National Cooperative Highway Research Program

Synthesis of Highway Practice 223

Cost-Effective Preventive Pavement Maintenance

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Transportation Research Board
National Research Council

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Cost-Effective Preventive Pavement Maintenance

A Synthesis of Highway Practice

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, 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 useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on 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 these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to highway agency executive management including administrative, budget, and finance personnel; pavement design, construction, and maintenance engineers; and maintenance operations personnel, including supervisors and maintenance crew leaders. This synthesis describes the state of the practice with respect to setting a coherent strategy of cost-effective preventive maintenance for extending pavement life.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available 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 reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board describes the practices of state, local, and provincial transportation agencies that are attempting to minimize the life-cycle costs of pavements and are identifying, during the design of the pavement rehabilitation, reconstruction, or construction projects, the future preventive maintenance treatments and the timing and funding for those treatments. It includes a review of domestic literature and a survey of current practices in North America. The appendices include a primer on pavement design and construction, the benefits of preventive maintenance of pavements, a summary of the questionnaire data collected, a simulation of pavement management strategies, and an example process to demonstrate the cost-effectiveness of preventive maintenance.

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

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

CONTENTS

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Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of David D. Gieber, Field Area Engineer Supervisor, Construction and Maintenance Division, Texas Department of Transportation; Dennis C. Jackson, State Design Engineer, Washington State Department of Transportation; Peter A. Kopac, Research Highway Engineer, Federal Highway Administration; Frank N. Lisle, Engineer of Maintenance, Transportation Research Board; Robert W. Moseley, Special Project Engineer, Mississippi Department of Transportation; Luis M. Rodriguez, Highway Engineer, Federal Highway Administration; Douglas L. Shaffer, Senior Program Officer, Transportation Research Board; Kenneth W. Shiatte, Assistant Commissioner Operations Division, New York State Department of Transportation; and Donald M. Walker, Professor, University of Wisconsin-Madison.

The Principal Investigators responsible for the conduct of this synthesis were Sally D. Liff, Manager, Synthesis Studies, and Stephen F. Maher, Senior Program Officer. This synthesis was edited by Linda S. Mason, assisted by Rebecca B. Heaton.

Scott A. Sabol, Senior Program Officer, National Cooperative Highway Research Program, assisted the NCHRP 20-5 staff and the Topic Panel.

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

COST-EFFECTIVE PREVENTIVE PAVEMENT MAINTENANCE

SUMMARY

Obtaining funds for preventive maintenance of pavements has always been a difficult task for maintenance managers. One problem is that if a preventive maintenance treatment is applied at the proper time, the motorist does not sense any change in the performance of the pavement because the treatment is applied before any serious pavement deterioration has occurred. Another problem has been the absence of documentation of the cost-effectiveness of preventive maintenance for pavement.

In 1989 the National Cooperative Highway Research Program sponsored the publication of *Synthesis 153: Evolution and Benefits of Preventive Maintenance Strategies* to assist highway maintenance managers in communicating the value of timely cost-effective preventive maintenance programs and thereby broadening the acceptance of the practice by transportation executives and legislative members.

Also in 1989, the Federal Highway Administration required, by an interim final rule, that every state department of transportation have an operational pavement management system and the American Association of State Highway and Transportation Officials published guidelines for developing a pavement management system. Section 1009(e)(4) of the Intermodal Surface Transportation Efficiency Act of 1991 provides that preventive maintenance activities on Interstate highways are eligible for Federal-aid Interstate maintenance funding when a department of transportation can demonstrate through its pavement management system that these activities are a cost-effective means of extending the life of Interstate pavements. During the preparation of this synthesis, the National Highway System bill was passed (November 1995). This bill made the requirement for management systems, including pavement management systems, optional and expanded the eligibility of funds for preventive maintenance projects by allowing a state to demonstrate to the satisfaction of the Secretary that a proposed project is cost-effective. In addition, it provides for preventive maintenance activities on Federal-aid highways rather than restricting these activities to only the Interstate pavement.

The installation of pavement performance monitoring sections to determine the long-term performance of pavements and to evaluate the effectiveness of maintenance treatments by the Strategic Highway Research Program has been completed. Some of the early performance results are available for implementation by the Federal Highway Administration and use by the state departments of transportation. Several research projects have been completed on cost-effective preventive maintenance practices for pavements. Additionally, various methods and techniques to successfully extend the service life of existing pavements are now being reported.

This synthesis reviews the literature and research currently underway and surveys current practices in setting a coherent strategy of cost-effective preventive maintenance practices for extending pavement life. This systematic process to select and budget preventive maintenance activities over the life of a pavement minimizes life-cycle costs.

To identify the current practices, a questionnaire was developed and distributed to the departments of transportation in 50 states, the District of Columbia, Puerto Rico, 13 Canadian agencies to include all ten provinces, and 37 local agencies (village, city, county, town, or public authorities) to obtain information on:

- The types of preventive maintenance treatments used for pavements,
- The observed increases in pavement service life obtained from the use of the treatment,
- The uses of preventive maintenance strategies,
- The cost-effectiveness of the strategy as measured by an increase in the time to rehabilitation, a reduction in the amount of time and money spent on demand maintenance activities, and an improvement in serviceability,
- The planning and funding of preventive maintenance for pavements,
- Agencies' reasons for not using pavement preventive maintenance strategies, and
- What further work or research is needed.

Sixty state, province, and local transportation agencies responded. The results of the survey and published information demonstrate the cost-effectiveness of preventive maintenance strategies. Agencies that use a preventive maintenance strategy most frequently reported an increase in the time to rehabilitate a pavement of 9 to 10 years for portland cement concrete pavement (PCC), and of 5 to 6 years for asphalt concrete (AC) and overlaid pavements. Those same agencies reported a decrease in the time and money spent on pavement demand maintenance activities of 5 to 10 percent for PCC and AC pavements, and 16 to 20 percent for overlaid pavements. A dollar invested in preventive maintenance at the appropriate time in the life of a pavement will save $3 to $4 in future rehabilitation costs. The survey also disclosed that the most cost-effective pavement management strategy is to perform preventive maintenance activities on the better-rated pavements first and then fund the rehabilitation of the poorer-rated pavements. The funding strategy that addresses the worst pavements first is the least cost-effective.

CHAPTER ONE

INTRODUCTION

BACKGROUND

It is difficult for maintenance managers in state or local transportation agencies to obtain adequate funding for preventive maintenance. While most people would agree with the conventional wisdom that it makes sense to do preventive maintenance to extend the service life of a pavement or bridge, funding for preventive maintenance does not fare well when competing with other transportation needs such as demand maintenance activities, (e.g., patching potholes, plowing snow, or mowing grass) and funding for rehabilitation, reconstruction, or new construction. Preventive maintenance is even less successful when competing with other governmental programs such as public safety, education, or social services. The National Cooperative Highway Research Program (NCHRP) sponsored the publication of *Synthesis 153* (*1*) in 1989 to assist highway maintenance managers in broadening the acceptance and communicating the value of timely, cost-effective preventive maintenance programs to transportation executives and legislative members.

Since that synthesis was completed, the Federal Highway Administration (FHWA) promulgated an interim final rule requiring every state department of transportation (DOT) to have an operational pavement management system (PMS) (*2*). A PMS has been defined as "a set of tools or methods that assists decision makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition"(*2*). The American Association of State Highway and Transportation Officials (AASHTO) developed and widely distributed guidelines for implementing a PMS (*3*). The guidelines describe how a PMS provides information useful for comparing alternative preventive maintenance strategies for pavements. A good PMS provides timely information on pavement condition. It enables a user to accurately calculate the effects and costs of alternative maintenance actions, and to evaluate the consequences of deferred maintenance. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, Section 1034 (*4*), incorporated a requirement that each state DOT have an operational PMS by October 1995. Section 1009(e)(4) of the same Act (*5*) provides that preventive maintenance activities on Interstate highways are eligible for Federal-aid Interstate maintenance funding when a DOT can demonstrate through its PMS that these activities are a cost-effective means of extending the life of the pavements. The states are then allowed the flexibility to transfer their allocated Interstate maintenance funds to other Federal-aid highway programs if they can show that they are adequately maintaining their Interstate highway system. This flexibility to transfer Interstate maintenance funds increases the importance of optimizing the use of preventive maintenance funds on the Interstate system as a means of making maintenance funds available for use on other Federal-aid systems. During the preparation of this synthesis, the National Highway System bill was passed. *(The National Highway System Designation Act of 1995 (P.L. 104–59), Section 309, Preventive Maintenance, November 28, 1995.)* This legislation makes optional the requirement for management systems, including a PMS, and expanded the eligibility of funds for preventive maintenance projects by allowing a state to demonstrate to the satisfaction of the Secretary that a proposed project is cost-effective. In addition, it specifically provides for preventive maintenance activities on Federal-aid highways rather than limiting these activities to only the Interstate pavement.

The installation of pavement performance monitoring sections by the Strategic Highway Research Program (SHRP) has been completed and some of the early results of the research are available for implementation by the FHWA and use by the DOTs. At least two technical research areas have the potential to provide results that would directly impact preventive maintenance strategies: these are research on long-term pavement performance and research on maintenance effectiveness (*6*).

The NCHRP and several DOTs have completed research projects pertaining to cost-effective preventive maintenance practices for pavements. Those are reviewed, referenced, and discussed later in this synthesis. In addition, DOTs have been successfully using various methods and techniques to extend the service life of existing pavements, many of which have not been reported or presented in the literature. A major focus of this synthesis was to gather from the state and local DOTs previously unreported information on the cost-effectiveness of pavement preventive maintenance. Finally, the following list of NCHRP reports recently completed or under development that relate to the use of cost-effective preventive maintenance practices were reviewed and are discussed later in this synthesis.

- *Asphalt Surface Treatments and Thin Overlays* (*7*)
- *Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments* (*8*)
- *Role of Highway Maintenance in Integrated Management Systems* (*9*)
- *Effective Maintenance Budgeting Strategies* (*10*)

PURPOSE AND SCOPE OF SYNTHESIS

There is a need to compile and synthesize all of the current information on cost-effective preventive maintenance for pavements. The purpose of this synthesis, therefore, is to review the literature and research currently underway and to survey current practices in setting a coherent strategy of cost-effective preventive maintenance practices for extending the service life of pavements. The synthesis reports on the practices of agencies that are attempting to minimize the life-cycle costs of pavements and are identifying, during the design of the pavement rehabilitation, reconstruction, or construction project, the future preventive maintenance treatments, and the timing and funding for those treatments.

Appendix A describes, in nontechnical language, terms commonly encountered when discussing the different types of pavements, categories of maintenance, the causes of the most commonly occurring problems for each type of pavement, and the categories of preventive maintenance treatments generally used for pavements. Appendix A serves as a "primer" that can be used by DOT engineering, operations, and maintenance personnel in briefing executive management, administrative, budget, finance, and legislative personnel on the benefits of preventive maintenance of pavements.

QUESTIONNAIRE

To identify the current practices, a questionnaire (duplicated in Appendix B) was developed and distributed to the DOTs in 50 states, the District of Columbia, Puerto Rico, 13 Canadian agencies, and 37 local agencies (village, city, county, town, or public authorities) to obtain information on:

- The types of preventive pavement maintenance treatments used for portland cement concrete (PCC), asphalt concrete (AC) and overlaid pavements,
- The age of the pavement at the time of the first application of the treatment,
- The frequency of application, if treatment is applied cyclically,
- The cost of applying the treatment,
- The observed increases in the pavement service life obtained from the use of the treatment,
- The uses of preventive maintenance strategies for pavements,
- The variations in the strategies for different functional classes and traffic volumes,
- A description of one strategy used by the agency for each type of pavement to include the treatment and year of application,
- The cost-effectiveness of the strategy as measured by an increase in the time to rehabilitation, a reduction in time and money spent on demand maintenance activities; and improved serviceability,
- The sources of the above information,
- The planning and funding of preventive maintenance for pavements,
- The reasons why an agency is not using preventive maintenance strategies, and
- What further work or research is needed.

RESPONSES

Table 1 summarizes the responses to the questionnaire. A complete listing of the agencies responding and the abbreviations used throughout this report is shown in Table C-1 in Appendix C. Appendix D provides responses to each question by agency. The Illinois DOT submitted a description of its Program of Maintenance for Mechanistically Designed Pavements (*11* and Appendix E). The Hawaii and Mecklenburg County, North Carolina DOTs indicated that they did not have preventive maintenance programs for pavement.

TABLE 1

SUMMARY OF AGENCIES RESPONDING TO THE QUESTIONNAIRE

Departments of Transportation	Number Sent	Number Returned	Percent Responding
States, District of Columbia, & Puerto Rico	52	45	87
Canadian Agencies	13	4	31
Local (Village, City, Town, County, Authority)	37	11	30
Total	102	60	59

CHAPTER TWO

OVERVIEW OF PREVENTIVE MAINTENANCE FOR PAVEMENTS

INTRODUCTION

Cost-effective preventive maintenance strategies are applied to pavements to minimize or prevent common pavement problems from occurring. Table 2 lists the different types of pavements that are discussed in this report—the more common pavement problems that can be minimized or avoided by preventive maintenance treatments and the commonly used preventive maintenance treatments. This report does not address the maintenance of unpaved, or gravel surfaced roadways.

For those who may not be familiar with pavements, the different categories of pavement maintenance, the causes of pavement problems, and the typical preventive maintenance treatments are discussed in the Primer on Pavement Maintenance in Appendix A.

PREVENTIVE MAINTENANCE STRATEGY FOR PAVEMENTS

Definition

A preventive pavement maintenance strategy is an organized, systematic process for applying a series of preventive maintenance treatments over the life of the pavement to minimize life-cycle costs. Table 3 illustrates a preventive maintenance strategy for a composite pavement. Table 3 represents the anticipated preventive maintenance needs of a section of pavement based on the observed deterioration of similar pavements. That does not mean the treatment is automatically done. Annually, a survey is made of the condition of each section of the pavement, and based on the results of that survey, the decision is made to perform the preventive maintenance activities or, if the pavement condition doesn't warrant it, to postpone the treatment for a year.

Cost-Effectiveness

One of the earliest studies on preventive maintenance strategies, conducted by the Utah Department of Transportation in 1977, indicated that every $1 invested in a preventive maintenance treatment early in the life of a pavement, avoided the expenditure of approximately $3 later on in the cost of a major rehabilitation (*12*).

