for making decisions that will provide benefits for the agency and for the highway user. The information, when properly used, should establish the need for funds to maintain the pavement systems. One of the main benefits is avoiding cost by not doing unnecessary work.

RECOMMENDATIONS

- The process of selecting alternative treatments should consider (a) present serviceability of the pavement, (b) probable performance of each alternative treatment, (c) required life for the treatments, (d) present and future costs, (e) effect of the improvement process on traffic flow, (f) effect of alternatives on the road user, (g) appearance of the improvement, and (h) availability of resources. The alternative of maintaining the present level of maintenance also must be considered.
- Each agency should have a maintenance manual that covers the major pavement defects, the alternative strategies of correction, the cost or resources required to implement each strategy, and the life of each strategy.
- Experimental sections to evaluate the effect of using a particular strategy or technique should abut sections with standard or no treatment to minimize the influence of other variables, such as traffic and weather. The evaluation procedure should be standard and should be for extended periods to assure proper long-range reporting. Documenting and reporting results are essential.
- A pavement management system is desirable to develop pavement maintenance strategies. Work is going on in the development of pavement management systems, and it is recommended that each agency consider the implementation of such a system to the level that would most effectively satisfy its needs.

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APPENDIX A

GLOSSARY

Alternatives: The various choices of treatments available for providing a solution to a pavement deficiency or problem.

Corrective maintenance: Type of maintenance used to take care of day-to-day emergencies and repair deficiencies as they develop. May include both temporary and permanent repairs; sometimes referred to as remedial maintenance.

Cost-effectiveness: The situation that exists when the benefits exceed the costs for a given treatment, strategy, or improvement or when the benefit-cost ratio is greater than one.

Deficiency: Any indication of poor or unfavorable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement, short of failure.

Dominant strategy: The strategy that will correct all problems and provide an acceptable level of service.

Failure: Unsatisfactory performance of a pavement or portion such that it can no longer serve its intended purpose.

Flexible pavements: Bituminous or similar pavements that depend on aggregate interlock, particle friction, and cohesion for stability.

Life-cycle cost: The long-term cost of constructing and maintaining a pavement above a minimum performance level for a predetermined time period, generally until the roadway reaches functional obsolescence.

Maintenance: Anything done to the pavement after original construction until complete reconstruction, excluding shoulders and bridges. It includes pavement rehabilitation and restoration.

Maintenance policies: The stated goals, objectives, and responsibility of an agency, generally established by top-level management.

Network basis or level: The level at which key administrative decisions that affect programs for road networks or systems are made. Sometimes referred to as the program level.

Optimum strategy: The alternative that minimizes the expected present value of total costs for each pavement condition state and maximizes the realization of management goals, subject to the constraints imposed.

Optimum treatment: The treatment that will correct the deficiencies of a pavement in the most cost-effective manner.

Pavement condition: The present status or performance of a pavement.

Pavement deficiency: See *Deficiency*.

Pavement failure: See *Failure*.

Pavement maintenance strategies: Plans of action embodying the continuing application of pavement maintenance techniques that are designed to improve or maintain the condition of a pavement segment above some predetermined minimum requirement.

Pavement maintenance techniques: Methods used to accomplish strategy or correct deficiency in pavement segment.

Pavement management: In a broad sense, all the activities involved in the planning, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program.

Pavement management system: A set of tools or methods that assist decision-makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time.

Pavement performance: Measure of accumulated service provided by a facility; i.e., the adequacy with which it fulfills its purpose based on all indicators or measurement types.

Preventive maintenance: The type of maintenance intended to keep the pavement above some minimum acceptable level at all times. It is used as a means of preventing further pavement deterioration that would require corrective maintenance. It may include either structural or nonstructural improvements to a pavement surface.

Project level or basis: The level at which technical management decisions are made for specific projects or pavement segments.

Rehabilitation: The act of restoring the pavement to a former condition so that it can fulfill its function.

Rehabilitation strategy: A complete set of activities and decisions that make up one rehabilitation action. See also *Pavement maintenance strategies*.

Remedial maintenance: See *Corrective maintenance*.

Resurfacing: Process of overlaying a pavement surface to increase load-carrying ability and to correct deficiencies.

Rigid pavements: Portland cement concrete pavements in which the concrete slabs provide both the main structural layer and the riding surface.

Routine maintenance: The day-to-day maintenance activities, generally consisting of permanent and emergency patching. Usually considered corrective.

Semirigid pavement: A composite pavement with a rigid base and a flexible surface, such as a bituminous surface course placed over a concrete base.

Strategy: The plan for the type of maintenance alternative, its time for enactment, its design life, and various physical, environmental, and economic constraints. See also *Pavement maintenance strategies*.

Surface dressing: A nonstructural pavement surface treatment. This term is commonly used in Europe.

Techniques: See *Pavement maintenance techniques*.

Three R (3-R): An FHWA program consisting of resurfacing, restoration, and rehabilitation of pavement surfaces.

Treatments: Materials and methods used to correct a deficiency in a pavement surface.

Unpaved road: A roadway where the surface course is an unbound material.

APPENDIX B

QUESTIONNAIRE SUMMARY

To obtain information on the current state of practice, a questionnaire was prepared and sent to all state highway or transportation departments, selected Canadian provinces, and selected turnpike or toll road authorities. Replies were received from 35 states, 3 provinces, and 8 toll roads. The results of the questionnaire are summarized in the body of this synthesis; this appendix presents pertinent information supplied by some agencies in response to the questions.

Question No. 1: What initiates or triggers maintenance on a pavement segment? (protect investment, correct deficiency, complaints, etc.)

Arizona DOT. The agency has been developing a pavement management system and hopes to implement it this spring. The system will enable the agency to plan pavement rehabilitation strategies based more on objective data and less on subjective judgment. All subjective judgment will not be eliminated, however, because there will still be input from district engineers and their field staff. Presently maintenance is triggered by observation and judgment of district maintenance forces. The agency has a maintenance management system, and the types and amounts of work are planned, based on the agency's performance and quality standards and the feature inventory of the highway system. Standards were developed on historical data but are reviewed regularly to determine their appropriateness for current conditions and the level of service that legislative allocations will allow.

California DOT. For routine pavement maintenance, routine inspections trigger work to protect the investment and correct deficiencies; complaints trigger work needed and overlooked (or considered low priority) during routine inspection. For rehabilitation, work is done to correct deficiencies and protect the investment.

Connecticut DOT. The agency preserves existing facilities to prevent loss of the capital investment. It eliminates every hazard or irregularity that may lessen the security or comfort of the road user.

Delaware DOT. Some of the agency's maintenance is in response to complaints, but it is expected that most of the routine work will be scheduled by area supervision based on needs determined by visual observation. Retreatment is scheduled insofar as possible to protect the investment.

Florida DOT. Generally repair or routine pavement maintenance is initiated by complaints from the general public and by area supervisors to correct minor deficiencies that will jeopardize the investment if left undone. Heavy or periodic pavement maintenance (e.g., overlays) is a planned program activity, even though it may not be completely accomplished due to inadequate funding.