Research done for the U.S. Army Corps of Engineers found that the equivalent uniform annual costs (EUAC) to repair a deteriorated pavement was four times that of applying a

TABLE 2

LIST OF PAVEMENTS, COMMON PROBLEMS, AND PREVENTIVE MAINTENANCE TREATMENTS

Types of Pavements	Common Pavement Problems	Preventive Maintenance Treatments
Flexible	Potholes	Drainage
	Edge cracking	Crack sealing
	Lane-to-shoulder drop-off	Slurry seal
	Aging	Micro-surfacing
	Thermal cracking	Chip seals
		Thin hot-mix asphalt overlays
Rigid	Blow-ups	Drainage
	Pumping	Joint and crack sealing
	Joint faulting	Retrofit load transfer
Composite	Potholes	Drainage
	Edge cracking	Crack sealing
	Lane-to-shoulder drop-off	Slurry seal
	Aging	Micro-surfacing
	Reflective cracking	Chip seals
	Thermal cracking	Thin hot-mix asphalt overlays
		Reseal sawed and sealed joints

TABLE 3

PREVENTIVE MAINTENANCE STRATEGY FOR A COMPOSITE PAVEMENT

	Preventive Maintenance Treatment	
Year	Seal Cracks	Clean and Seal Sawed and Sealed Joints
1		
2	X	
3		
4	X	
5		
6	X	
7		
8	X	X
9		
10	X	
11		
12	X	
13		
14	X	
15		
16	Rehabilitate Pavement	

surface treatment at the proper time (*13*). The comparable ratio for a thin overlay was 3.62 and for a thick overlay, 3.00.

In Kansas a strategy was implemented to treat the pavements in need of preventive maintenance before funding the reconstruction of poorer pavements (*12*). After the first 4 years, the quantities of aggregate and asphalt for both surface repairs and resurfacing decreased progressively.

The New York State Department of Transportation compared two maintenance strategies for managing a mile of newly constructed flexible pavement in the Southern Tier region of the state over a 24-year period (*14*). The first strategy under consideration consisted of preventive maintenance treatments applied at appropriate times during the life of the pavement. The second strategy was to do no preventive maintenance during the life of the pavement and completely reconstruct the pavement after 24 years. On the basis of a life-cycle analysis, the first alternative was found to be 3.65 times more cost-effective than the second. This conclusion was based on the observational experience of maintenance engineers that the preventive maintenance treatments would reduce the rate of pavement deterioration and extend its service life.

Table 4 summarizes the results of the simulation of several pavement management strategies conducted by the Wisconsin Transportation Information Center at the University of Wisconsin-Madison. This study was conducted for a small city with a 68-mile roadway network and demonstrates the benefits of a preventive maintenance strategy. The pavement condition rating is on a scale of 1 to 10, with 10 equal to new pavement and 1 equal to failed pavement. The network initially had $2.4 million of work backlogged and a condition rating of 5.88. The table summarizes the costs, expenditures, and pavement condition after 5 years. Further details of this simulation are contained in Appendix F. (Personal communication with Dr. Donald M. Walker, Director, Wisconsin Transportation Information Center.)

The above simulation demonstrates that the most beneficial strategy, which also results in the highest pavement condition rating, is to perform preventive maintenance on those pavements when and where preventive maintenance treatments are appropriate and then to resurface and reconstruct those pavements where the condition has deteriorated below the point where preventive maintenance is effective. The least beneficial strategy is to allow a pavement to deteriorate until it needs to be resurfaced or reconstructed.

Table 5 summarizes the results of applying alternative pavement strategies to a 1,000-mile network. The pavement is rated in five condition levels: Very Good, Good, Fair, Mediocre, and Poor and the analysis compares the number of lane

TABLE 4

EXAMPLE OF BENEFITS OF PREVENTIVE MAINTENANCE ON A SMALL CITY NETWORK AFTER 5 YEARS

Pavement Management Strategy	Expenditure (Mil $)	Cost of Work Backlogged (Mil $)	Pavement Condition Rating
Do-Nothing	0	$5.1	3.98
Preventive Maintenance Only	$0.5	$3.6	5.58
Preventive Maintenance first then Resurface & Reconstruction	$2.7	0	7.18
Do-Everything	$2.7	0	7.07
Worst-First	$3.5	0	7.03
Resurface & Reconstruction, no Preventive Maintenance	$3.5	$0.3	6.45

TABLE 5

EXAMPLE COMPARISON OF THE EFFECT OF ALTERNATIVE STRATEGIES ON NETWORK CONDITION AFTER 5 YEARS

	Lane Miles				
		Year 5 Network End Condition			
				Preventive Maintenance Annual Funding Level	
Pavement Condition	Year 0	Do-Nothing	Worst-First $8 Million Annually	$8 Million	$6.4 Million
Very Good	200	66	334	352	294
Good	280	48	124	146	132
Fair	370	100	140	175	170
Mediocre	100	68	80	101	100
Poor	50	717	321	225	303

miles in each condition level after 5 years with a do-nothing strategy, a worst-first strategy funded at $8.0 million annually, and two preventive maintenance strategies, one funded at $8.0 million annually and one at $6.4 million annually. The process used to perform the analysis is discussed in Chapter 4 and the details of the analysis are described in Appendix G. This example also demonstrates the cost-effectiveness of preventive maintenance. The network condition after 5 years is approximately the same for the worst-first strategy funded at $8 million annually and the preventive maintenance strategy funded at $6.4 million annually for an annual savings of $1.6 million or 20 percent.

Relationship to Pavement Management Systems

Preventive maintenance strategies are an essential element of an operational PMS and rely on other components of the PMS to provide information on which to base the preventive maintenance strategies and feedback on the performance of the preventive maintenance treatments and the cost-effectiveness of the strategies. Figure 1, an abbreviated flow diagram that illustrates the relationship between preventive maintenance strategies and some of the other activities in the pavement management process, is described in the following steps. A more detailed description of a PMS and the pavement management process is provided by AASHTO, NCHRP, and Haas and Hudson in their respective publications (*3,15,16*).

Step 1. Based on information provided by the DOT's PMS database, the agency identifies the increase in the service life of pavements resulting from preventive maintenance, develops and adopts one or more preventive maintenance strategies for each type of pavement. If the DOT does not have a database of pavement performance information, the preventive maintenance strategies can be developed using the observational experience of its engineering staff and the experience reported by neighboring agencies.

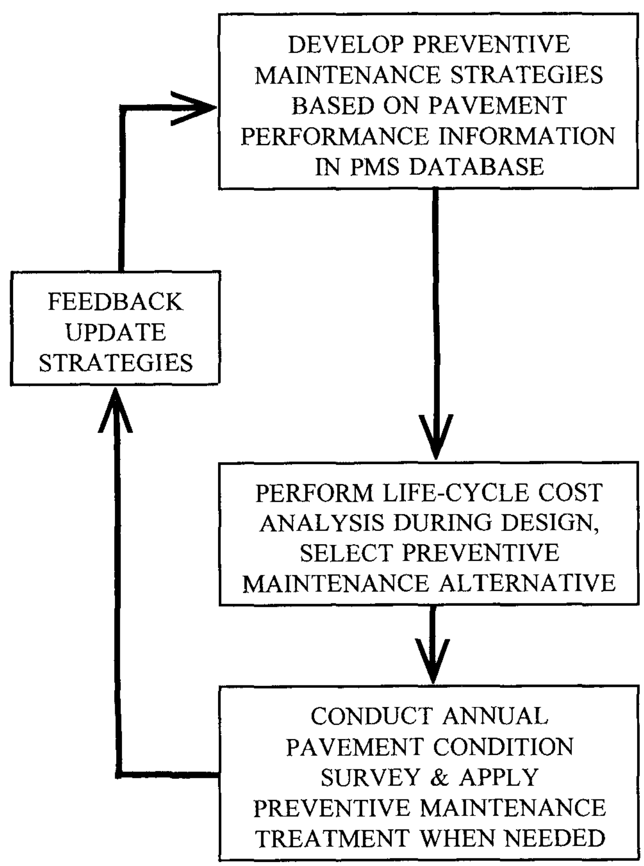

FIGURE 1 Relationship between preventive maintenance strategies and the pavement management process.

Step 2. The agency's designers use the preventive maintenance strategies and the projected increases in pavement service life as some of the alternatives considered when performing the least life-cycle cost analysis. A preventive maintenance strategy is normally the alternative that minimizes life-cycle cost. When the pavement is constructed, the agency earmarks monies in its future program to fund the preventive maintenance needs as they occur.

Step 3. Annually the agency conducts a pavement condition survey to update the PMS database. The pavement's actual condition is used to make the decision to apply a preventive treatment in a given year. If the pavement's condition, in a year in which a preventive maintenance treatment is planned, is better than anticipated, the treatment is postponed until needed. Likewise, if the condition of the pavement on a section of highway requires a preventive maintenance treatment prior to its planned application, the treatment should be performed in the year when it is needed.

Step 4. The new pavement condition information is used to update the pavement service life and/or modify the preventive maintenance strategy initially established in Step 1.

Availability of Funding

The anticipated cost-effectiveness obtained by using a preventive maintenance strategy that minimizes life-cycle cost when selecting a pavement or rehabilitation design, presupposes that the strategy is implemented. If preventive maintenance is not performed when needed, none of the cost-effectiveness is realized and the pavement prematurely reaches an unsatisfactory pavement condition sooner than its designed service life.

Of the 60 DOTs that returned the survey questionnaire, 26 (43 percent) indicated that they assumed a preventive maintenance strategy in selecting a least life-cycle cost pavement design. Eleven of the 26 (18 percent of the responders), earmark future monies to fund the strategy. However, most of these agencies indicated that the funding for preventive maintenance is inadequate and that there is no transfer of capital funds to the maintenance program to fund the strategy, although a preventive maintenance strategy that minimizes life-cycle costs generally reduces the initial capital cost.

CHAPTER THREE

PERFORMANCE OF PREVENTIVE MAINTENANCE TREATMENTS

INTRODUCTION

This chapter reviews the existing literature and the current practice and experience of the agencies responding to the Survey Questionnaire pertaining to the performance of specific preventive maintenance *techniques* with a focus on preventive maintenance treatments. Preventive maintenance *strategies* for pavements will be discussed in Chapter 4.

The specific performance of a preventive maintenance treatment is not directly transferable from agency to agency and may not even be transferable from one geographic region in a state to another because of the following factors (*17*):

1. The condition of the pavement at the time of treatment application;
2. The traffic conditions and, specifically, the number of heavy trucks;
3. The type of pavement base and subbase materials;
4. Surface and subsurface drainage conditions;
5. Shoulder conditions;
6. Moisture and temperature conditions;
7. Type of preventive maintenance materials used and the quality of the workmanship in applying them; and
8. The weather conditions, (i.e., temperature and moisture) and the time of the year when the treatment is applied.

However, it is reasonable to expect that if a specific treatment performs well in one location it will perform equally well, in comparison to other treatments, in another location with similar conditions if applied in a proper and timely manner.

Therefore, the summary of published information presented in Table 6, and the summaries of the results of the survey in Tables 8, 9, and 10 can serve as indicators of the performance that an agency can expect from a specific treatment. That information, along with the agency's estimate of the cost of materials, labor, and equipment to apply the treatment, can provide a preliminary indication of the cost-effectiveness of the treatment.

PUBLISHED INFORMATION

Table 6 summarizes the published information on the performance of specific preventive maintenance treatments.

CURRENT PRACTICES AND EXPERIENCE WITH THE USES OF PREVENTIVE MAINTENANCE TECHNIQUES

One of the purposes of the Survey Questionnaire was to obtain information on the preventive maintenance technique used by each agency for each type of pavement and to indicate the performance of those treatments.

Preventive Maintenance Treatments Used

The response to the question on the uses of various preventive maintenance treatments for the three types of pavements is summarized in Table 7. Appendix D provides a detailed listing of each agency's response in Table D-1, for PCC pavements, Table D-2 for AC pavements, and Table D-3 for overlaid pavements. In addition to the treatments listed in Table 7, the agencies identified additional treatments they use in the process of maintaining their pavements. These other treatments are identified as footnotes to the appropriate tables in Appendix D. In addition to the agencies counted in the summary above, Illinois DOT uses some of the above treatments in its Program of Maintenance for Mechanistically Designed Pavements.

Performance of Preventive Maintenance Treatments

The agencies were asked to complete the Pavement Preventive Maintenance Category Worksheet, shown in Appendix B, for each preventive maintenance treatment used. The worksheet asked the agency to provide the following information for each treatment:

- Age of pavement at the time of first application,
- Frequency of application, if done cyclically,
- Cost of treatment, per lane mile,
- Observed increase in pavement life obtained from the use of this treatment, and
- The source(s) of the information.

Tables 8, 9, and 10 provide a summary of the performance of preventive maintenance treatments for portland cement concrete pavements, asphalt concrete pavements, and overlaid pavements respectively. For each treatment, the table identifies the number of agencies (state, province and local) that provided a worksheet reporting on the performance and cost of the preventive maintenance treatment, the source table in Appendix D that provides a detailed listing of each agency's response, the minimum, maximum, and modal (most common or frequently occurring) values reported for pavement age at the time of first application of the treatment, the frequency if done cyclically, and the observed increase in pavement life from the use of the treatment. The cost per lane mile of applying the treatment was not summarized because of the extremely wide variations among the agencies. The variations in costs are most likely a reflection of who does the work, (i.e.,

TABLE 6

SUMMARY OF PUBLISHED INFORMATION ON THE PERFORMANCE OF PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS

Agency	Treatment	Service Life	Source and Reference
Oregon DOT	Chip Seal	Range 3-6 yrs; Median 4 yrs	Parker (*18*)
Indiana DOH		For good road conditions	Feighan, Sharaf, White & Sinha (*19*)
	Chip Seal	Range 38-55 mos Avg 48 mos	
	AC Crack Seal	Range 21-32 mos Avg 26 mos	
Ontario MTC	AC Rout & Seal	2-5 yrs	Joseph (*20*)
U.S. Corps of Engineers	Slurry Seal	3-6 yrs	Brown (*21*)
	Surface Treatment	3-6 yrs	
	Crack Seal	3-5 yrs	
NY State DOT	PCC Joint & Crack Filling	2 yrs	Pavement Rehabilitation Manual (*22*)
	PCC Joint & Crack Seal	8 yrs	
	AC Rout & Crack Seal	5 yrs	
	AC Crack Filling	2 yrs	
	Thin overlay	8 yrs	
	Surface Treatments	Median 3 yrs	Hahn (*23*)
NCHRP	Chip Seal	1-6 yrs	Shuler (*7*)
	Slurry Seal	1-6 yrs	
	Micro-surfacing	4-6 yrs	
	Thin overlay	>6 yrs	
FHWA	Micro-surfacing	5-7 yrs	Raza (*24*)
	Slurry Seal	3-5 yrs	Overview (*25*)
	Micro-surfacing	4-5 yrs	
	Chip Seal	4-7 yrs	
	Thin Overlay	8-11 yrs	
SHRP	All	Treatments haven't been in place long enough to determine effectiveness	Smith, Freeman & Pendleton (*17*)

agency forces or contractors), different methods used by the agencies in performing the work, scope of the work, (i.e., what is included), specification requirements, number of lanes, and traffic conditions, as well as the condition of the pavement at the time of application. Not all of the agencies that indicated using a specific preventive maintenance treatment provided a worksheet. Therefore, the number of agencies shown as responding in Tables 8, 9, and 10 is less than the number of agencies listed as using the treatment in Table 7.

Table 11 summarizes the sources of the performance and cost information the agencies provided for preventive maintenance treatments. By far the most frequently cited source of the information is the observational experience of the agency's maintenance, material, or pavement engineers. The second most frequently cited source is the agency's pavement management system, which was followed by the agency's maintenance management system. The least frequently cited source is research projects conducted by the agency to determine the

TABLE 7

SUMMARY OF THE TYPES OF PREVENTIVE MAINTENANCE TREATMENTS USED BY AGENCIES

Type of Pavement	Treatment	Number of Agencies Using: State/ Prov	Local	Total
Portland Cement Concrete	Joint Spall Repair	31	1	32
	Joint Sealer Replacement	35	2	37
	Other	15	2	17
Asphalt Concrete	Fill Cracks	45	9	54
	Single Application Chip Seal	38	5	43
	Multiple Application Chip Seal	18	2	20
	Slurry Seal	12	5	17
	Micro-Surfacing	24	2	26
	Thin Hot-Mix Overlay	34	2	36
	Other	13	4	17
Overlaid (AC/PCC)	Fill Saw and Sealed Joints	18	3	21
	Fill Cracks	39	8	47
	Single Application Chip Seal	22	4	26
	Multiple Application Chip Seal	11	2	13
	Slurry Seal	7	2	9
	Micro-surfacing	15	1	16
	Thin Hot-Mix Overlay	27	3	30
	Other	13	3	16

TABLE 8

SUMMARY OF THE PERFORMANCE OF PREVENTIVE MAINTENANCE TREATMENTS FOR PORTLAND CEMENT CONCRETE PAVEMENTS

Treatment, Number of Agencies Reporting and Table in Appendix D		Pav't Age at the time of first application (yrs)	Frequency of Application (yrs)	Observed increase in pavement life (yrs)
Joint Spall Repair (26) D-4	Min	2-4	2-4	2-4
	Mode	9-10	5-6	5-6
	Max	>20	10+	15
Joint Sealer Replacement (27) D-5	Min	2-4	2-4	2-4
	Mode	9-10	7-8	5-6
	Max	>20	12-15	9-10

TABLE 9

SUMMARY OF THE PERFORMANCE OF PREVENTIVE MAINTENANCE TREATMENTS FOR ASPHALT CONCRETE PAVEMENTS

Treatment, Number of Agencies Reporting and Table in Appendix D		Pav't Age at the time of first application (yrs)	Frequency of Application (yrs)	Observed increase in pavement life (yrs)
Crack Filling (45) D-6	Min	<2	<2	<2
	Mode	5-6	2-4	2-4
	Max	10-20	9-10	9-10
Single Application Chip Seal (36) D-7	Min	<2	2-4	2-4
	Mode	7-8	5-6	5-6
	Max	15-20	9-10	7-8
Multiple Application Chip Seal (14) D-8	Min	5-6	2-4	2-4
	Mode	7-8	5-6	5-6
	Max	15-20	9-10	9-10
Slurry Seal (13) D-9	Min	4-5	2-4	2-4
	Mode	5-6,7-8,9-10	5-6	5-6
	Max	9-10	7-8	7-8
Micro-Surfacing (16) D-10	Min	5-6	5-6	2-4
	Mode	9-10	5-6	5-6
	Max	10-15	9-10	7-8
Thin HMA Overlay (29) D-11	Min	5-6	2-4	>2
	Mode	9-10	9-10	7-8
	Max	15+	11-12	9-10

TABLE 10

SUMMARY OF THE PERFORMANCE OF PREVENTIVE MAINTENANCE TREATMENTS FOR OVERLAID PAVEMENTS (AC/PCC)

Treatment, Number of Agencies Reporting and Table in Appendix D		Pav't Age at the time of first application (yrs)	Frequency of Application (yrs)	Observed increase in pavement life (yrs)
Fill Saw & Sealed Joints (14) D-12	Min	<2	2-4	2-4
	Mode	5-6	2-4	2-4
	Max	9-10	9-10	9-10
Crack Filling (38) D-13	Min	<2	<2	<2
	Mode	2-4	2-4	2-4
	Max	10+	9-10	9-10
Single Application Chip Seal (19) D-14	Min	2-4	2-4	2-4
	Mode	7-8	5-6	5-6
	Max	15-20	7-10+	7-8
Multiple Application Chip Seal (7) D-15	Min	5-6	2-4	2-4
	Mode	7-8	5-6	5-6
	Max	15-20	5-6	5-6
Slurry Seal (6) D-16	Min	4-5	2-4	2-4
	Mode	5-6	5-6	5-6
	Max	9-10	9-10	9-10
Micro-Surfacing (11) D-17	Min	5-6	5-6	2-4
	Mode	9-10	5-6	5-6
	Max	10-15	7-8	7-8
Thin HMA Overlay (21) D-18	Min	5-6	2-4	2-4
	Mode	9-10	9-10	2-4
	Max	12-13	10-11	9-10

TABLE 11

SUMMARY OF THE SOURCES OF INFORMATION REPORTED BY AGENCIES FOR EACH PREVENTIVE MAINTENANCE TREATMENT

Type of Pavement	Treatment	Number of Agencies Citing as the Source*			
		PMS	MMS	RP	OE
Portland Cement Concrete	Joint Spall Repair	6	5	1	24
	Joint Sealer Replacement	6	3	1	27
Asphalt Concrete	Fill Cracks	15	8	3	39
	Single Application Chip Seal	11	7	3	31
	Multiple Application Chip Seal	3	3	0	13
	Slurry Seal	3	2	0	10
	Micro-Surfacing	3	0	3	13
	Thin Hot-Mix Overlay	8	4	0	26
Overlaid (AC/PCC)	Fill Saw and Seal Joints	6	3	1	14
	Fill Cracks	13	9	1	34
	Single Application Chip Seal	6	6	1	15
	Multiple Application Chip Seal	3	3	0	6
	Slurry Seal	1	1	0	6
	Micro-surfacing	2	1	3	9
	Thin Hot-Mix Overlay	9	7	0	21

* PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project conducted to determine the benefits of preventive maintenance, OE=Estimate based on the observational experience of maintenance, material, or pavement engineers.

cost-effectiveness of preventive maintenance treatments. This indicated the need for more formal evaluations of the cost-effectiveness of pavement preventive maintenance treatments. The sources cited by each agency for each specific treatment are listed in Tables D-4 through D-18 in Appendix D.

RELATED STUDIES

Asphalt Surface Treatments and Thin Overlays

An essential element in implementing cost-effective preventive maintenance for pavements is knowledge of the performance of preventive maintenance treatments, where they are applicable, the cost to apply, and other factors. As previously discussed, one agency's experience is not directly transferable to another agency. However, knowledge of another agency's experience is invaluable in developing one's catalog of preventive maintenance treatments. Not only does it serve as a guide of what can be expected in terms of performance, it also provides lessons learned and mistakes to be avoided. Tables 6, 8, 9, and 10 were prepared with that objective. Another source is NCHRP Synthesis Topic 24–10, Asphalt Surface Treatments and Thin Overlays (*7*), which consolidates the known information on the following preventive maintenance treatments: three spray-on materials: chip, fog, and sand seals; four mixed-in-place materials: slurry and cape seals, micro-surfacing, and thin road mix; and four plant-mixed materials: thin asphalt cement overlay, thin asphalt emulsion overlay, open-graded friction course, and stone mastic asphalt. The draft for Topic 24–10 describes the design procedures, construction methods, and engineering details for each treatment, includes the results of a survey of current practices of 65 state, province, and local agencies, and summarizes performance and cost information for the 11 treatments.

Application

Two SHRP publications, SHRP Asphalt Pavement Repair Manuals of Practice (*26*) and SHRP Concrete Pavement Repair Manuals of Practice (*27*) are the most recent and complete publications on these subjects. The manuals have been prepared to guide pavement maintenance engineers, maintenance field supervisors, crew personnel, maintenance contractors and inspectors in the process of performing asphalt and concrete pavement repairs. The scope of the manuals includes determining the need for the treatment, planning and designing the treatment, construction, implementation, and finally, evaluating and assessing the performance of the treatment.

The FHWA publication on the State of the Practice of Micro-Surfacing is the most recent and complete synthesis of this surface rehabilitation technique (*24*).

CHAPTER FOUR

COST-EFFECTIVENESS OF PREVENTIVE MAINTENANCE STRATEGIES

INTRODUCTION

This chapter reviews the existing literature and the current practice and experience of the agencies responding to the survey questionnaire pertaining to the cost-effectiveness of preventive maintenance strategies for pavements. This includes a review of the methods used to determine cost-effectiveness, published reports on the cost-effectiveness of preventive maintenance strategies, and the experience of the 60 agencies responding to the survey questionnaire.

METHODS OF QUANTIFYING COST-EFFECTIVENESS

Four methods used to quantify the cost-effectiveness of preventive maintenance are described in the literature. These are: (1) life-cycle costing, (2) cost-effectiveness analysis, (3) equivalent annual cost, and (4) longevity cost index.

Life-Cycle Costing

The life-cycle costing methodology is widely recognized and commonly used in pavement design and maintenance to compare the equivalent uniform annual cost (EUAC) of pavement sections with different service lives, initial costs, maintenance costs, and salvage values (*28*). The FHWA Pavement Policy (*2*) encourages DOTs to use life-cycle costing in selecting pavement sections and treatments.

Darter, Smith, and Shahin reported on the use of a basic life-cycle cost analysis procedure to determine the cost-effectiveness of maintenance and rehabilitation treatments for the Metropolitan Transportation Commission in Oakland, California (*29*). The process they used is summarized below:

1. Select interest and inflation rates,
2. Select an analysis period,
3. Select alternative maintenance strategies for the pavement section under consideration and estimate the unit costs,
4. Estimate the life of each treatment in each strategy,
5. Compute the EUAC per unit of pavement area, and
6. Compare the EUAC and select the strategy having the lowest life-cycle costs.

Sharaf, Shahin, and Sinha reported on the use of life-cycle costing to quantify the effects of deferring the maintenance and rehabilitation of pavements based on data obtained from five U.S. military installations (*13*). Mouaket, Al-Mansour, and Sinha used the life-cycle costing technique to evaluate the cost-effectiveness of chip and sand seal coatings for the Indiana DOT (*30,31*). Joseph used life-cycle costing as one of two methodologies to evaluate the cost-effectiveness of crack sealing in Ontario (*20*).

Life-cycle costing is also the methodology that has been proposed to evaluate the cost-effectiveness of the preventive maintenance treatments installed under SHRP Project H-101, Pavement Maintenance Effectiveness (*17*).

Because pavement condition is not considered in the life-cycle costing analysis, this methodology assumes that all the pavement options being compared provide the same level of service and that the preferred option is the one that minimizes life-cycle costs.

Cost-Effectiveness Analysis

The cost-effectiveness analysis approach considers both the benefits received by users and the cost to provide those benefits. When the benefits and costs can be quantified in monetary terms, a benefit-cost analysis can be made and a B/C ratio can be computed. However, the benefits to the users of a well-maintained pavement are numerous and difficult to quantify in monetary terms. These benefits include reduced accidents, reduced travel times, reduced tort liability, reduced vehicle operating and maintenance costs, reduced disruptions to adjacent businesses, increased motorist comfort, and reduced or deferred capital expenditures through the preservation of a capital asset (*1*). Therefore, a method involving the use of the pavement performance curve has been developed as a means of assessing and quantifying the nonmonetary benefits of well-maintained pavements.

Pavement Performance Curve

The performance of pavements can be characterized by a curve as illustrated in Figure 2. The ordinate is a performance index that provides a measure of the condition of the pavement. There are several scales currently in use to measure pavement condition. One is the Pavement Condition Index (PCI), which ranges from 0 to 100, with 100 representing a new pavement in excellent condition and 0 representing a completely deteriorated pavement that is impassable. Another is the Present Serviceability Index (PSI), which ranges from 0 to 5 with 5 being the highest level of serviceability. At least one DOT uses a scale ranging from 0 to 10, with 10 being an excellent pavement, 1 being very poor and 0 being impassable. Others use roughness as a measure of performance. The abscissa provides a measure of the life of the pavement since its construction or reconstruction, measured in years, traffic volumes, or equivalent single axle loads. For the purposes of determining the benefits to the users of a well-maintained pavement, the scales used are not critical, provided that the same scales are used for all the alternatives being compared. However, the scale used may affect the appearance and shape of the performance curve.

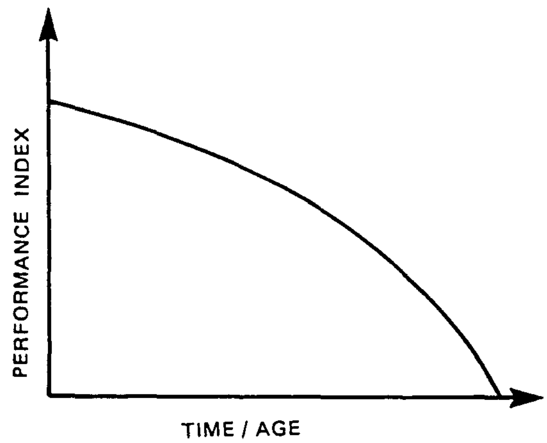

FIGURE 2 Generalized pavement performance curve *(32)*.

User Benefits

Kher and Cook reported on the method of assessing user benefits used by the Ontario Ministry of Transportation and Communication's Program Analysis of Rehabilitation System (PARS) (*32*). As a surrogate for user benefits, PARS uses the area under the pavement performance curve as illustrated in Figure 3. The rationale for the use of this approach is that good roads (i.e., a large area under the pavement performance curve) provide the user greater benefits than poor roads, which are characterized as having a smaller area under the pavement performance curve.

Smith, Shahin, Darter, and Carpenter reported on the use of this methodology to establish a constrained funding allocation procedure for the San Francisco Bay Area Metropolitan Transportation Commission (*33*). Shahin, Kohn, Lytton, and McFarland reported on the use of the area under the condition-time curve as a measure of performance in developing the budget optimization techniques for PAVER, the U.S. Army Corps of Engineers' pavement management system (*34*).

Joseph used the area under the performance curve combined with the average annual daily traffic (AADT) and the length of the pavement section as a means of comparing the cost-effectiveness of preventive maintenance strategies, some of which involved routing and sealing cracks in AC pavements (*20*).

The New York State Department of Transportation (NYSDOT) used the area under the pavement performance curve to compare the cost-effectiveness of alternative preventive maintenance strategies (*35*).

Determining the Pavement Performance Curve

The actual pavement performance curve for a section of pavement is determined by performing a regression analysis of the condition-time data. Sharaf, Shahin, and Sinha reported that the best model to represent the condition-time data at five U.S. Army military installations was in the following form (*13*):

$$C = 100 - bx^m$$

where:

C = pavement condition expressed in terms of PCI,
b = slope coefficient,
x = pavement age (months), and
m = a parameter, the value of which controls the degrees of curvature of the performance curve.