Georgia DOT. Maintenance is triggered by an annual work plan based on a maintenance management system; by pavement needs based on roadway maintenance inspections reports (twice a year); by routine visual inspection by maintenance manager and foreman; by complaints from public.

Hawaii DOT. Maintenance is done to protect the investment, correct deficiencies, and respond to complaints.

Illinois DOT. Maintenance is done to correct deficiencies and respond to complaints.

Iowa DOT. Maintenance is performed primarily to correct deficiencies and return pavement surface to prescribed serviceability.

Kansas DOT. (a) The agency has a preventive maintenance program of repair and contractual resurfacing. (b) There is routine roadway maintenance between contractual resurfacings. (c) Special roadway maintenance is done as needed to correct situations not addressed under a or b.

Kentucky DOT. Maintenance is done to correct deficiencies, maintain safety, and protect the investment.

Lousiana Department of Transportation and Development. Ideally maintenance on a pavement segment is triggered by the agency's maintenance quality-of-service objectives. In turn, maintenance quality-of-service objectives are based on the best estimate of what is required for protection of the investment, safety, ridability, or other considerations deemed worthy of emphasis. Maintenance quality-of-service objectives are, for the most part, threshold values based on observable deficiencies.

Nebraska Department of Roads. Maintenance is done to correct deficiencies and protect the investment. Maintenance supervisors travel roads weekly and identify problem areas.

New Hampshire Department of Public Works and Highways. Correcting deficiencies is the major reason for initiating maintenance, with ridability and visual observations being the primary indicators to the local foreman.

New Jersey DOT. A major portion of the pavement maintenance activity is generated because of the need to correct existing pavement deficiencies. A lesser portion of maintenance activity is related to protection of the investment, complaints, and antiskid overlays.

Ohio DOT. Deficiencies (potholes, spalled joints, weak base areas) causing a poor ride usually are observed by ODOT personnel. Maintenance is occasionally triggered by outside complaints.

Oklahoma DOT. Preventive maintenance is performed when possible, but most maintenance is done to correct failed areas.

Oregon Highway Division. Usually maintenance is done to correct a deficiency. Extensive skin patches are often applied to areas in which deficiencies are starting to show up. These serve to protect the investment in the nondistressed portion.

Pennsylvania DOT. Corrective maintenance is done to correct deficiencies and is triggered or initiated by regular, periodic inspections and/or complaints. Preventive mainte-

nance is done at predetermined time intervals to protect the commonwealth's investment.

South Carolina Department of Highways and Public Transportation. Maintenance is done to correct deficiencies and protect the investment.

South Dakota DOT. Maintenance is done to protect the investment.

Tennessee DOT. Maintenance is done to correct deficiencies, respond to complaints, and respond to early signs of impending deficiencies. Supervisory inspection is performed.

Texas Department of Highways and Public Transportation. Rehabilitation is done to (a) correct major deficiencies in pavement structure, serviceability, and drainage as determined by measured and visual determination and (b) reduce excessive maintenance costs. Maintenance is done to (a) protect the investment and (b) correct deficiencies in pavement structure. The agency is currently developing a pavement evaluation system to project maintenance and rehabilitation on a system basis.

Virginia Department of Highways and Transportation. The primary maintenance initiator is the need to correct a deficiency; next is the need to protect the investment. Complaints are a minor initiator.

Washington DOT. Maintenance is done primarily to correct deficiencies. A seal coat program is used mainly to protect the investment and also to correct deficiencies.

West Virginia Department of Highways. Pavement maintenance normally is performed to correct a deficiency, and occasionally in response to complaints.

Manitoba Department of Highways and Transportation. The highway system is maintained and operated to (a) preserve the investment in highway facilities, (b) accommodate highway users with safety and reasonable convenience, (c) conserve esthetic values, and (d) respond to complaints.

Nova Scotia DOT. Maintenance is done to protect the investment, correct deficiencies, and respond to complaints.

Ontario Ministry of Transportation and Communications. Corrective action is traditionally done. Ontario is now adopting a preventive maintenance approach. Complaints are occasionally the basis for action.

Illinois State Toll Highway Authority. An Annual Condition Report compiled by the authority's general engineering consulting firm and daily surveillance by roadway maintenance supervisors initiate routine repair and maintenance operations.

Indiana Toll Road. Maintenance is done to protect the investment and correct deficiencies as soon as they are evident. Settlement and open joints are most critical in the northern Indiana climate.

Massachusetts Turnpike Authority. The authority's obligation is to maintain the highway in good repair, working order, and condition.

New York State Thruway Authority. The authority's obligation is to maintain the highway in good repair, working order, and condition.

Ohio Turnpike Commission. Repairs are scheduled to correct deficiencies, which may pertain to safety, riding quality, etc. Preventive maintenance is designed to protect the initial investment.

Oklahoma Turnpike Authority. Maintenance is done to protect the investment and to keep the pavement in good condition in order to alleviate major detriments and consequent complaints.

Rhode Island Turnpike and Bridge Authority. Maintenance is based on visual condition of pavements as determined by continuous inspection.

Texas Turnpike Authority. Maintenance is done (a) to protect the investment, based on continued close observation, and (b) to respond to complaints.

Question No. 2: What pavement maintenance strategies do you use? (maintain above minimum serviceability level, predetermined time interval, correct failures or deficiencies as they develop, etc.) Identify whether the strategies are for a network or project basis.

Arizona DOT. The maintenance management system anticipates and plans for most of the work load, but numerous changes must be made to correct failures or deficiencies as they occur. The system is flexible enough to accommodate such contingencies. Some strategies are for a network and some are for a portion (project) of the system. As the pavement management system is implemented, more strategies will be applied on a network level.

California DOT. On a network basis, routine pavement maintenance takes place; pavements are maintained as long as possible at a level above minimum serviceability, and deficiencies are then corrected as they develop. On a project basis, failures or deficiencies are corrected as they develop.

Connecticut DOT. There is semiannual inspection of the highway network and establishment of a priority sequence.

Delaware DOT. Pavement management is performed on a network basis. The total network is to some extent broken into three subdivisions according to road type: concrete (hot-mix or portland cement), which encompasses most of the primary and secondary roads; surface treatment, which includes most of the rural system; and dirt. The agency is attempting to secure funds so that all hard-surfaced roads can be resurfaced on a predetermined schedule. However, at this time most maintenance is done to correct deficiencies as they develop.

Florida DOT. Routine pavement maintenance is scheduled through an annual work plan in order to maintain a minimum level of service. Actual work is scheduled periodically to correct failures as they develop. Periodic maintenance or pavement rehabilitation for the entire network or the statewide system is developed and put in priority order through use of an annual pavement condition survey.

Georgia DOT. An annual work plan is developed from historical data; a resurfacing program is based on need on a yearly basis (network); failures are corrected as they occur (project); PCC pavement rehabilitation is done on the Interstate network.

Hawaii DOT. On a project basis, failures or deficiencies are corrected as they develop.

Illinois DOT. On a statewide basis, pavement is restored to an as-built condition.

Iowa DOT. For the most part, work is performed to correct failures or deficiencies as they develop. Routine mainte-

nance is performed on a network basis. Special maintenance (usually contract) is performed on a project basis.

Kansas DOT. The present strategy is to maintain pavement, as nearly as possible, in the as-built condition or as subsequently modified. Work is programmed on a 5-year basis, and programs are fine-tuned yearly.

Kentucky DOT. Pavement is maintained above minimum serviceability level. Failures or deficiencies that the agency sees developing are corrected before there is major damage and the road becomes unsafe. Minor repairs are done on a network basis; major work is done only on a project basis due to limited funding.

Louisiana Department of Transportation and Development. Pavement management strategy is based on a subjective attempt to obtain the best trade-off among maintaining minimum serviceability levels, correcting failures as they develop, protecting investments, etc. For major maintenance activities, this usually means adoption of a predetermined time interval or identification of threshold conditions that are used to schedule both major and routine maintenance. The strategy is applied to a network or project based on the type and extent of the effort; for example, the hot-mix-in-place program is a contract maintenance effort designed to give the district administrator a "quick strike" capability for response to incipient failure. Funds are allocated based on network analysis to determine expected quantities. Projects are selected on a local analysis heavily weighed for consideration of safety and ridability. A great deal of data collection and analysis is required to approach optimum trade-offs under the constraint conditions imposed.

Maine DOT. The agency uses a predetermined time interval to plan pavement maintenance, but the actual work is done by crisis because maintenance allotments do not allow the agency to keep up with the time interval. The majority of pavement maintenance is done on a project basis.

Massachusetts Department of Public Works. An annual resurfacing program is developed to correct failures and deficiencies on a project basis. Available funding determines depth and scope of the program.

Michigan DOT. All trunk lines are visually inspected annually by a maintenance team. Deficiencies are noted. Resurfacing projects are scheduled on a priority basis. Joint repair projects are likewise scheduled.

Missouri Highway and Transportation Department. Deficiencies and failures are corrected as they occur. Preventive maintenance, such as annual crack pouring and relief joints, is done at bridge approaches.

Montana Department of Highways. Maintenance is performed on a project basis to correct failures or deficiencies as they develop and also to maintain serviceability levels.

Nebraska Department of Roads. Failures or deficiencies are corrected as they develop on pavements. Preventive measures, such as crack filling, are taken to help prevent future problems. Heater-plane or rotomill asphalt rutted surfaces are used for additional life. Joint cutting is used to relieve pressure.

New Hampshire Department of Public Works and Highways. Although protecting the highway investment and providing a safe, comfortable ride is the goal, fiscal constraints dictate limitations on scheduling overlays and surface treatments (seal coats) on highway segments. Frequency of surfacing is considered, but greater emphasis is placed on the remaining life and the consequences of deferring overlays and seal coats if ratings fall below desirable levels.

New Jersey DOT. Theoretically, three pavement maintenance strategies are used: (a) predetermined time intervals—pouring joint seals and sealing cracks; (b) correction of failures or deficiencies on a priority basis—overlays; and (c) correction of failures as they develop—patching pavement, cutting joints, etc.

New York DOT. In theory, the agency now uses a predetermined time interval for bituminous pavements but is exploring a strategy dependent on minimum serviceability levels. Both strategies are on a network basis.

Ohio DOT. Failures or deficiencies are corrected as they develop. The attempt is to make best use of limited funds to either patch holes or prevent holes from developing.

Oklahoma DOT. Attempts are made to maintain pavements above minimum serviceability level. Because of severe weather and increases in truck traffic, much work must be done to correct failures as they develop. The strategy is on a network basis.

Oregon Highway Division. Serious failures are repaired as they develop. Preservation treatment in the form of permanent patches on PCC or skin patches on asphalt concrete are performed during the paving season as time and funds permit.

Pennsylvania DOT. Predetermined time interval strategies are used on a network basis. Minimum serviceability strategies are used on a project basis. Failures and/or deficiencies that present a hazard or an inconvenience to the motorist are corrected as they develop.

South Carolina Department of Highways and Public Transportation. Failures or deficiencies are corrected as they develop on a project basis.

South Dakota DOT. Failures or deficiencies are corrected on an annual predetermined interval.

Texas Department of Highways and Public Transportation. Rehabilitation: selection of high-priority projects at district level (non-Interstate) and state level (Interstate); because of low funding, projects are usually selected to correct the worst distresses or deficiencies as they develop. Maintenance: predetermined time interval for preventive maintenance seal coats on project basis; failures or deficiencies are corrected as they develop on network basis.

Utah DOT. Seal coating is performed once every 6.5 years; this has been considered sufficient to protect the pavement from excessive surface deterioration. PCC transverse joint maintenance is performed as inspection dictates.

Vermont Agency of Transportation. The agency has an annual network evaluation and project programming by priority. Funding level does not permit network resolution of pavement rehabilitation.

Virginia Department of Highways and Transportation. Strategy is primarily to correct deficiencies as they develop on a project basis; however, a predetermined time interval is also considered.

Washington DOT. Primarily deficiencies are corrected as they occur, but many of the corrections are made shortly after the first indication of the deficiency. This is done on a project basis.

West Virginia Department of Highways. Failures or de-

ficiencies are corrected as they develop on a project-by-project basis.

Wyoming Highway Department. During the preparation of the annual budget, each district establishes a work plan for each road segment based on highway needs according to established maintenance standards.

Manitoba Department of Highways and Transportation. A regular surface maintenance program is carried out annually according to approved performance standards. Additional funds are provided to cover nonroutine maintenance, such as heavy bituminous repairs, or to correct a serious rutting problem. Seal coat is placed on asphalt surface treatment roads approximately every 5 years and on hot or cold mix every 8 to 10 years.

Nova Scotia. Pavement is maintained above minimum serviceability, and strategies are identified on a project basis.

Ontario. Primarily failures or deficiencies are corrected on a project basis; general strategies are to restore riding qualities, skid resistance, and structural integrity and to achieve planned plant life.

Illinois State Toll Highway Authority. A long-range pavement maintenance program is prepared by a consultant firm using serviceability.

Indiana Toll Road. With rigid pavement, mudjacking is used when settlement occurs but before pavement breaks severely. Smooth riding quality is maintained and impact is kept to a minimum.

Massachusetts Turnpike Authority. The authority repairs, rehabilitates, and resurfaces, giving priority to those sections in which deterioration, wear, settlement, drainage, and pavement distortion are the most severe.

New York State Thruway Authority. Strategy is to maintain pavement above minimum serviceability level. Budget limitations can restrict work to the correction of failures as they develop.

Ohio Turnpike Commission. The attempt is to maintain the pavements at a high level of serviceability because of the unique nature of the organization, which depends on the tolls paid by patrons. Maintenance strategies are normally set up on a project basis.

Oklahoma Turnpike Authority. Pavement maintenance is on a network basis, and the authority tries to correct any undesirable irregularities as they develop. Preference is given according to the importance of the type of trouble that develops.