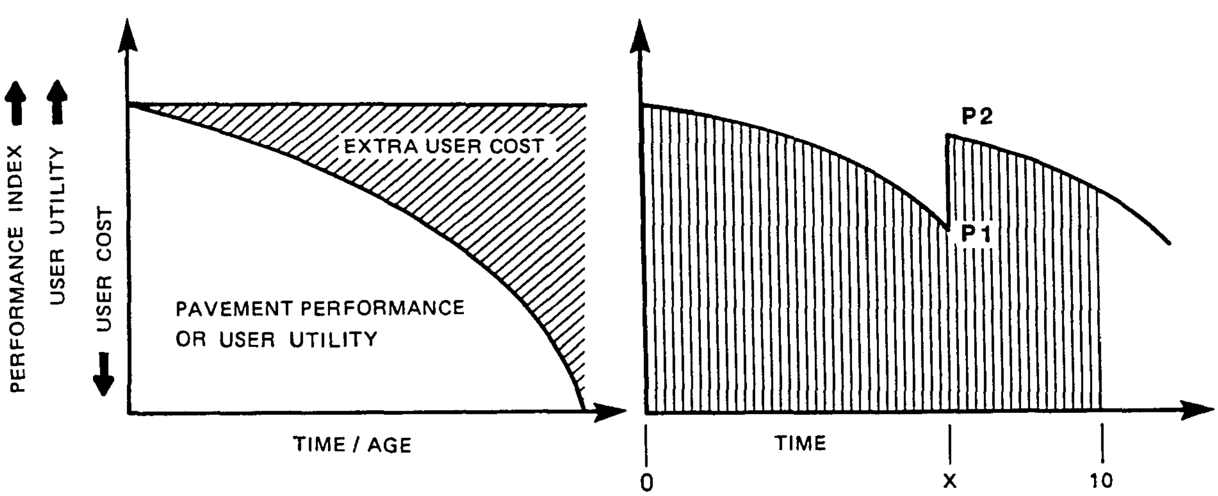

FIGURE 3 Pavement performance as a surrogate for user benefits with the area under the curve as a measure of that benefit *(32)*.

The NYSDOT found that the regression analysis for the condition-time data for full-depth AC pavements in the Southern Tier Region of the state also followed the same model (*35*).

Joseph reports that, based on data acquired over 12 years in Ontario, the performance curve is curvilinear (*20*). However, the computer program developed in Ontario to perform the life-cycle analysis assumes that the PCI varies linearly with time within the estimated service life because, "generally speaking this assumption is quite reasonable, particularly for evaluating different maintenance treatments, since the shape of the performance curve is not likely to affect the final outcome of the results." Al-Mansour and Sinha (*31*) reported that the best model to predict the PSI of pavements in Indiana to identify the optimal timing for the application of a chip or sand seal was a straight line following the form:

$$\mathrm{PSI} = a + b \bullet \mathrm{Age}$$

where

PSI = pavement serviceability index,
Age = pavement age (in years) since construction or last resurfacing, and
a, b = estimated regression parameters

The principal difference between the life-cycle cost approach and the cost-effectiveness approach is the use of the area under the pavement performance curve as a surrogate for user benefits. This technique requires that the pavement performance curve be known. Previous work indicates that the curve may be curvilinear or linear and can be estimated using regression analysis if the condition-time data are available. However, if the condition-time data are not available, a linear relationship between condition and time can reasonably be assumed. Therefore, this technique can be used to determine the cost-effectiveness of preventive maintenance treatments if the effect of the treatment on extending the service life is known.

Equivalent Annual Cost

Chong and Phang defined the equivalent annual cost as the average of the cost of preventive maintenance treatments over the years until another treatment or repair was required (*36*). The goal of their research in Ontario was to select the best treatment for each pavement condition. Usually this meant identifying the most cost-effective treatments. The costs used for the analysis were the unit costs to install a treatment as shown by the following equation:

$$\text{unit cost} = \frac{\text{cost of manpower} + \text{equipment} + \text{materials}}{\text{accomplishment per day.}}$$

To account for the difference in the effectiveness of the treatments, the unit cost of each treatment was divided by the life of each treatment as shown by the following:

$$\text{equivalent annual cost} = \frac{\text{unit cost}}{\text{expected life of treatment in year(s).}}$$

In Ontario, the treatment with the lowest equivalent annual cost was found to be the most cost-effective and was recommended for implementation unless an other factor prevailed. This methodology does not consider the performance of the pavement.

Longevity Cost Index

The Oregon Department of Transportation developed the Longevity Cost Index (LCI) to evaluate the cost-effectiveness of thin surface pavement treatments in different climatic regions (*18*). A large part of the study was an effort to define cost-effectiveness. The DOT found that the most useful information to the decision makers was:

- What is the typical life for each type of treatment?
- How much did it cost to construct and maintain the treatment throughout its life?
- What kinds of weather and traffic conditions was the treatment exposed to?

They considered three approaches to define cost-effectiveness that would provide the decision makers with the information they needed. These were:

1. Determine the service life of the treatment or the life-cycle cost established at failure.
2. Measure and report the change in the overall condition rating of the road.
3. Measure the change in each specific pavement distress.

The last two approaches were dropped from consideration for a number of reasons, including the lack of immediate post-construction data, the lack of control sections that would have permitted the effect of climate and original pavement condition to be factored out of the analysis, variations in the distress surveys caused by different evaluators, inability to precisely define failure, and the length of the time for the study.

Oregon DOT concluded by developing an index that relates the three main factors considered important in evaluating cost-effectiveness: (1) treatment unit cost, (2) traffic loading, and (3) life of the treatment. The LCI relates the present value of the cost of the treatment to the life of the treatment and the traffic loading as shown in the following equation:

$$\mathrm{LCI} = \frac{\mathrm{PRICE/sy} + \mathrm{MCOST/sy}}{\mathrm{LIFE} \times \text{Annual MEGASALs}}$$

where:

PRICE/sy = Initial unit price of the treatment
MCOST/sy = Present value of the unit maintenance cost during treatment life
LIFE = Average or median life of a treatment
MEGASAL = One million equivalent single axle loads.

Process

In addition to the four methods to evaluate the cost-effectiveness of preventive pavement maintenance, *NCHRP Report 285: Evaluating Alternative Maintenance Strategies,* describes a microcomputer-based program to make an economic analysis of agency costs for different pavement maintenance strategies (*37*). The process described is an integral part of a pavement management system.

PUBLISHED INFORMATION ON COST-EFFECTIVENESS OF PREVENTIVE MAINTENANCE TECHNIQUES

Crack Sealing

The Ontario Ministry of Transportation and Communication found that the rout and seal treatment of transverse cracks "can extend the serviceability of the pavement by at least 4 years" (*38*). Joseph (*20*) compared the three alternatives shown in Figure 4 using both the life-cycle cost and the cost-effectiveness analysis techniques. Each alternative consisted of a 50-mm hot-mix overlay or a combination of the 50-mm hot-mix overlay and routing and sealing cracks. A summary of his analyses is shown in Table 12.

The following computations for Alternative Strategy 2 shown on Figure 4 illustrate this process:

Area under the first curve for Strategy 2 = 410 PCI-Yr
Area under the second curve = 397.5 PCI-Yr
Area under the third curve = 202.5 PCI-Yr
Total area = 1010 PCI-Yr
Length of Pavement Section = 21 km
Average Traffic Volume = 1591
Effectiveness = (1010)(21)(1591) = $33{,}745.1 \times 10^3$.

The most cost-effective option is Alternative 3, which consists of two routing and sealing applications before a major rehabilitation is performed. Alternative 2, which consists of one routing and sealing application, is nearly as cost-effective. The research in Ontario indicates that the first rout and seal treatment must be performed between the third and fifth years of the pavement service life and the second treatment should be performed between the eighth and ninth years to achieve maximum cost-effectiveness (*39*). The life-cycle costs for Alternative 1, the do-nothing alternative, are approximately 50 percent more than the other two alternatives. Ontario's experience demonstrates the cost-effectiveness of its preventive maintenance strategies. Furthermore, the same conclusions are obtained from either the life-cycle cost or the cost-effectiveness analysis methodologies.

A study conducted for the Indiana DOH shows that when more crack sealing was done in the fall, less patching was required after the winter (*40*). This resulted in a reduction in fuel consumption by the maintenance equipment fleet. The study concluded that there was a definite trade-off between the amount of sealing (preventive maintenance) done in the fall and the amount of patching (demand maintenance) required after the winter. This resulted in a direct cost savings, attributable to the reduction in fuel consumption by maintenance equipment performing demand maintenance activities (patching). Although it wasn't mentioned in the report, it follows that there was also a reduction in the cost of labor hours spent on the road patching and in the cost of patching materials. Finally, there was an increase in the comfort and convenience to the users because of the better pavement condition during and after the winter.

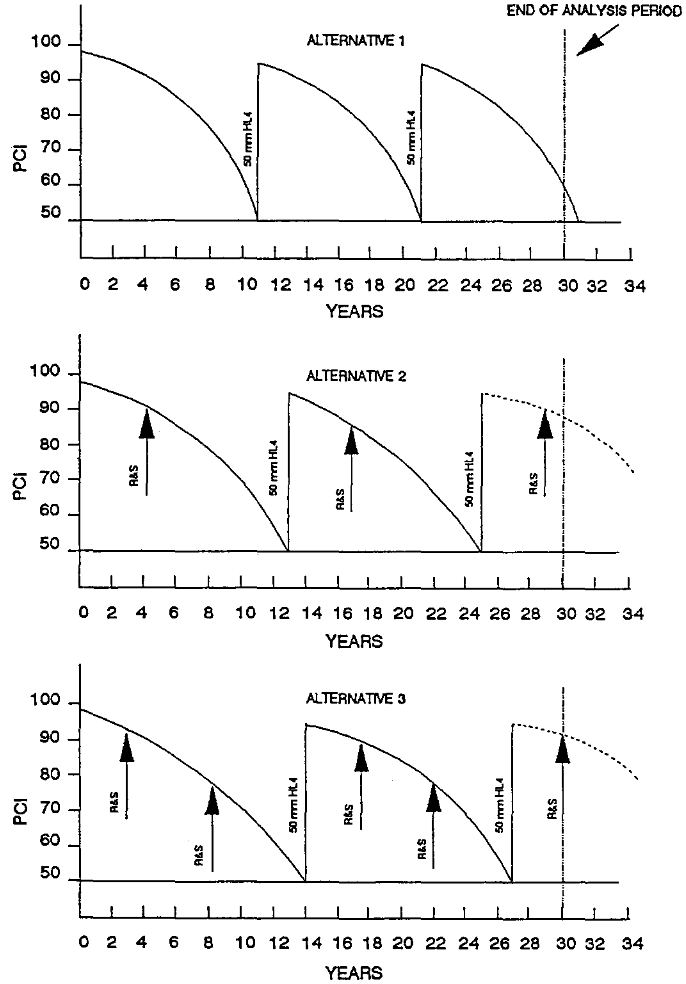

FIGURE 4 Performance histories of three alternative strategies in Ontario (*20*).

Crack Sealing and Thin Overlay

The NYSDOT compared two maintenance strategies for managing a mile of newly constructed flexible pavement in the Southern Tier region of the state over a 24-year period (*14*). The first alternative consisted of filling cracks in years 4, 8, 16, and 20 and applying a 38-mm (1½ in.) HMA thin overlay in years 12 and 24. The second alternative was to do no preventive maintenance and a complete reconstruction in year 24. As shown in Table 13, the present worth life-cycle cost of Alternative 1 is 37.6 percent of Alternative 2. On the basis of a

TABLE 12

SUMMARY OF THE COST-EFFECTIVENESS OF ROUTING AND SEALING IN ONTARIO *(20)*

Description	Alternative Strategies 1	2	3
Life-Cycle Costs ($1000)	855.26	623.95	584.23
Effectiveness* (1000)	31281	33745	32742
Cost-Effectiveness Factor	36.57	54.08	56.04
Cost-Effectiveness Ratio	1	1.48	1.53

*Effectiveness = A x AADT x PL
where
A = area under the performance curve in PCI-Years
AADT = average traffic volume between year zero and the end of the analysis period
PL = length of pavement section.

TABLE 13

SUMMARY OF THE COST-EFFECTIVENESS OF PAVEMENT PREVENTIVE MAINTENANCE IN NEW YORK STATE *(14)*

Description	Alternative Strategies: Preventive Maintenance	Do-Nothing
Life-Cycle Cost	$144,036	$382,590
Life-Cycle Cost Ratio	0.376	1.0
Effectiveness (Condition Yrs)	176.0	128.0
Cost-Effectiveness Factor	1.22	0.335
Cost-Effectiveness Ratio	3.65	1.0

cost-effectiveness analysis, Alternative 1 is 3.65 times more cost-effective than Alternative 2.

The NYSDOT also determined the effectiveness of filling cracks in a 38-mm (1½ in.) HMA overlay over a 24-year period. Several of the Department's maintenance engineers indicated that they had observed an approximate 4-year increase in pavement service life when the cracks were filled on a 4-year cycle, extending the service life of the overlay from about 8 years to about 12 years. Over a 24-year period, the present worth life-cycle cost with crack sealing was $94,116, compared to a life-cycle cost without crack sealing of $161,868, for a savings of $67,752 or 42 percent.

Retrofit Load Transfer

Based on the experience in Puerto Rico, FHWA expects that 10–15 years of additional service life can be obtained from a PCC pavement by the installation of retrofit load transfer devices *(41)*. The cost of these devices installed in Washington state is $34.40 per device, or approximately $72,650 per lane mile. In June 1994, the installed cost in a Kansas DOT contract was $22.00 per device. (Personal communication with Roger M. Larson, FHWA.) At these prices, FHWA indicates that retrofit load transfer devices appear to be a cost-effective preventive maintenance technique for reestablishing the load transfer in PCC pavements.

Sealing PCC Joints

The observational experience of most pavement and maintenance engineers indicates that sealing the joints or cracks in PCC pavements is beneficial because it reduces the amount of water that can enter the pavement structure through the joint or crack. Water that enters the pavement base and subbase causes pumping, faulting, and loss of support. There are published articles and reports that recommend sealing joints and cracks to increase pavement life *(42,43,44)*. A survey of transportation agencies conducted by the NCHRP found that 35 of the 39 agencies responding to the questionnaire resealed joints in PCC pavements and 33 out of the 39 resealed cracks in PCC pavements *(45)*. A recent synthesis on the design, construction, and maintenance of PCC pavement joints reports that, "Perhaps the two most cost-effective preventive maintenance activities are cleaning and other maintenance of drainage features and resealing of joints" *(46)*. There is not however, complete agreement on the need to seal all PCC pavement joints. A research project, ongoing since the 1950s in Wisconsin *(47,48)* reports that "the pavement with unsealed joints performed better than the pavement with sealed joints" and "contraction joint sealing costs cannot be justified." The Wisconsin conditions consisted of a permeable base, short joint spacing, and dowel joints, which may account for this finding. Ray indicates that in California, the joints are sealed only in mountain areas where there is greater than average precipitation *(44)*.

In conclusion, the preponderance of the published reports and the observational experience of practicing pavement and maintenance engineers strongly supports the sealing and resealing of joints and cracks in PCC pavements. There is information however, that suggests that in certain specific conditions or climates, sealing joints may not be cost-effective. The findings from the SHRP pavement performance studies should provide more insight on the cost-effectiveness of this practice.

CURRENT PRACTICES AND EXPERIENCE WITH THE USE OF PREVENTIVE MAINTENANCE STRATEGIES

Uses of Preventive Maintenance Strategies

The agencies were asked in the questionnaire if they had a pavement preventive maintenance strategy and if they did, what uses were being made of the strategy. They were also asked if their strategies varied by highway functional class and by traffic volumes. Of the 60 agencies responding to the questionnaire, 31 agencies (52 percent) indicated that they did have a pavement preventive maintenance strategy. The uses of the strategies and the variations by functional class and traffic volumes are summarized in Table 14. A listing of each agency's response is contained in Table D-19 in Appendix D.

In summary, 52 percent of the agencies responding have a preventive maintenance strategy and of those, approximately 50 percent use it to select the least cost life-cycle pavement design, approximately 60 percent use it to prepare the agency's maintenance budget and schedule maintenance work, and approximately 40 percent use it to order materials. Approximately 60 percent of the strategies vary by functional class or traffic volumes.

TABLE 14

USES OF PREVENTIVE MAINTENANCE STRATEGIES AND VARIATIONS BY FUNCTIONAL CLASS AND TRAFFIC VOLUME

Use or Variation	Number of Agencies	Percent of Agencies With Strategies
Select pavement section or treatment during the design process that provides the least life-cycle cost	17	55
Prepare the maintenance organization's budget	20	65
Order materials	12	39
Schedule work by agency forces or maintenance contract	21	68
Vary by functional class	19	61
Vary by traffic volume	22	71

Reasons For Not Using Preventive Maintenance Strategies

The agencies were also asked to identify the reasons why their agency did not have or was not fully using pavement preventive maintenance strategies. Thirty-five of the 60 agencies (58 percent) responded to this question. Of these, 24 agencies had indicated in a previous question that they did not have a strategy and 11 agencies had previously indicated that they had and used a preventive maintenance strategy. Table 15 summarizes the reasons given by the 24 agencies that don't have a strategy. Table 16 is a summary of the reasons given by the 11 agencies that use a strategy only partially or not at all. A listing of each agency's response to this question is in Table D-20 in Appendix D.

A comparison of Tables 15 and 16 shows some interesting results. Approximately 20 percent of the agencies without a preventive maintenance strategy indicate that the cost-effectiveness of pavement preventive maintenance strategies has not been adequately demonstrated or that the funding agencies have not accepted the demonstrated cost-effectiveness of pavement preventive maintenance as the reason for their not having a preventive maintenance strategy. This is approximately the same percentage as the agencies that have a preventive maintenance strategy that is not fully utilized. Likewise, approximately 50 percent of both groups cite the lack of adequate funding as the reason for not having or fully using a preventive maintenance strategy.

Planning and Funding Pavement Preventive Maintenance

The benefits gained from using a preventive maintenance strategy that minimizes life-cycle cost when selecting a new or rehabilitation pavement design presupposes that the strategy is implemented. The agencies were asked if they assumed a preventive maintenance strategy during design to minimize life-cycle cost and, if they did, to indicate (a) if their agency earmarked monies in future years to fund the preventive maintenance strategy, (b) if the funding for their preventive maintenance program was adequate, and (c) if their agency transferred funds from capital to maintenance to adequately fund the preventive maintenance program. Of the 60 agencies who returned the questionnaire, 26 indicated that they assumed a preventive maintenance strategy in selecting a least life-cycle cost pavement design and 34 indicated that they did not. Table 17 provides a summary of the responses to the funding of preventive maintenance by the 26 agencies who indicated that they assumed preventive maintenance in selecting the pavement design. Eleven of the 26 agencies who assume a preventive maintenance strategy in pavement design earmark future monies to fund the strategy. However, most of the agencies indicated that the funding for preventive maintenance is inadequate and that there is no transfer of capital funds to the maintenance program to fund the strategy, even though a preventive maintenance strategy that minimizes life-cycle costs generally reduces the initial capital cost. A listing of each agency's response is in Table D-21 in Appendix D.

The agencies were not asked to indicate in the questionnaire if they used Federal-aid funds to fund pavement preventive maintenance. However, the question was raised in a group discussion at the Seventh AASHTO/TRB Maintenance Management Conference held from July 18 to 21, 1994 in Orlando, Florida. Approximately 45 state DOTs were represented at the conference and, by a show of hands, only 10 state DOTs use Federal-aid funds to fund preventive maintenance for pavements. The following reasons were provided by the state DOTs for not using Federal-aid funding for preventive maintenance:

- The amount of Federal-aid available to the state is inadequate to fund the reconstruction and rehabilitation program and preventive maintenance. The state has elected to use the Federal-aid funds for the reconstruction and rehabilitation program.
- Preventive maintenance can be done much more economically with state funds because the required federal contracting provisions (e.g., prevailing wages, MBE/WBE requirements) increases the cost of doing the work with federal funds.
- A significantly larger amount of preventive maintenance work can be done with state funds because of the federal requirements to bring the highway up to current design standards (e.g., flatten embankment slopes, install new guardrail,

TABLE 15

REASONS GIVEN FOR NOT HAVING A PAVEMENT PREVENTIVE MAINTENANCE STRATEGY*

Reason Given	Number of Agencies	Percent of Agencies w/o Strategy Responding
Cost-effectiveness of pavement preventive maintenance strategies has not been adequately demonstrated	5	21
Agencies providing funding have not accepted the demonstrated cost-effectiveness of pavement preventive maintenance	5	21
All agencies agree with the benefits but there just isn't enough money to fund the strategies	11	46
Pavement management system under development will include preventive maintenance strategies	7	29

* 24 Agencies

TABLE 16

REASONS GIVEN FOR NOT FULLY USING A PAVEMENT PREVENTIVE MAINTENANCE STRATEGY*

Reason Given	Number of Agencies	Percent of Agencies not fully using Strategies
Cost-effectiveness of pavement preventive maintenance strategies has not been adequately demonstrated	2	18
Agencies providing funding have not accepted the demonstrated cost-effectiveness of pavement preventive maintenance	2	18
All agencies agree with the benefits but there just isn't enough money to fund the strategies	5	45
Preventive maintenance is not considered in least life-cycle cost analysis during design	2	18
Preventive maintenance strategy is assumed during design but maintenance funding is not adequate to perform all that is assumed	1	9

* 11 Agencies

raise the profile in sags and lower the profile in crest vertical curves to improve sight distance) when Federal-aid is used for preventive maintenance activities.

The Chief Maintenance Engineer from Washington state DOT indicated that the legislature had revised the law to require that Washington DOT consider least life-cycle costing. In preparing his biennial budget for 1995 to 1997, he requested an additional $5 million so that the worst pavements could be held together until the benefits of preventive maintenance catch up with the needs (Personal communication with David Bowers, Washington State DOT).

In its FY 93-94 budget request, the New York State DOT proposed a comprehensive preventive maintenance program for pavements and bridges to its legislature and requested an additional $140 million ($52 million for bridges and $88 million for pavements) in addition to its previous annual appropriation of $80 million, which would have resulted in a

TABLE 17

FUNDING PREVENTIVE PAVEMENT MAINTENANCE

Of the 26 Agencies Who Assume Preventive Maintenance Strategy in Design	Number		
	Yes	No	No Reply
Identifies or earmarks monies in future years to fund the preventive maintenance treatments identified in the strategy	11	14	1
Appropriated adequate monies to fund preventive maintenance	3	21	2
Transfers funds from capital to maintenance to adequately fund the preventive maintenance program	2	23	1

proposed total program of $220 million (*14*). The legislature approved the program but provided only an additional $83 million for preventive maintenance for a total program of $163 million, which was less than requested but was a doubling of the funding compared to prior years. In FY 94-95, the legislature approved an additional $108 million to fund the enhanced preventive maintenance program at a total level of $191 million. In approving the additional funding, however, the legislature also required the DOT to submit a Five-Year Preventive Maintenance Plan to the governor and legislature every year. The plan is required to describe the current condition of pavements and bridges, establish goals for the conditions for each for the next 5 years, describe the preventive maintenance activities and the level of funding needed to achieve the goals, and demonstrate the cost-effectiveness of the preventive maintenance activities. (Personal communication with K. Shiatte, NYSDOT).

Cost-Effectiveness of Preventive Maintenance Strategies

The agencies were asked to describe the preventive maintenance strategies they used for each type of pavement and to report on the cost-effectiveness of the strategy as measured by the:

- Increase in the time to rehabilitation,
- Decrease in the amount of time spent on pavement demand maintenance activities,
- Decrease in the cost of pavement demand maintenance activities, and
- Increase in pavement serviceability.

They were also asked to identify the source(s) of the above information.

Table 18 is a summary of the cost-effectiveness information provided. For each type of pavement, the table indicates the number of preventive maintenance strategies provided, and the minimum, modal (most common or frequently occurring), and maximum values of the time to pavement rehabilitation without the strategy, the increased time to rehabilitation with the strategy, the reduction in the amount of time spent on pavement demand maintenance activities, the reduction in the cost of pavement demand maintenance activities, and the improvement in pavement serviceability. Tables D-22a through D-24d, in Appendix D show the above information for each strategy and the schedule of treatments for each strategy for PCC pavements, AC pavements, and overlaid pavements, respectively.

The agencies were also asked to identify the sources of the cost-effectiveness information for each strategy; they are summarized in Table 19. The most frequently cited source of the information provided is the observational experience of the agency's maintenance, material, or pavement engineers. The second most frequently cited source is the agency's Pavement Management System, which was followed by the agency's Maintenance Management System. The least frequently cited source is research projects conducted by the agency to determine the cost-effectiveness of preventive maintenance strategies. The sources cited by each agency for each specific strategy are listed on Tables D-22a through D-24d in Appendix D.

In addition to the strategies detailed in the questionnaire, some states provided additional information on the strategies they were using.

The Illinois DOT has detailed maintenance and rehabilitation schedules for mechanistically designed pavements. Tables 5.02a through 5.02d from Illinois' mechanistic pavement design procedures are shown in Appendix E. These tables describe the amount and schedule for each maintenance and rehabilitation activity for full-depth AC pavements.

The British Columbia Ministry of Transportation and Highways indicated that they "do not use a standard strategy because environmental, topographic, and subgrade variations are so extreme that the maintenance is done in response to distress appearance."

The Ontario Ministry of Transportation provided the table in Figure E-5, which describes the maintenance treatment, year of treatment, design life, and scheme (type) of pavement for a freeway facility.

The New York State DOT does not have a single departmentwide preventive maintenance strategy that is applied to each project. Rather, the department's policy is to require designers to evaluate alternative strategies as part of the least life-cycle cost analysis for each project and to select the appropriate strategy. The department's *Pavement Rehabilitation Manual* (*22*) provides detailed guidelines to assist designers in the selection of the appropriate preventive maintenance treatments for the life-cycle cost analysis procedures. An example of the treatment guidelines from the Manual for a thin HMA overlay is shown in Figures E-6 and E-7 of Appendix E. Figure E-8 is an example of a timeline with the appropriate treatments from the New York State DOT's manual.

TREATMENT SELECTION AND TIMING

The timing of the application of a preventive maintenance treatment is critical to achieving the cost-effectiveness benefits of the treatment. If performed too early, there is no increase

TABLE 18

SUMMARY OF THE COST-EFFECTIVENESS OF PAVEMENT PREVENTIVE MANTENANCE STRATEGIES

		Portland Cement Concrete Pavement	Asphalt Concrete Pavement	Overlaid Pavement
Number of Strategies		20	27	18
Time to rehabilitation w/o the strategy (yrs)	Min	<10	2-3	<10
	Mode	13-15	10-12	10-12
	Max	>25	16-20	21-25
Increase in the time to rehabilitation with the strategy (yrs)	Min	3-4	2-3	3-4
	Mode	9-10	5-6	5-6
	Max	>10	>10	12-14
Reduction in the amount of time spent on pavement demand maintenance activities (%)	Min	5-10	5-10	5-10
	Mode	5-10, 20-25	5-10	16-20
	Max	75	75	>75
Reduction in the cost of pavement demand maintenance activities (%)	Min	5-10	<5	5-10
	Mode	5-10, 20-25	5-10	16-20, >25
	Max	75	75	>75
Improvement in pavement serviceability (%)	Min	5-10	5-10	5-10
	Mode	5-10	16-20	>25
	Max	>25	>25	>25

in performance to offset the cost of performing the preventive maintenance technique. If performed too late, the pavement is too deteriorated to benefit from the treatment. One state maintenance engineer described the timing of preventive maintenance as being similar to surfing: "You have to catch the wave at the right time to have a good ride, you have to apply the preventive maintenance treatment at the right time to get any benefits." There is no formula to determine the "right" time to apply a preventive maintenance technique.

In Ontario, "the tasks of predicting the expected rate of pavement deterioration and recommending pavement preservation strategies for action plans are assigned to experienced regional staff. These individuals are in constant contact with the portion of the highway network over which they have responsibility and can fully exercise their engineering judgement and knowledge of local conditions" (*49*).

Many DOTs follow the practice in Ontario and leave the selection of the timing for the application of preventive maintenance treatments up to experienced field personnel. The Utah DOT prepared guidelines for use by its field personnel in establishing priorities for asphalt pavement maintenance (*50*). The department also developed a process to determine the action needed to correct an identified pavement deficiency that can be corrected as a maintenance activity (*51*). The FHWA's Denver Region (Region 8), in conjunction with the state DOTs in that region, prepared a pavement and shoulder maintenance guide (*52*). The guide provides the following information for seven maintenance activities:

- Type of distress
- Probable cause(s)
- Criteria or warrant(s)
- Materials used
- Frequency
- Expected life
- Production rates
- Cost per unit
- Procedures.

TABLE 19

SUMMARY OF SOURCES OF COST-EFFECTIVENESS INFORMATION REPORTED BY AGENCIES FOR EACH PREVENTIVE MAINTENANCE STRATEGY

		Number of Agencies Citing as the Source*			
	Type of Pavement	PMS	MMS	RP	OE
Increase in the time to rehabilitation with the strategy (yrs)	PCC	8	0	0	14
	AC	13	2	3	18
	AC/PCC	8	2	1	13
Reduction in the amount of time spent on pavement demand maintenance activities (%)	PCC	1	5	0	14
	AC	3	6	0	21
	AC/PCC	2	5	0	14
Reduction in the cost of pavement demand maintenance activities (%)	PCC	1	5	0	15
	AC	2	6	1	21
	AC/PCC	2	6	1	16
Improvement in pavement serviceability (%)	PCC	8	3	1	17
	AC	10	4	2	17
	AC/PCC	8	2	0	14

* PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project conducted to determine the benefits of preventive maintenance, OE=Estimate based on the observational experience of maintenance, material, or pavement engineers.

The seven maintenance activities were:

- Crack sealing of AC pavements
- Crack and joint sealing of PCC pavements
- Shoulder maintenance-AC shoulders with AC pavements
- Shoulder maintenance-AC shoulders with PCC pavements and PCC shoulders with PCC pavements
- Seal coating of AC pavements
- Repair of concrete joints and spalled areas
- Bridge approach settlement correction.