Rhode Island Turnpike and Bridge Authority. On bridge decks, approaches, and plaza areas, the attempt is to correct deficiencies as they develop.

Texas Turnpike Authority. Failures are corrected as they occur or as they are observed during continued surveillance; impending failures are corrected prior to occurrence.

Question No. 3: What basis is used for selecting a strategy? (rational engineering concepts, cost-effectiveness, traditional allocation, etc.)

Arizona DOT. (a) Rational engineering concepts, (b) cost-effectiveness, (c) maintenance management system, (d) pavement management system.

California DOT. For routine pavement maintenance: (a) rational engineering concepts (as funds permit), (b) cost-effectiveness (as funds permit). For rehabilitation: (a) rational engineering concepts, (b) cost-effectiveness—determines general level of repair (i.e., maintenance or rehabilitation; then deflection studies and other engineering analyses are used to design the most effective solution).

Connecticut DOT. (a) Rational engineering concepts, (b) cost-effectiveness, (c) visual observation, (d) priority sequence.

Delaware DOT. (a) Rational engineering concepts—road condition surveys, traffic counts, accident summaries, skid numbers; (b) cost-effectiveness—maintenance management systems; (c) traditional allocation—previous budgets plus inflation factors.

Florida DOT. Cost-effectiveness and rational engineering concepts are used to develop various strategies; however, traditional allocations—or actually what is left over from other work programs—generally dictate funding levels that control what can be accomplished.

Georgia DOT. (a) Rational engineering concepts—PCC pavement rehabilitation program; (b) cost-effectiveness—routine roadway maintenance work; (c) traditional allocation—annual resurfacing program.

Hawaii DOT. (a) Traditional allocation, (b) periodic inspections (deficiencies noted).

Illinois DOT. Utilization of existing maintenance personnel and equipment.

Iowa DOT. (a) Rational engineering concepts, (b) cost-effectiveness, (c) sufficiency rating.

Kansas DOT. Maintenance strategy is to develop a total program based on inventory, performance standards, and needs of the system. Needs, once established, must be reconciled with fiscal realities. Standards take into account rational concepts as well as cost-effectiveness.

Kentucky DOT. Traditional allocation, adjusted to funds that are available annually.

Louisiana Department of Transportation and Development. Agency uses a cost-effectiveness analysis based on rational engineering concepts; protection of the investment, ridability, safety, esthetics, and legal and environmental concerns are considered and analyzed as objectively as possible.

Maine DOT. Agency tries to set up projects in an entire area to achieve a lower contract price.

Massachusetts Department of Public Works. Traditional allocation is used, based on the average life span of the pavement.

Michigan DOT. Cost-effectiveness is used, based on experience.

Missouri Highway and Transportation Department. Because of financial constraints, the department has not been able to do much resurfacing for preventive maintenance except for seal coats.

Montana Department of Highways. This large, rural state has funding problems; over 50% of its primary system is deficient. Rational engineering concepts, cost-effectiveness, and traditional allocation play a part in the decision-making process, but emphasis has to be on problems as they develop on substandard highways with poor substructures.

Nebraska Department of Roads. Traditional allocation is used; a maintenance management system establishes anticipated volumes of repairs.

New Hampshire Department of Public Works and Highways. (a) Rational engineering concepts: in future, pavement serviceability method will be a most beneficial tool and a mechanism to justify adequate legislative funding. (b) Cost-effectiveness comparison of various strategies is helpful. (c) Traditional allocation: used in past; a pavement serviceability rating system will improve allocation of funding. (d) Visual inspection: definite requirement by competent personnel regardless of sophistication of system or strategy concepts.

New Jersey DOT. Budgetary restraints on availability of manpower, funds, and equipment.

New York DOT. Present strategy is based on rational engineering concepts; in the future it may be based on cost-effectiveness.

Ohio DOT. Traditional allocation is used, dictated by available funds. Cost-effectiveness and rational engineering concepts are automatically built into strategies because of years of past experience.

Oklahoma DOT. (a) Rational engineering concepts, (b) cost-effectiveness, (c) traditional allocation.

Oregon Highway Division. (a) Cost-effectiveness, (b) traditional allocation. District allocations are adjusted by engineering judgments, considering systemwide needs and total available resources. Maintenance management system is used to formulate statewide program.

Pennsylvania DOT. The predetermined time interval strategy was selected on the basis of management principles and rational engineering concepts. This strategy permits standard procedures for work planning and budgeting in each of 67 counties. The minimum serviceability strategy was selected on the basis of rational engineering concepts.

South Carolina Department of Highways and Public Transportation. Cost-effectiveness.

South Dakota DOT. Budgetary restrictions.

Tennessee DOT. Planning data are used for annual work load.

Texas Department of Highways and Public Transportation. For rehabilitation: (a) rational engineering concepts—on statewide basis for Interstate rehabilitation; (b) traditional allocation—to district for non-Interstate rehabilitation. For maintenance: traditional allocation—based on historical funding levels plus inflation.

Utah DOT. (a) Rational engineering concepts: engineering judgment is used in setting a level of maintenance that will best assure pavement performance for its design life. (b) Judgment based on experience dictates, to some extent, what must be done to protect the pavement from excessive deterioration.

Vermont Agency of Transportation. (a) Rational engineering concepts, (b) fund availability.

Virginia Department of Highways and Transportation. (a) Rational engineering concepts—primary basis; (b) cost-effectiveness—considered in selecting strategy.

Washington DOT. As the maintenance budget is reduced, less preventive work is planned and more reaction to deficiencies is anticipated.

West Virginia Department of Highways. Traditional allocation.

Wyoming Highway Department. (a) Rational engineering concepts, (b) cost-effectiveness.

Manitoba Department of Highways and Transportation. (a) Experience and field observations, (b) performance standards and planning values.

Nova Scotia. (a) Rational engineering concepts, (b) cost-effectiveness, (c) availability of asphalt plants and special crews.

Ontario. Rational engineering concepts and cost-effectiveness are used. Traditional allocation is not a significant factor. Budget constraints affect strategies now; potential energy shortfall will do so in the future.

Illinois State Toll Highway Authority. For cost-effectiveness, terminal value is weighed against recurring rehabilitation costs. A long-range pavement resurfacing program is based on an established serviceability index developed from roughness surveys.

Indiana Toll Road. (a) Rational engineering concepts, (b) cost-effectiveness, (c) desire to keep employees engaged in meaningful and worthwhile projects, (d) desire to maintain pride in project and workmanship.

Massachusetts Turnpike Authority. Rational engineering concepts.

New York State Thruway Authority. Strategy is based about 90% on cost-effectiveness; revenues for a toll facility are also dependent on level of service.

Ohio Turnpike Commission. The commission uses rational engineering concepts that have been developed and tested over the years and have proven effective. These concepts are reviewed periodically and modified as new technical data and procedures become available.

Oklahoma Turnpike Authority. Rational engineering concepts and cost-effectiveness are used to keep roads in good condition at all times.

Rhode Island Turnpike and Bridge Authority. (a) Rational engineering concepts, (b) annual inspections by consulting engineers and follow-up on recommendations.