Others have developed decision trees or treatment selection matrices as part of their PMS to assist pavement and maintenance engineers in identifying the need for preventive pavement treatments based on the pavement condition surveys (*3*). New York State DOT has combined both approaches. Based on the network pavement condition survey, a treatment selection matrix identifies potential candidate pavement sections for preventive maintenance, corrective maintenance, and various levels of rehabilitation. This information is provided to the resident engineers who serve as the department's first-line pavement managers and are responsible for the department's highway maintenance operations in a county-size geographic area. Their intimate knowledge of the highway systems under their jurisdiction is invaluable in developing and recommending an integrated and coordinated program of pavement projects, consisting of preventive maintenance, corrective maintenance, and capital rehabilitation (*35*).

SHRP sponsored research to develop an instrument for monitoring pavement deterioration that can be repaired by maintenance techniques (*53*). Considerable field testing was planned to define the accuracy needed by the equipment, but the efforts have not yet produced an operational instrument. NCHRP recently completed a Synthesis of Highway Practice to identify the current practices in determining pavement condition (*54*). From the perspective of preventive maintenance, the most important finding was that the variation in the type and amount of data collected for pavement distress was the greatest of all the data collected. The Synthesis recommended that the degree of standardization being developed in the measurement of pavement roughness and friction also be achieved for the evaluation of distresses to facilitate the exchange of information between agencies on the performance and evaluation of pavements.

Some agencies are already working toward that end. For example, the Connecticut DOT has developed an operational laser video disk photolog technology that enables an operator with a personal computer to retrieve a particular highway photo image and lay precisely located grid lines over the photolog image. At this time, the retrieval and viewing sequence of photolog images is preprogrammed, but the actual distress evaluation is left to technicians familiar with pavements.

Regardless of the means used to select the "right" treatment at the "right" time, there is considerable information on the cost-effectiveness of performing preventive maintenance treatments at the proper time compared to waiting until the pavement needs to be rehabilitated.

An early report from the SHRP Project H-101, *Making Pavement Maintenance More Effective* (*55*), confirms the appropriateness of the universal application of the above findings.

> The initial data coming in from test sections covering the continent suggest that it will be more cost-effective to apply preventive maintenance treatments throughout the life of the pavement rather than allow the pavement to deteriorate until major rehabilitation is needed.
>
> Initial data from the test sections through the end of the initial research suggest that if modest-cost surface treatments are applied at the right time in the decay cycle, the PSI (pavement serviceability index) can be extended out over a much longer time. . . Thus, applying modest-cost surface treatments at the right time can delay the need for future major rehabilitation. This will save money in the paving budget. It may also save in the high cost of longer traffic delays and increased accidents that major reconstruction work zones often produce.
>
> The initial data from observing the test sections started in SHRP H-101 also suggest that the pavement life will be extended longer if a particular maintenance treatment is applied before significant deterioration has set in, rather than waiting until the pavement has deteriorated badly.

POLICY APPLICATIONS

Reported Experience

There are studies and reported findings that indicate that the worst-first strategy practiced by many highway agencies is not cost-effective. France began a nationwide program of preventive maintenance in 1972 as a way of maintaining the capital investment value of her 28 000 km network (*56*). Officials considered the following four strategies:

Strategy 1. Allow deterioration of the pavement to continue and repair failures as they occur.
Strategy 2. Resurface with approximately 10 cm (1/2 inch) of asphalt every 5 years.
Strategy 3. Reconstruction followed by preventive maintenance.
Strategy 4. Reconstruction followed by demand maintenance.

Based on their detailed comparative studies, they selected Strategy 3 as the preferred and most cost-effective strategy. Although this strategy requires a large initial expenditure, it protects the investment and meets the needs of the users.

It was reported that in Kansas, a strategy was implemented that treated the pavements in need of preventive maintenance first before funding the reconstruction of poorer pavements (*12*) and that after the first 4 years, quantities of aggregate and asphalt for both surface repairs and resurfacing decreased progressively.

Darter, Smith, and Shahin reported that in their analysis of the pavements in the San Francisco Bay area, the preventive maintenance treatments applied to pavements in good condition were the most cost-effective strategy (*29*). For pavements in poorer condition, the most cost-effective strategy was to bring the pavement up to a good condition and then to apply preventive maintenance treatments to retain that condition. This is the same conclusion arrived at by the simulation conducted by the Wisconsin Transportation Information Center, which is described in Appendix F and summarized in Table 4.

Process to Compare Pavement Strategies

A PMS provides the database, analytical tools, and the process to evaluate the effect of alternative pavement management strategies, including preventive maintenance, on an agency's highway network. To determine the effects of a preventive maintenance strategy on the network, the effect of preventive maintenance on each segment is determined and then the end results on each segment are totaled to obtain the impact on the network, the agency's budget, select segments for maintenance, resurfacing, reconstruction, etc.

Unfortunately, not all agencies have an operational PMS. For those agencies that do not, a process that can be used to assess the impact of alternative pavement management strategies on a highway network and does not require detailed knowledge of each segment of the network is described with an example in Appendix G. This process was adapted from a presentation made by Ray Gerke at the Seventh AASHTO/TRB Maintenance Management Conference held in Orlando, Florida from July 18 to 21, 1994 (*57*). By sampling a small portion of the network, an agency can construct a network pavement performance curve and compare the performance of alternative pavement management strategies on the network at a level that is adequate for many of the decisions made by executive management and budgetary agencies. The comparison of the effect of alternative strategies on the network condition after 5 years summarized in Table 5 was made using this process. This process does not replace a PMS and should only be used in the absence of an operational PMS. This process contains several assumptions and limitations, which are:

- The present pavement condition of the network can be characterized by a network pavement performance curve and a simple matrix,
- The performance of the network with no work being done can be approximated as the average of the performance of the individual segments,
- The effect of a pavement management strategy on the network can be approximated by the effect of the strategy on an individual segment, and
- Results cannot be used to select individual segments of the network for specific treatments, to plan work, order materials, etc.

RELATED STUDIES

The decision-making process that results in cost-effective preventive maintenance for pavements depends on reliable and timely information on the condition and performance characteristics of the pavement, the type and volume of traffic, the performance of treatments, the cost to apply the treatments, and the analytical processes in the PMS. The necessary information is usually a product of a DOT's pavement management system, maintenance management system, and cost accounting system.

Integration of Management Systems

NCHRP Report 363: The Role of Highway Maintenance in Integrated Management Systems (*9*) provides a Maintenance Management Information System (MMIS) concept that facilitates obtaining all the required information from other management systems in the DOT. The concept allows the following types of analyses to be made:

- Tradeoffs between preventive maintenance, corrective maintenance, and capital projects,
- Tradeoffs between deferred maintenance and the levels of service provided,
- Life-cycle cost analyses, and
- Optimal resource allocations.

NCHRP Report 363 provides five alternative system architectures for use by DOTs in integrating their current systems or developing new systems. The following brief description provides an indication of the types of information covered in the report. There are many factors to be considered by an agency when it selects a system architecture, including how the agency elects to manage its management information systems, the type of computer platform it has or will acquire, the organizational location of decision making (centralized versus decentralized), the communication network, and the geographic distribution of operations. The report discusses how each of the architectures address these factors. The five alternative system architectures presented are:

- Centralized Mainframe. In this architecture, all MMIS software and data reside on a single statewide mainframe, and all users dial in to the mainframe to use the MMIS.
- Centralized District Minicomputer. In this architecture, the software and data for the MMIS reside on a minicomputer in the district where some of the processing is done. Each minicomputer is connected to a mainframe computer in the central office to provide for the transmittal of data and information in both directions.
- Centralized Client-Server. A central database resides on a central computer whose only role is to serve as the collector and distributor of data and to be the database manager. Analytical software is contained in and reporting is done through remote client workstations, which are personal computers.
- Decentralized Client-Server. This scheme is similar to the centralized client-server model except that each remote workstation is also a server for other remote workstations or the central database.
- Distributed Database. In this system there is no central database. Portions of the database reside in each workstation personal computer and each is both a client and a server.

Selecting Preventive Maintenance Treatments

Once the required information is available, it is necessary to have a process or methodology to analyze the information. *NCHRP Synthesis of Highway Practice 222: Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments* (*8*), provides DOTs with a description of the three methodologies currently in use to select projects and their associated treatments for pavement preservation and the advantages and disadvantages of each. These are: Pavement Condition Analysis, Priority Assessment Models, and Network Optimization Models. For each, the report discusses:

- Benefits,
- Requirements,
- Applicability,
- Practical and theoretical constraints, and
- Barriers to implementation.

Budgeting

Richard Braun, former Commissioner of the Minnesota DOT and former President of AASHTO, stated at a pavement management conference that there are two keys to achieving and then maintaining an adequate transportation system (*58*). They are: (1) having solid, factual, believable information to support a request for funding, and (2) communicating the information effectively.

The previous references all dealt with the first point. *NCHRP Report 366: Guidelines for Effective Maintenance-Budgeting Strategies*, deals with the second point (*10*). The project, which reports on the findings of a survey of state transportation, budgeting, and legislative officials, provides numerous conclusions including:

- Effective maintenance-budgeting process requires consistent, comprehensive, but flexible strategies.
- The strategy must establish and maintain internal and external maintenance-budgeting credibility, and foster internal and external cooperation.
- The budget strategy should be based on an understanding of what has worked well in the past.
- The strategy must deal with change, develop means for overcoming threats, and respond to improvement opportunities.
- An effective strategy has to include extensive and proactive communications outside of the normal budget submission process.

The report also provides 23 guidelines and a detailed discussion of each. The guidelines cover the budgeting process, the key actors in the process, the information needs for an effective budget, and methods to clearly present and communicate the information.

TABLE 20

SUMMARY OF RESPONSES ON FURTHER WORK NEEDED

Further Work Needed	Number of Agencies	Percent of Agencies Responding
Research to demonstrate the cost-effectiveness of preventive maintenance	27	61
Presentations and literature to convince funding agencies of the benefits of preventive maintenance	28	64

FURTHER WORK NEEDED

The DOTs were asked to indicate if additional research was needed to demonstrate the cost-effectiveness of pavement preventive maintenance and if presentations and literature were needed to convince the funding agencies of the benefits of preventive maintenance. Table 20 is a summary of the responses of the 44 agencies who answered this question.

In addition to the two areas shown in Table 20 that needed further work, the agencies also identified the following considerations:

- Management systems need to be developed as soon as possible to provide data for preventive maintenance strategies.
- Work is needed to outline the preventive maintenance process, including performance curves and life-cycle cost analysis procedures.
- Pavement cost and performance information is needed.
- Research, presentations, and literature aimed at increasing public awareness of the benefits of pavement preventive maintenance.

A listing indicating each agency's response to this question is shown in Table D-25 in Appendix D.

CHAPTER FIVE

CONCLUSIONS

The following conclusions can be drawn from a review of the literature and from state, province and local DOT responses to the questionnaire regarding cost-effective preventive maintenance of pavements.

The survey responses, which are supported by numerous reports in the literature, demonstrate the cost-effectiveness of preventive maintenance strategies. The most significant findings are:

- Several literature sources indicate that one dollar invested in preventive maintenance at the appropriate time in the life of a pavement may save $3 to $4 in future rehabilitation costs.
- From the literature and a few computer simulations of preventive maintenance strategies, the most cost-effective pavement management strategy is to perform preventive maintenance activities on the better-rated pavements first and then fund the rehabilitation of the poorer-rated pavements. The worst-first funding strategy is the least cost-effective.
- Based on the observational experience of agencies using a preventive maintenance strategy, the most common reported increase in the time to rehabilitate a pavement is 9 to 10 years for PCC pavement, and 5 to 6 years for AC and overlaid pavements.
- The most commonly reported decrease in the amount of time and money spent on pavement demand maintenance activities, based on observational experience of agencies using preventive maintenance strategy is 5 to 10 percent for PCC and AC pavements, and 16 to 20 percent for overlaid pavements.
- There is a need to conduct and publish the results of formal research on the cost-effectiveness of pavement preventive maintenance techniques. The majority of existing information regarding the cost-effectiveness of such techniques now resides within agencies and is related from observational experience.

All of the agencies that completed the survey questionnaire use one or more preventive maintenance techniques and these agencies report significant increases in pavement life (Tables 8, 9, and 10) from the use of these treatments.

Approximately one-half (31) of the agencies responding to the survey have preventive maintenance strategies for pavements and of those, 26 assume a preventive maintenance strategy to select the least life-cycle cost pavement design. Eleven agencies identify or earmark monies in future years to fund the preventive maintenance treatments in the strategy. Three agencies indicated that adequate funding was appropriated for preventive maintenance and two agencies transfer monies from capital to maintenance to fund preventive maintenance. The reason most frequently given by those agencies without a preventive maintenance strategy is lack of funding. This is also the reason given by agencies with a preventive maintenance strategy that is not fully implemented.

The development, implementation, and institutionalization of pavement management systems by the DOTs is a long process. The initial introduction of PMS at the national level dates from the late 1970s and early 1980s. Yet, nearly 15 years later, most DOTs continue to rely on the experience of their engineers, rather than their PMS, to determine the performance of their preventive maintenance treatments and strategies. The largest and most frequently cited sources of performance information for treatments and strategies are estimates based on the observational experience of the agencies' maintenance, material, and pavement engineers. Analytical tools (i.e., life-cycle costing, cost-effectiveness analysis, equivalent annual cost) are available to determine the cost-effectiveness of preventive maintenance treatments and strategies. These tools can be used without the pavement performance curves, provided that the increase in pavement service life can be determined or reasonably estimated. Therefore, even though PMS are not fully developed in all agencies, the observational experience and tools exist that allow a DOT to analyze alternative pavement management strategies and take advantage of the cost-effectiveness of preventive maintenance.

More effort is needed to inform decision makers of the benefits and cost-effectiveness of preventive maintenance for pavements and nearly one-half of the agencies responding to the survey suggested that additional research is needed to demonstrate the benefits. The national SHRP Project H-101 studies are continuing at this time. The results of these efforts should be analyzed before additional national research efforts are initiated in this area. There was adequate information to demonstrate the benefits of preventive maintenance in at least two states. The state legislatures in New York and Washington require that the DOTs use life-cycle costing or preventive maintenance and, in New York, the legislature provided additional funds for preventive maintenance.

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APPENDIX A

Primer on Preventive Maintenance for Pavements

This appendix describes terms commonly encountered when discussing preventive maintenance of pavements. This includes the different types of pavements, the causes of the most commonly occurring problems for each type of pavement, and the categories of pavement maintenance and preventive maintenance treatments generally used.

The objective of this appendix is to serve as a primer that can be used by DOT administrative, engineering, operations, and maintenance personnel in briefing administrative, budget, finance, and legislative personnel on the benefits of preventive maintenance for pavements. It is not intended to be a complete or authoritative discussion of pavement design, rehabilitation, reconstruction, construction, maintenance, or management. There are many excellent references that cover each of those areas in considerable depth (*1-14*, e.g.). Rather, it covers basic information and terminology that is part of the daily vernacular of practicing highway, pavement, and maintenance engineers. Furthermore, the scope of the primer is limited to a discussion of those pavement activities generally considered to be preventive and generally performed by either in-house or contract maintenance forces. Pavement activities or treatments that are corrective, (e.g., grinding PCC pavements to improve the rideability) or done as part of a rehabilitation project, (e.g., crack and seat of PCC pavements to reduce or eliminate reflective cracking) are not covered in this primer.

TYPES OF PAVEMENTS AND SHOULDERS

There are four types of roadway surfaces: (1) flexible, (2) rigid, (3) composite, and (4) gravel or unpaved. This report does not address the maintenance of gravel or unpaved roads. The subsequent discussion is limited to the three types of paved surfaces.

Flexible Pavement

A flexible pavement is a roadway structure consisting of subbase, base, and surface courses over a prepared roadbed. The surface course generally consists of one or more layers of asphalt cement concrete (AC). The materials used for the base and subbase depend on several factors, including the amount, mix, and weight of heavy trucks, the drainage conditions, the repetition of freeze-thaw cycles, the local availability of durable crushed stone, gravel, or other granular materials, and the native roadbed soils. Materials commonly used for the base and subbase include AC, for the higher type pavements (i.e., Interstates and expressways), crushed stone, crushed or natural gravel, and locally available materials treated with an asphalt emulsion, asphalt cement, lime, calcium chloride, or portland cement to give it strength and stability. Figure A-1 shows the cross section of a typical flexible pavement. The strength of a flexible pavement is obtained from the strength of the individual layers, with each layer stronger than the one below it. A flexible pavement distributes the wheel loads downward to the roadbed. Flexible pavements may be full-depth asphalt concrete, layered, as described above, or may simply consist of a surface treatment over a treated granular base. Flexible pavements are commonly known as asphalt pavements, asphalt concrete pavements (ACP), asphalt cement concrete pavements (ACCP) and bituminous concrete pavements (*13,14,15*).

Rigid Pavement

A rigid pavement consists of a portland cement concrete (PCC) slab and may have a base or subbase over a prepared roadbed. The base or subbase may be a crushed stone or gravel, locally available natural granular materials, may be

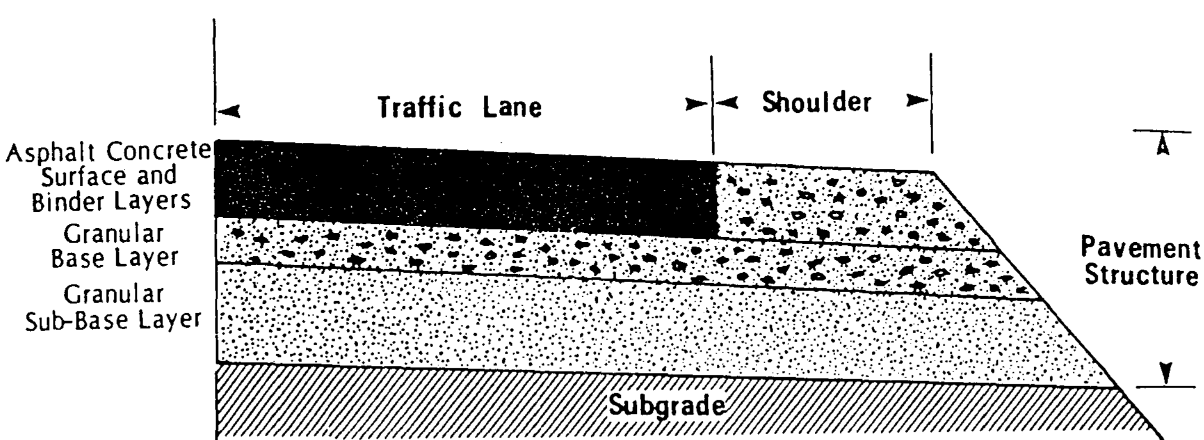


FIGURE A-1 Typical flexible pavement cross section (*8*).

treated as discussed in the section on flexible pavements, or the concrete slab may be placed directly on the native soil. Figure A-2 shows a cross section of a typical rigid pavement. A rigid pavement distributes the wheel loads over a wide area through the strength and bending action of the PCC slab.

There are two basic types of rigid pavements: (1) jointed concrete pavement (JCP), and (2) continuous reinforced concrete pavements (CRCP). The primary differences between the two are the joint spacing and the amount of reinforcing steel.

Jointed concrete pavements have expansion and contraction joints perpendicular to the direction of traffic to allow for the expansion and contraction of the slab with changes in temperature and moisture. A dowel bar or other type of load transfer device may be provided to carry the wheel load from one slab to the next. The opening for the joint is provided either by the form work before the slab is poured or saw cut after the PCC slab has cured. A flexible sealer is then placed in the joint opening. The sealer material can either be preformed neoprene of the proper width; an extruded material, such as silicone; or a poured material, such as hot liquid asphalt.

The slab contracts to its shortest length in the winter with the coldest temperatures and expands to its longest length with the hot summer temperatures. Generally, the joint spacing for JCP ranges from approximately 4 to 35 m (12 to 113 ft) however, hardly anyone uses the longer spacings anymore. The changes in length of the longer slabs caused by changes in temperature may be 250 mm (1 in.) or more. Joints are provided in CRCP only at bridges or to facilitate construction. Additional reinforcing steel is provided in CRCP to resist the stresses caused by changes in temperature and moisture (*13-15*). For those interested in a more in-depth discussion of rigid pavements, the two synthesis reports by McGhee provide detailed information on current practices (*12,16*).

Composite Pavement

A composite pavement usually is an asphalt concrete overlay of a portland cement concrete pavement. This includes both pavements where the initial design and construction provided for an AC overlay of a PCC pavement and where the AC overlay was subsequently added during the rehabilitation of an old PCC pavement.

Shoulders

Shoulders are defined by AASHTO as "the portion of the roadway contiguous with the travelled way for accommodation of stopped vehicles for emergency use, and for lateral support of base and subbase courses"(*13*). Shoulders can be paved or unpaved. Unpaved shoulders are normally constructed using gravel or sod. Most paved shoulders, with the exception of some Interstates and expressways, consist of asphalt concrete or an asphalt-treated granular material over a granular base and subbase. Furthermore, on many facilities constructed prior to the mid 1970s, the shoulder layers are not as thick as the adjacent pavement. Some, but not all, of the Interstates and expressways with rigid pavements have a PCC shoulder. Presently, AASHTO and FHWA suggest, for high-volume roadways, that paved shoulders be constructed of the same material as the adjacent pavement (*13,17*).

CATEGORIES OF MAINTENANCE ACTIVITIES

There is no nationally recognized glossary of maintenance terms and activities. Local and regional usages vary. An activity that one maintenance engineer may call routine maintenance may be referred to as corrective maintenance by another. The finance and budget laws of each state may affect the terminology. An activity that is considered a preventive treatment in one state because it is funded from the maintenance budget may be considered a corrective treatment in an other state because it is funded from the capital budget. There are also variations in terminology based on whether the work is done by in-house forces or contractor forces.

One way to categorize maintenance activities is by the urgency needed to accomplish the work. The two common

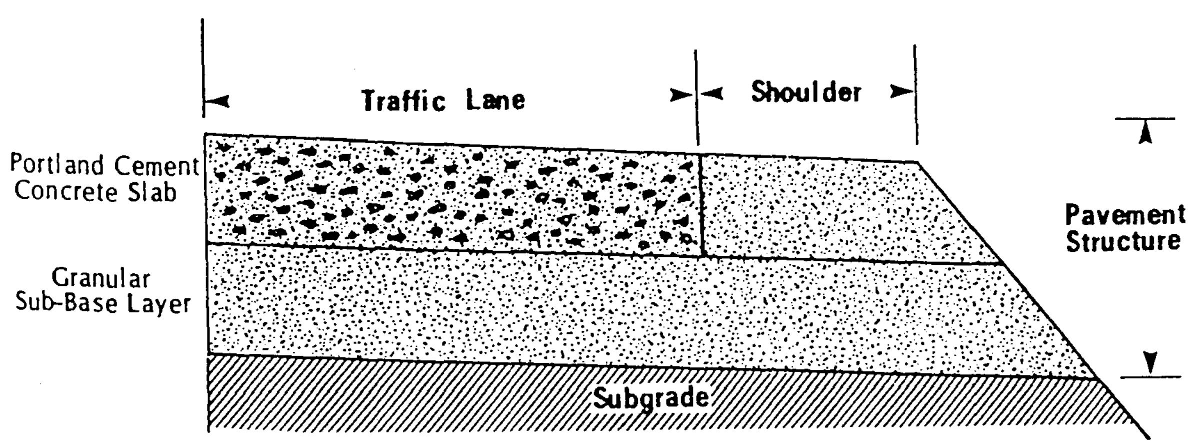


FIGURE A-2 Typical rigid pavement cross section (*8*).

categories of tasks based on urgency are demand maintenance and routine maintenance. A second method of categorizing maintenance activities is based on the effect of the activity. In this method, work is either preventive or corrective. There are differences of opinion among the practitioner and agencies in both methods. The service life of a pavement also requires continuing work involving preventive maintenance, corrective maintenance, minor rehabilitation, major rehabilitation, and reconstruction. There is no clear demarcation between preventive and corrective maintenance and some activities can be in both. Likewise, between corrective maintenance and minor rehabilitation.

Routine Maintenance

These are day-to-day maintenance activities that are scheduled or whose timing is within the control of maintenance personnel. Examples of routine maintenance include mowing and cleaning roadsides, cleaning ditches, sealing cracks in the pavement, paving, painting pavement markings, and pruning trees.

Demand Maintenance

Demand maintenance activities are those that must be done in response to events beyond the control of the DOTs' maintenance organization. Some of the events require a response by maintenance personnel as soon as possible to avoid serious consequences because a present or imminent danger exists. Demand maintenance activities, by definition, cannot be scheduled because they occur without warning and often must be immediately addressed. Frequently, demand maintenance activities are performed all hours of the day or night and on an overtime basis. Examples of demand maintenance activities include snow plowing, pothole patching, removing and patching pavement blowups, unplugging drainage facilities, replacing a regulatory sign knocked down by traffic, assisting law enforcement officials at and cleaning up the scene of an accident, removing tree limbs and branches fallen on the pavement, and responding to a road closing because of flooding.

Corrective Maintenance

Corrective maintenance includes planned activities that are performed to repair deficiencies, to restore elements of the highway to its original condition, or to increase the service life of elements of the facility. The repairs can be either temporary or permanent. Corrective maintenance is performed after an element of the highway has deteriorated or failed (*7,18*). Examples of corrective maintenance activities include grooving or grinding a rigid pavement, permanent pavement repairs (patching or wedging to strengthen AC pavement or partial or full-depth patching of PCC), repairing a section of guardrail, replacing all the faded signs along a section of highway, and installing new and larger drainage culverts.

Preventive Maintenance

Preventive maintenance has been defined as "those planned activities undertaken in advance of critical need or of accumulated deterioration so as to avoid such occurrence and reduce or arrest the rate of future deterioration. These activities may correct minor defects as a 'secondary benefit'" (*19*). Another definition consistent with the first and perhaps more descriptive states that, preventive maintenance is "a program strategy intended to arrest light deterioration, retard progressive failures, and reduce the need for routine maintenance and service activities. Preventive maintenance is generally cyclical in nature. It is planned maintenance. Preventive maintenance activities do not significantly improve the load-carrying capacity of pavements but extend the useful life and improve the level of service" (*1*). Timing is crucial in preventive maintenance: it should be performed *before* a failure occurs (*7*). Examples of preventive maintenance activities include pavement joint and crack sealing, pavement surface treatments, thin overlays, and cleaning drainage ditches and culverts.

Summary

The principal differences between preventive maintenance and the other types of maintenance are illustrated in Table A-1. Preventive maintenance is planned, it is performed before deterioration or failure has occurred, and it extends the useful performance or service life of the facility.

NATURE AND CAUSES OF COMMON PAVEMENT PROBLEMS

There are numerous causes and types of pavement problems. A 1970 Highway Research Board report illustrated 24 flexible pavement and 20 rigid pavement deficiencies (*15*). Recently, SHRP described 15 flexible pavement, 16 jointed PCC pavement, and 15 CRCP distresses (*20*). The causes of some of these pavement deficiencies can only be prevented by changes in design or construction practices. However, others are within the scope of work that can be done by a maintenance operation. For example, alligator cracking is a common distress found in many AC pavements. Alligator cracking is generally caused by a deficiency in the structural strength of the pavement section that cannot be prevented by a simple maintenance treatment such as sealing cracks. A commonly used solution to address the cause of the alligator cracking is to add a structural overlay to the pavement. The causes and solutions for alligator cracking are not discussed in this primer. The following, therefore, is a description of the nature and causes of pavement problems that can be avoided, minimized, or retarded by preventive maintenance practices.

Flexible Pavement

Potholes

The most common flexible pavement problem that can be avoided or at least minimized by preventive maintenance is

TABLE A-1

PRINCIPAL DIFFERENCES IN TYPES OF MAINTENANCE ACTIVITIES

Type of Maintenance	Planned?	Performed Before Deterioration Has Occurred?	Extends The Useful Life Of The Facility?
Routine	YES	NOT NECESSARILY	SOMETIMES
Demand	NO	NO	NOT NECESSARILY
Preventive	YES	YES	YES
Corrective	GENERALLY	NO	YES

the pothole. Figure A-3 illustrates a deep pothole in an asphalt concrete pavement. Typically, water seeps into the subbase either through cracks in the surface or from standing water along the side of the pavement. If the water is not properly drained from the subbase, it softens the subbase materials and reduces its strength. The repetitious pounding of the wheel loads from traffic, especially those of heavy trucks, fatigues the asphalt concrete surface, thus increasing the size and number of cracks, which allows more water to enter the subbase and further weaken the surface layer. Eventually, the surface layer caves in and breaks into pieces. At that point, every pass of a wheel enlarges the hole by ejecting water, chunks of asphalt concrete, base, and subbase material. In northern climates, this process is accelerated in the spring by the daily cycle of freezing at night and thawing during the day. The expansion caused by freezing raises the surface layer while the thawing further softens the base and subbase *(21)*. This process is illustrated in Figure A-4.

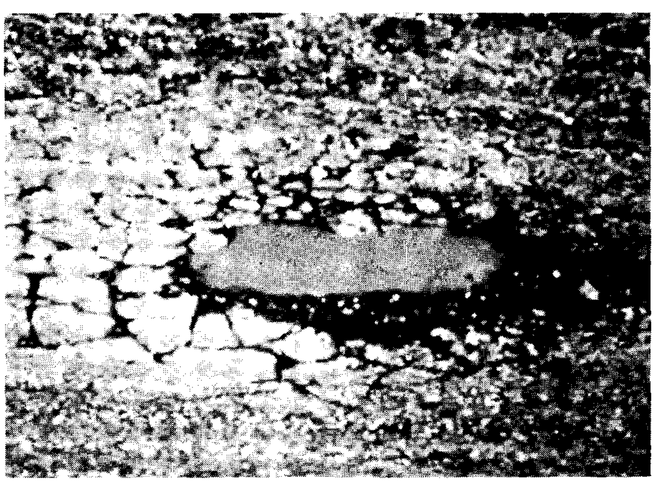


FIGURE A-3 Pothole *(20)*.