Texas Turnpike Authority. Rational engineering concepts.

Question No. 4: What methodologies, if any, were used in developing the process identified in (3) above?

Arizona DOT. Maintenance management system and pavement management system incorporate rational engineering concepts, cost-effectiveness, and allocation based on historical data, developed standards, and feature inventory.

California DOT. For routine pavement maintenance, work plans are developed by the area supervisors and approved by the maintenance engineer. For rehabilitation, methodologies are based on the FHWA research project *Development of the California Pavement Management System* (*35*).

Connecticut DOT. Budgetary restrictions limit repair to highway sections most in need in each category.

Delaware DOT. Primary consideration for maintenance activities is derived from road condition surveys, with additional evaluation of information contained in skid number reports, accident reports, and traffic counts (in that order). Consideration is also given to routine maintenance costs as gathered by a maintenance management system to determine if costs per mile warrant preventive maintenance, even though other factors may not show this.

Florida DOT. An annual pavement condition survey determines distribution of available funds to identified needs and establishes project priorities.

Georgia DOT. (a) Trial and error, using test sections; (b) development of performance standards from historical data and current maintenance practices.

Illinois DOT. Agency uses district maintenance technical personnel plan and scheduled maintenance operations.

Iowa DOT. (a) Field review, analysis of test results (cores, Road Rater, etc.), and engineering judgment; (b) primarily observation to determine effectiveness relative to cost and anticipated useful life of pavement; (c) roughometer readings, friction coefficients, geometrics (horizontal and vertical), safety hazards, surface width.

Kansas DOT. No "packaged methodologies" are in use, but the agency has developed a pavement evaluation procedure that is being used on a trial basis. Standards for development were based on committee work and will be revised, if needed, as data accumulate.

Kentucky DOT. Resurfacing projects are chosen after they are evaluated by an evaluation team. Projects are evaluated on average daily traffic (ADT), condition, and safety. Projects are chosen for resurfacing or seal treatment by a point system. This is an annual program based on funds available; work is accomplished by contract. This is in addition to routine surface repairs and maintenance.

Louisiana Department of Transportation and Development. Methodology so far has consisted of a simple and often subjective analysis of trade-offs between two or three competing alternatives, as opposed to a global analysis of all possible alternatives.

Maine DOT. An area concept is used to take advantage of (a) permanent hot-mix plants or (b) good gravel quantities, where portable plants can be used. Also, this concept is used because the contractor will not have many equipment moves and haul distance will be kept to a minimum.

Massachusetts Department of Public Works. Methodology is based on continuity of the program operation, funding requests, and funding availability.

Michigan DOT. The district engineer and staff recommend sections for resurfacing or repair in order of district priority. These recommendations are then assembled and refined in the central office.

Missouri Highway and Transportation Department. Financing problems limit resurfacing for preventive maintenance to seal coats.

Montana Department of Highways. No sophisticated methodology is used. All strategies are developed by observation and the performance of the pavements.

Nebraska Department of Roads. Historical data provide basis for work plans.

New Hampshire Department of Public Works and Highways. The department is attempting to develop and use the Vermont AOT methodologies as published in "Pavement Condition Report, 1978" rather than the subjective methods used in the past.

New York DOT. Present strategy is based on the opinions of a committee of experienced maintenance engineers.

Ohio DOT. District safety review team investigates accident-prone sections of highway. Allocation is based on necessity and past history of district's maintenance needs.

Oklahoma DOT. Level of service is projected by maintenance activities and presented to the legislature.

Oregon Highway Division. Methodologies are based on experience. Maintenance management system components include features inventory, performance standards, standard costs, and a generalized level of service; the system is 6 years old.

Pennsylvania DOT. The predetermined time interval is based on quality standards that describe what the service levels should be and that define the way a road and its appurtenances should look, serve, and be preserved as a result of the maintenance. The intervals necessary to maintain the required quality are determined subjectively for the most part. They were determined from historical data and opinions expressed by knowledgeable maintenance people and are generally accepted nationwide. The minimum serviceability methodology was developed by the AASHO Road Test and has gone through many changes. Such a variety of other indexes have been developed that there is no standard practice for quantifying pavement performance. Pennsylvania employs the terminal pavement index methodology.

South Dakota DOT. A maintenance management work plan is prepared 18 months in advance of legislative allocation of dedicated funds.

Tennessee DOT. The agency uses planning data for its annual work load, based on quantities used in other states.

Texas Department of Highways and Public Transportation. For rehabilitation, each district has its own methodology. Most use some form of measured deficiency and visual inspections to determine pavement rehabilitation needs. For maintenance, each district has its own methodology, usually based on visual observations and inspections.

Utah DOT. Through the UDOT maintenance management system, an acceptable level of surface maintenance was determined. The goal is to maintain pavements to this predetermined quality level.

Vermont Agency of Transportation. An annual present serviceability rating inspection is made of the state highway system, from which is developed the proposed paving program for the ensuing year, with project priority being determined largely on the basis of its serviceability rating.

Washington DOT. A maintenance work plan is based on the anticipated needed repairs and maintenance work for the network plus field review of the roadway network.

Wyoming Highway Department. Maintenance management techniques and historical cost analysis were used to develop maintenance standards.

Manitoba Department of Highways and Transportation. Performance standards are developed in conjunction with a maintenance management system. The standard planning values (cubic yards of premix patching per mile, gallons of asphalt per mile for spray patching) were developed using results from other highway jurisdictions and the experience of Manitoba highway maintenance personnel. These values have been refined during the past 10 years by actual results in the field. The seal coat projects are put in priority order by field inspections and the experience of the maintenance engineer.

Nova Scotia. Transportation laboratory and selected personnel are used.

Ontario. Consultant-assisted studies are used to develop

suitable maintenance standards aimed at safety and protection of capital investment.

Illinois State Toll Highway Authority. Service life curves are derived from the combined projections of anticipated traffic loads and environmental deterioration.

Indiana Toll Road. In this small organization, approximately 100 employees are assigned to roadway maintenance (divided into 5 areas).

Massachusetts Turnpike Authority. There is visual survey of cracking, patching, and rutting.

New York State Thruway Authority. The self-supporting nature of the toll highway dictates the strategy.

Oklahoma Turnpike Authority. Because people pay to ride on the road, it must be kept in satisfactory condition. Whatever methods are necessary to accomplish this are immediately put into operation, whether to repair present irregularities or prevent future ones.

Question No. 5: What pavement maintenance techniques are used and how effective is each in satisfying the requirements of the strategies? Identify whether the technique is used for preventive or corrective maintenance or both. (Pavement maintenance techniques include such activities as overlays, seal coats, pothole repair, crack sealing, etc.)

Arizona DOT. Hand patch with premix—corrective; level with premix—preventive and corrective; fill cracks—preventive; spot seal patching—preventive and corrective; surface/base replacement—preventive and corrective; seal coating (major)—preventive and corrective; seal coating (minor)—preventive and corrective; flush coating—preventive; spot flush coating—preventive; temporary hand patching—corrective; other paved surface maintenance—preventive and corrective; overlays by contract construction—preventive and corrective.

California DOT. For routine pavement maintenance, rejuvenators and seal coats are applied for preventive purposes. Spot seals, crack filling, and blankets are used to correct minor deficiencies; digouts, pothole repair, and spot heavy blankets are used to correct more severe deficiencies. For rehabilitation, techniques are based on the FHWA research project. *Development of the California Pavement Management System (35).*

Connecticut DOT. The agency uses bituminous concrete overlays, thin surface treatments (45–60 lb bituminous concrete per square yard), liquid seal coats, joint and crack cleaning and sealing, and pothole patching.

Delaware DOT. Primary techniques in pavement repair are pothole patching (temporarily corrective and totally unsatisfactory) and crack sealing (preventive). The agency recently began using a rubberized asphalt crack sealer (Overflex) to extend the length of service. Overlays and seal coats are used preventively; results are very satisfactory if the work is performed at the proper time and with the correct design.

Florida DOT. Routine pavement repair is generally limited to patching holes, in accordance with the *Guide to Asphalt Pavement Repair.* Periodic pavement maintenance has generally been limited to asphalt overlays, with some concrete rehabilitation.

Georgia DOT. Spot patching, deep patching, and leveling are effective methods of improving ridability and extending the period between resurfacings (preventive and corrective). Undersealing, grinding, and sealing joints on PCC pavement are effective methods of improving ridability (corrective). Sealing cracks is an effective method of extending pavement life (preventive). Using chip seal and using slurry seal are cost-effective methods of rejuvenating low-volume roads. Resurfacing is effective in maintaining ridability on high-volume roads (corrective).

Hawaii DOT. Pothole repair—correct deficiencies; overlay—correct deficiencies; slurry seal—extend life.

Illinois DOT. Pothole repair is used as corrective maintenance; it is more effective when completed in warm weather with hot-mix material. Pavement patching is used as corrective maintenance; it is very effective in restoring pavement to as-built condition. Cutting 4-in. expansion joints is used as preventive maintenance; it is effective in relieving stress in pavement and eliminating blowups.

Iowa DOT. Maintenance standards entail in-house efforts on a routine network basis. Other strategies performed on a project basis (e.g., seal coating, thin overlays, surface milling) are done by maintenance contract. Moderate to thick overlays and reconstruction are done by construction contracts. (See Table B-1 for details of Iowa's maintenance techniques.)

Kansas DOT. All conventional procedures are used for prevention and special maintenance (e.g., crack filling, surface repair, surface patching, dilute sealing).

Kentucky DOT. Contract resurfacing, seal coats, and crack sealing are used for corrective and preventive maintenance. Other items are routine corrective work.

Louisiana Department of Transportation and Development. Most maintenance techniques are related to specifically defined objectives. Major repair techniques are oriented toward reduction of skid accidents, protection of the investment, and preventive maintenance. For skid reduction, overlay is the dominant technique used. Plant-mix seal and slurry seal techniques have been used on a very limited scale. The principal techniques used for protection of the investment include seal coats, sealing shoulders, and restoration of nonpaved shoulders. These preventive maintenance techniques are limited by skid reduction considerations. Minor repair techniques include the traditional classifications (e.g., pothole patching), most of which are corrective in nature. The only preventive minor maintenance techniques are repairing roadway joints, cutting and hauling high shoulders, painting bridges, repairing bridge joints, lubricating movable bridges, and cleaning drainage structures. Preventive maintenance as used here refers to prevention of further deterioration, as opposed to prevention of accidents, and includes techniques that can be scheduled on a time-interval basis before severe conditions develop.

Maine DOT. The agency uses an overlay concept almost exclusively, with a minimum of seal coats and crack sealing. It could be classified as both preventive and corrective maintenance. The normal ⅝-in. overlay is preventive. When wheel rutting or superelevation deficiencies are encountered, a shim is applied just ahead of the overlay; this is corrective.

Massachusetts Department of Public Works. Pothole repair is used to correct deficiencies. Crack sealing is used for preventive maintenance of existing pavements. Thin (¾-in.) overlays are used for preventive maintenance (because of limited funds). Overlays (2–4 in.) are used to correct deficiencies.

Michigan DOT. For concrete pavements, corrective treatment involves joint repair, pothole patching, and resurfacing; preventive treatment involves installing pressure relief joints to prevent blowups. For bituminous pavements, corrective treatment involves crack sealing, pothole patching, and overlays.

Missouri Highway and Transportation Department. Crack pouring—preventive (effective); mudjacking—preventive (partially effective); spot sealing—corrective (effective); continuous seal coat—preventive (effective on routes with 2,000 ADT); pothole repair—corrective (effective); concrete patching—corrective (effective); bituminous overlays—corrective (effective).

Montana Department of Highways. Pavement overlays provide necessary corrections and effectively extend the life of the roadway. Seal coats effectively extend the life and prevent the deterioration of the pavement. Surface patching (hand) is effective for repairing small potholes. Surface patching (machine) is effective when the repairs are larger than pothole size and work can be accomplished more efficiently using a motor grader. Pavement rejuvenation is effective in extending the life of the pavement when a special commercial rejuvenating agent is used. Crack filling is both preventive and corrective. Mudjacking of PCC pavement effectively alleviates settlements in concrete pavements.

New Hampshire Department of Public Works and Highways. Previously resurfacing was based strictly on recommendations of the division engineers, with allocation of funds

TABLE B-1
PAVEMENT MAINTENANCE TECHNIQUES (IOWA DOT)

Activity	Preventive	Corrective	Effectiveness
Spall patching		X	Usually considered temporary
Temporary blowup repair		X	Effective for short term
Full-depth patching		X	Considered permanent
Hand-leveling		X	Usually will be repeated periodically during life of pavement
Joint and crack filling	X	X	Effective if diligently performed annually
Seal coating	X	X	Effective but must be repeated every 5 to 7 yr
Winter seal patching		X	Effective as interim measure
Edge seal	X	X	Effective but must be repeated every 2 to 3 yr
Slurry seal	X	X	Effective (when properly applied) but must be repeated every 5 to 7 yr
Strip seal		X	Effective but must be repeated every 3 to 5 yr
Burn/plane surface		X	Very effective
Raise pavement		X	Successfully accomplished in 75% to 80% of attempts
Cut blowup control joints		X	Have been cut at 1,000-ft intervals and proven to be effective
Cut pressure relief at bridges		X	Effective when recut approximately every 5 yr
PCC surface milling		X	Effective, at least for short term (3 yr of experience)
In-place surface recycling		X	Effective in removing rutting and other surface defects
Plant recycling of asphalt concrete surface		X	Short-term experience indicates method is effective
1-in. hot sand mix asphalt concrete overlay		X	Effective in restoring surface of otherwise structurally adequate asphalt concrete surfaced paving
1½-in. to 4-in. asphalt concrete overlay		X	Effective—anticipate at least 8-yr life
1½-in. dense PCC overlay		X	Jury still out on this

by the maintenance engineer determined after review of recommendations by headquarters personnel. After resurfacing programs including overlays and seal coats were established, other pavement maintenance activities were performed to alleviate deficiencies and prevent accelerated deterioration requiring expensive reconstruction.

New Jersey DOT. (a) Preventive and corrective—pouring of joints and sealing of cracks (relatively effective); (b) corrective—overlays (very effective); (c) corrective—pothole repair (effective); (d) corrective—repairing of joints (effective).

New York DOT. For preventive maintenance: thin asphalt concrete overlays (less than 1 in.) and surface treatment (asphalt emulsion and stone chip). For corrective actions: numerous techniques.

Ohio DOT. For corrective maintenance: (a) emergency pothole patching (includes patrol patching)—eliminates dangerous condition on a short-term basis; (b) permanent pothole patching (clean, tack, and compact); (c) wedge patching with grader or paver using asphalt concrete; (d) joint repair; (e) asphalt concrete overlay. For preventive maintenance: (a) crack filling, (b) skin patching, (c) surface treatments, (d) seal coats.

Oregon Highway Division. Corrective maintenance: pothole patching with cold mix—not effective; with Sta-Fil, Spec 200, or Sylvax—moderately effective; hot-mix patching and skin patching—effective; PCC patching with low-slump, high-early-strength concrete—effective. Preventive maintenance: on open, dry mixes, Reclamite is effective; on resilient pavements, rubber-asphalt chip seals are reasonably effective; designed overlays are effective, but not a standard 2-in. thickness.

Pennsylvania DOT. If performed as described in the manual *Performance Standards,* pavement maintenance techniques are effective in satisfying the strategy requirements. The techniques are used for both corrective and preventive maintenance.

South Carolina Department of Highways and Public Transportation. Pothole repair is used to correct a deficiency. Crack sealing and seal coats are used to protect the investment on roads with good cross section and grade. Overlays are used on roads that need improvement to the cross section and longitudinal riding surface.

South Dakota DOT. Pothole repair—corrective; overlays—preventive; seal coats—preventive; crack sealing—corrective and preventive; PCC joint repair—corrective and preventive.

Tennessee DOT. The agency's manual describes recommended procedures, which are used for preventive or corrective maintenance.

Texas Department of Highways and Public Transportation. Rehabilitation: (a) level-ups and overlays (1½ in. or more of asphalt concrete)—effective in increasing pavement strength and serviceability (both corrective and preventive); (b) repair of continuously reinforced concrete pavement punchouts to restore serviceability (corrective); (c) crack sealing and seal coats—does not affect pavement strength or serviceability (preventive). Maintenance: (a) spot level-ups and overlays, pothole repair, spot seals, crack sealing, and base repairs for flexible pavements; (b) crack sealing, pressure grouting, joint sealing, blowup repair, and punchout repair for rigid pavements. Techniques used are very effective when needed rehabilitation can be performed on a timely basis.

Utah DOT. Chip seal coats are placed using CRS-2h emulsified asphalt and rock or slag cover material on an average of once every 6.5 years. Pothole repair, lane leveling, and crack sealing are performed as per acceptable standards. The standard for each activity has been established as the most effective of several alternative methods tried and evaluated.

Vermont Agency of Transportation. The crack sealing program (100,000 lb annually) is deliberately preventive. Funding is never quite adequate to meet the needs, so paving activities must be corrective rather than preventive. Funds are stretched by applying seal coats on highways with lower traffic volume and by using asphalt overlays of varying depths (½ in. to 1½ in.) on roadways with higher traffic volume. Depth is a function of present condition and ADT.

Virginia Department of Highways and Transportation. Depending on the pavement condition, the department uses all the techniques mentioned in the question and on occasion also rips up and replaces sections.

Washington DOT. Routine maintenance seals are corrective and preventive. With the decrease in funds they will become more corrective.

West Virginia Department of Highways. Corrective overlay normally is performed by contractor.

Wyoming Highway Department. In the pavement overlay program, the highest-priority roadways are overlaid. Funding is limited, so some roadways are just leveled and sealed. The department has an aggressive sealing program and has found that some roadways stay in good shape if they are sealed every 5 or 6 years. Other maintenance activities (e.g., patching, pothole repair, crack sealing) are used to maintain roadways for day-to-day use.

Manitoba Department of Highways and Transportation. Seal coat is used; for the most part it is preventive, except for correction of a bleeding condition.

Nova Scotia. Overlays—corrective; seal coat—preventive; pothole patching—corrective; crack seal—corrective.

Ontario. Crack sealing and seal coating—preventive; pothole repair—corrective; overlay patching—mostly corrective but can be considered preventive depending on existing condition.

Illinois State Toll Highway Authority. Effective results have been obtained from the traditional practices of full-depth and partial-depth repairs and shoulder rehabilitation accompanied by a nominal 3 in. bituminous overlay let to contract. Interim activities (e.g., crack sealing, limited partial-depth repairs, and local drainage corrections) are done in-house.

Indiana Toll Road. Preventive maintenance has continued to be the primary strategy. Settlement is corrected by mudjacking; pavement joints are kept sealed during fall, winter, and spring; pavement blowups and potholes are patched immediately; and, after 20 years of service, the pavement has been overlaid with asphalt.

Massachusetts Turnpike Authority. Bituminous concrete overlays, pavement repair, and crack sealing have been effective for corrective and preventive maintenance.

New York State Thruway Authority. Preventive maintenance: crack sealing and underdrain installation. Corrective

maintenance: pothole repair, replacement of deteriorated slabs, and overlays.

Ohio Turnpike Commission. The original 241 miles of four-lane, 10-in. reinforced concrete pavement, which was opened to traffic in 1954 and 1955, has since been resurfaced at least once with asphalt concrete. A very effective program for crack and joint sealing goes on from late fall to early spring; this has proved to be the best time to seal the cracks and joints, because the pavement has contracted and the cracks and joints are most visible. Resurfaced areas, depending on their locations and the amount of traffic, last from 6 to 9 years. One of the most significant improvements made to the original pavement was the installation of longitudinal stone drains along the entire edge of the pavement, with transverse storm drains to bleed off the longitudinal drain at each pavement joint, approximately every 60.5 ft. The installation of these drains was accomplished over the years during the resurfacing of the original concrete pavement. This program has been most successful in eliminating water-associated problems, such as pumping of pavements and the eventual deterioration of the concrete slab. The pavement has tightened up, and frost heaving, which is a serious problem in this geographical area, has been reduced considerably. In addition, runoff is contained in high fill sections by asphalt curbs with outlets into slope drains.

Oklahoma Turnpike Authority. All the methods mentioned in the question are used, but use of overlays is by far the best. This applies to rigid and nonrigid pavement.

Rhode Island Turnpike and Bridge Authority. Overlay, pothole repair, and crack sealing are used for both preventive and corrective maintenance. Crack sealing must be done annually.

Texas Turnpike Authority. Joints and cracks are resealed annually for full project length. Surface failures are repaired immediately upon or prior to occurrence. Overlay is used when many surface defects become prevalent.

Question No. 6: What problem areas or deficiencies do you have in providing or obtaining the needed information for management decisions in selecting appropriate pavement maintenance strategies?

Arizona DOT. It is felt that all problem areas can be solved by the implementation of the agency's pavement management system to complement the maintenance management system.

California DOT. For routine pavement maintenance, the major problem is developing a priority system to determine the order of repairs and then providing funding for the entire list. There are no rehabilitation problems.

Connecticut DOT. There is a need for a uniform numerical rating procedure, which is now being developed.

Delaware DOT. The major problem is not in obtaining information, but in getting accurate, reliable information based on comparable judgments or performance throughout the state.

Florida DOT. Traditional apathy for the unglamorous "stepchild" of resurfacing or rehabilitating the existing facility is believed to be the main cause for inadequately funded programs. The agency presently has a system to identify deficiencies but is keenly interested in developiong a complete pavement management system to identify the proper alternative repair techniques for various structural conditions.

Georgia DOT. Present methods of establishing priorities for pavement maintenance strategies are subjective.

Hawaii DOT. A pavement management system is needed for better pavement evaluation.

Illinois DOT. None.

Iowa DOT. The agency needs (a) accurate projections of remaining service life on a project basis, (b) training in the recognition of causes for pavement deficiencies, (c) correlations between conditions and safety, (d) a computerized system of identifying priority needs and analyzing treatment options.

Kansas DOT. The agency wants to be sure that (a) work being proposed and performed is based on needs and (b) needed work is performed correctly and efficiently. The agency feels strongly that it will be receiving the proper information to make correct decisions when its management system is fully operational.

Kentucky DOT. The timetable is a problem for contract work because of the need to evaluate projects. The maintenance management section programs routine surface repairs and maintenance of pavements based on funds available annually.

Louisiana Department of Transportation and Development. Major problem areas are related to an inability to tie construction strategies to maintenance strategies in order to select appropriate total pavement maintenance strategies. The effect of overlays and other activities performed by the construction organization is not easily correlated with maintenance strategies used by state maintenance personnel. An effective pavement management system that provides for analysis of a global strategy is required to address this question effectively. Additionally, routine major maintenance work must be more precisely located than the existing control section method allows. Some technique that allows identification of major maintenance work by route, log mile, and structure number will be required to resolve this problem. Without proper location information, maintenance repair histories cannot be used to analyze the cost-effectiveness of alternative maintenance strategies.

Maine DOT. None; no matter where we decide to use pavement maintenance, it is needed.

Massachusetts Department of Public Works. There is (a) lack of consistent funding on an annual basis to meet the consistent need and (b) lack of a pure, objective method of selecting priorities.

Michigan DOT. There is no great difficulty identifying projects requiring maintenance; the problem is insufficient funding.

Missouri Highway and Transportation Department. Information is subjective, particularly regarding ridability and state of deterioration.

Montana Department of Highways. Obtaining information for maintenance strategies is generally not a problem, as it is the maintenance foreman's responsibility in each division to periodically inspect all the roads within his area and compile

a file on maintenance needs, which in turn is reviewed and approved by the chief of the field maintenance bureau.

New Hampshire Department of Public Works and Highways. Because a formal strategy is just beginning, no problems have surfaced other than lack of funding. Because New Hampshire is small, one two-person team performs all highway segment ratings.

New Jersey DOT. There is a lack of manpower.

New York DOT. The agency has no problems determining the age of a pavement because of detailed information kept in local offices. The agency is working on the development of a pavement management system based on physical measurements of pavement roughness.

Ohio DOT. A better comparison of cost-effectiveness for various maintenance techniques is needed. The pavement condition rating system needs to be refined. Allocation on a district basis does not always order projects according to priority on a statewide basis.

Oklahoma DOT. The problems are materials availability and increased prices for fuel, equipment, and materials.

Oregon Highway Division. Needs include (a) accurate prediction of rate of pavement deterioration; (b) value received, in terms of extended pavement life from skin patches, Reclamite treatments, fog seals, chip seals, etc.; (c) determination of time at which preventive maintenance treatments should be applied.

Pennsylvania DOT. Problems encountered in obtaining information are related to two areas: no data base has been developed showing typical pavement performance; and, due to fiscal contraints, no uniform maintenance program is available from year to year.

South Carolina Department of Highways and Public Transportation. The problem is not lack of information but lack of funds.

South Dakota DOT. There is political maneuvering and indecision and an unwillingness to accept a long-range pavement management system.

Tennessee DOT. Evaluation of pavement design is needed, and there are poor construction procedures.

Texas Department of Highways and Public Transportation. Rehabilitation: because of the method of allocating non-Interstate rehabilitation funds, it is not possible to assure that funds and corrective actions are directed to the most needed projects on a statewide basis. Maintenance: there is an inability to assess pavement condition for estimating needed maintenance efforts and a consequent difficulty in allocating maintenance funds.

Utah DOT. Present criteria for sealing cracks in bituminous pavements are unsatisfactory. Better identification of conditions that warrant crack filling is needed. The present PSI is not very reliable in indicating when a pavement is in need of maintenance. Perhaps a refinement in quantifying the various factors that make up the PSI would be beneficial.

Vermont Agency of Transportation. None.

Virginia Department of Highways and Transportation. The department needs an added ability to run deflection studies to aid in determining maintenance techniques. Financing always plays a part in selecting the appropriate strategies.

Washington DOT. The department needs (a) budgetary restraints, (b) the ability to forecast maintenance needs 2 years in advance, and (c) categorization of routine maintenance costs for bituminous and PCC pavements.

West Virginia Department of Highways. None; maintenance management system and field surveys provide all needed information.

Wyoming Highway Department. Budgeting process starts about 12 months prior to the actual start of the fiscal year. There is some flexibility in changing priorities and work plans, but normally no additional funds are available once the budget is established.

Manitoba Department of Highways and Transportation. It is necessary to ensure that the performance standards are followed; seal coats lack written standards; decisions need to be made regarding when a road should be seal coated.

Nova Scotia. There are not enough funds to carry out required work.

Ontario. Present maintenance management computerized system is voluminous and unwieldy; translation into hard and usable facts is difficult.

Illinois State Toll Highway Authority. There is a lack of subbase information to document the problem areas of excess moisture and lack of load transfer across joints. The authority is presently considering instrumentation in order to monitor moisture, deflections, loss of surface texture, rutting, etc.

Indiana Toll Road. The 157-mile facility was constructed in 2 years and equipped with new maintenance equipment; there have been no problems with decisions.

Massachusetts Turnpike Authority. None.

Ohio Turnpike Commission. There is no great difficulty in selecting appropriate maintenance strategies because of an annual inspection of all facilities—bridges, culverts, pavements, buildings, and roadways—by the general engineering consultant. This is reviewed by the engineering staff and supplemented by the commission's investigations where warranted. This inspection provides the basic information to be used in developing maintenance strategies.

Rhode Island Turnpike and Bridge Authority. The authority tries to find "proven" products; it receives product literature and likes to try "samples" in the field.

Texas Turnpike Authority. None.

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