Edge Cracking

Edge cracking is longitudinal cracking along the edge of the pavement, as shown in Figure A-5. Edge cracking may be caused by a lack of support along the edge of the pavement from water softening the base and subbase. Water flowing off the pavement seeps into the base and subbase through the edge joint between the pavement and the shoulder.

Lane-to-Shoulder Dropoff

The lane-to-shoulder dropoff is the difference in elevation between the pavement and the shoulder. Figure A-6 illustrates lane-to-shoulder dropoff. It is caused by the differences in material characteristics and layer thicknesses between the pavement and the shoulder. Trucks encroaching on the shoulder are one of the major causes of lane-to-shoulder dropoff *(13)*. Another contributing factor is the softening of the base and subbase beneath the shoulder from water entering at the edge joint between the pavement and the shoulder, through surface cracks in the shoulder, or seeping in from the outside edges of the shoulder. Research has shown that excessive lane-to-shoulder dropoff can affect vehicle dynamics and may contribute to accidents *(22)*.

Pavement Oxidation

As an asphalt pavement ages, the asphalt cement that binds the aggregate together becomes brittle and the pavement begins to ravel. Initially the raveling consists of the loss of the asphalt binder and the fine aggregate, but in the more advanced stages, the coarse particles are also lost. Figure A-7 shows three examples of raveling, slight to severe.

Composite Pavement

All of the problems encountered in flexible pavements are possible also in composite pavements. In addition, the transverse joints in the underlying portland cement concrete pavement over time reflect up through the asphalt concrete overlay causing a transverse crack in the AC overlay. There are several techniques that may be used during construction to minimize reflective cracking. One technique however, which is to saw through the newly paved AC overlay directly over the old joint and to fill the saw cut with a joint sealing material, requires subsequent preventive maintenance *(24)*.

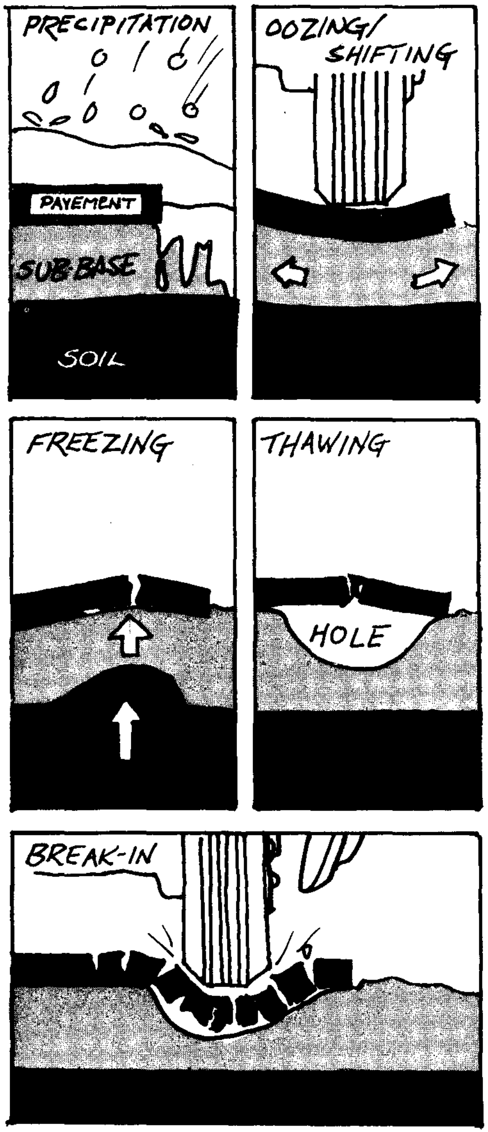


FIGURE A-4 Formation of a pothole *(21)*.

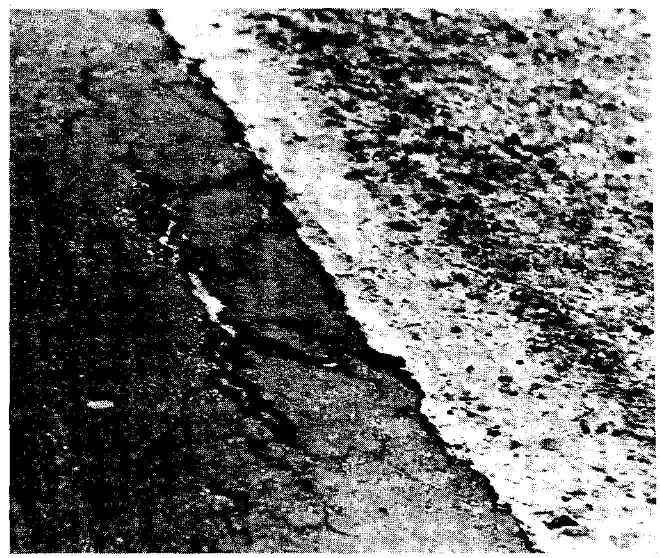


FIGURE A-5 Flexible pavement edge cracking *(15)*.

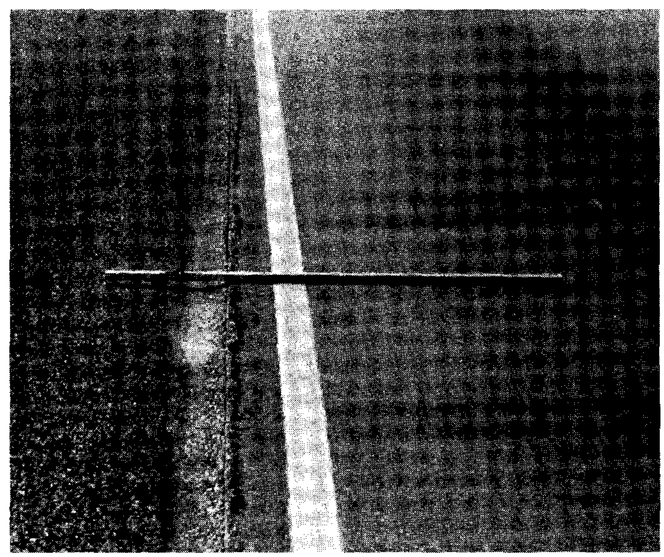


FIGURE A-6 Lane-shoulder dropoff *(20)*.

Rigid Pavement

Blow-up

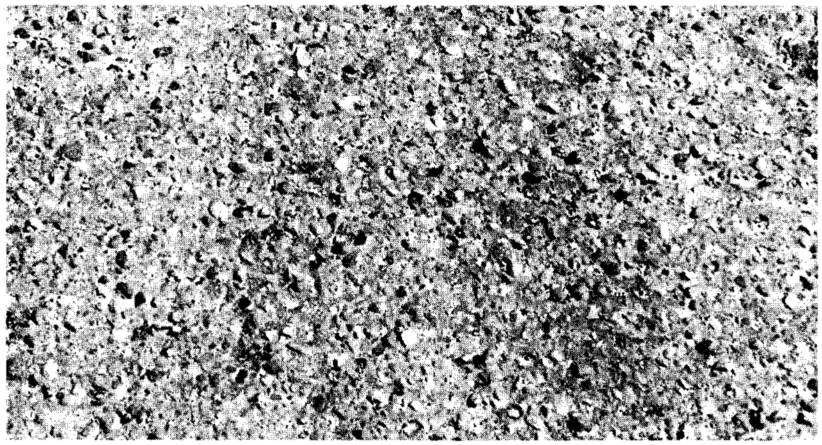
The blow-up is the most disruptive and potentially dangerous rigid pavement problem. Figure A-8 illustrates the blow-up or buckling of a rigid pavement. Blow-ups are caused by the excessive expansion of the slab from heat or moisture, frequently resulting from insufficient joint space. The joint and crack spaces fill up with incompressible materials, such as sand, grit, and metal particles. This is compounded when the joint sealer comes out of the joint opening under the action of traffic *(12)*. Sanding and salting operations in northern states during the winter, when joint and crack openings are at their widest, further add to this problem. Moisture infiltration is much more severe when joint seals have failed or are missing.

Pumping

Pumping is the ejection of mixtures of water and clay or silt along or through joints, cracks, or pavement edges *(15)*. Figure A-9 illustrates pumping. The expulsion of water is caused by the repetitive action of wheel loads. As the water and suspended solids are ejected through the transverse and longitudinal pavement joints, a progressively larger void is formed under the pavement. With a loss of support, pavement slab edge and corner cracks develop *(12)*.

Joint Faulting

Joint faulting is the differential vertical displacement of abutting slabs at joints or cracks, caused by repetitive axle loads, creating a "step" in the pavement surface *(12,15)*. Figure A-10 illustrates faulting. The PCC slab prior to the transverse joint in the direction of traffic is known as the "approach" slab and the slab after the joint is known as the "leave" slab. Faulting is caused by the action of repetitive axle loads slowly forcing water and suspended solids, which are under the approach slab, beneath the leave slab as the wheel



Slight

Smallest aggregate particles worn away exposing tops of large aggregate

Moderate to severe

Erosion further exposes large aggregate

Severe

Loss of large aggregate leaves very rough texture (foreground)

FIGURE A-7 Raveling *(23)*.

FIGURE A-8 Blowup of portland cement concrete pavement *(15)*.

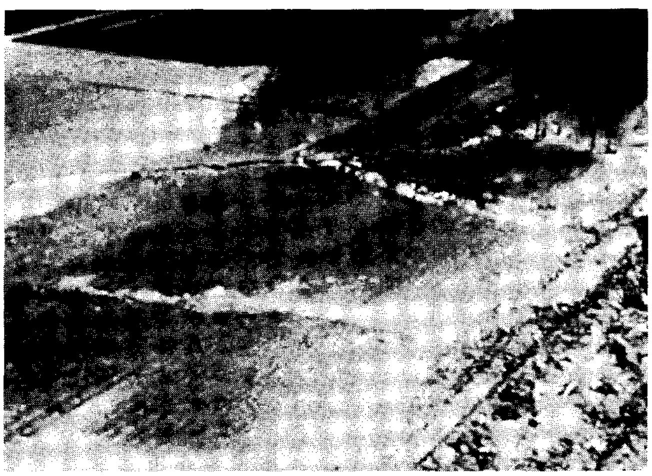


FIGURE A-9 Pumping of portland cement concrete pavement *(20)*.

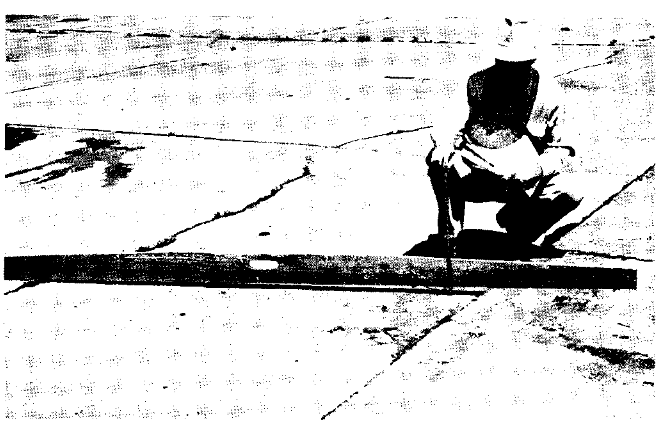


FIGURE A-10 Faulting of portland cement concrete pavement *(15)*.

approaches the joint. When the wheel crosses the joint onto the leave slab, the water and solids are forced back underneath the approach slab at a high velocity. This action causes a void under the leave slab and a buildup of material under the ap proach slab. Thus, what appears to be a depression of the leave slab, is rather the lifting of the approach slab (*12*).

Summary

All of the above pavement problems, with the possible exception of blow-ups of rigid pavement, have one thing in common: water. The presence of water in a pavement base or subbase accelerates the deterioration of flexible, composite, and rigid pavements.

CATEGORIES OF PREVENTIVE MAINTENANCE TREATMENTS FOR PAVEMENTS

The pavement and shoulder are the "roof" of the highway. One of their functions is to keep water from entering the pavement base and subbase from above. Therefore, the purpose of most preventive pavement maintenance techniques is to keep water away from the pavement base or subbase, either by sealing the surface of the pavement and shoulders or by facilitating drainage.

DRAINAGE

Periodically cleaning ditches and driveway culverts parallel to and cross culverts beneath the roadway facilitates the rapid flow of water away from pavement sections and avoids ponding in ditches and seepage into the pavement base and subbase. In addition, a DOT should cut back or blade the shoulders to remove the build up of material along the outer edge of the shoulder that blocks water from flowing off the paved surface. These preventive pavement maintenance drainage practices are applicable to all types of pavements.

Flexible Pavement

Water enters the flexible pavement section through cracks in the surface of the pavement and shoulder and through the longitudinal joints between the pavement and shoulder. The types of preventive maintenance treatments for flexible pavements are:

Crack Sealing and Crack Filling

Crack sealing and crack filling are both preventive maintenance treatments for flexible pavements. SHRP has provided the following definitions to delineate the differences between the two treatments (*9*).

- Crack sealing is "the placement of specialized materials either above or into *working* cracks using unique configurations to prevent the intrusion of water and *incompressibles* into the crack."

• Crack filling is "the placement of materials into *non-working* cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement."

All the surface cracks, the longitudinal joint between the pavement and the shoulders, and the longitudinal joint between lanes that may develop because of the cold edge during the paving process should be sealed or filled. There are several techniques for sealing and filling cracks. The simplest and quickest, which also has the shortest life, is to clean the debris out of the crack with compressed air and then spread a hot asphalt sealer over the crack with a squeegee. A better treatment is to rout or countersink the crack to form a reservoir for the sealer and to use a polymer-modified polyester fiberized asphalt as the sealing material. Some of the simplest and quickest treatments may last only 6 months, while the routing (countersinking) treatment has lasted up to 5 and 6 years in Ontario and New York respectively (*25* and personal communication with John Bugler, NYSDOT).

When the surface of the asphalt pavement has numerous cracks, or it has raveled and it is no longer feasible or practical to treat the individual cracks, a sealing technique that seals the entire surface is used. These are referred to as surface treatments and include slurry seals, micro-surfacing, chip seals, and thin overlays.

Slurry Seals: a mixture of well-graded fine sand, mineral filler, and dilute asphalt emulsion. The mixture is spread over the entire surface with either a squeegee or spreader box attached behind a truck. Slurry seals are considered to have a nominal life of 3 to 5 years (*26*).

Micro-Surfacing: a mixture of polymer-modified asphalt emulsion, crushed mineral aggregate, mineral filler, water, and additive to control the time to harden. The mixture is spread on the pavement with a spreader box attached behind a truck. Generally micro-surfacing is used to fill ruts and to improve surface texture. However, it has been used to seal surface cracks with mixed results (*27*).

Chip Seals: also known as surface treatment in some sections of the country, are constructed by spraying an asphalt emulsion with a liquid asphalt distributor on the pavement and then spreading on a layer of small crushed stone with a self-propelled spreader or a spreader box attached behind a truck. Some agencies use an additive in the asphalt cement or emulsion to increase stone retention and the performance of the chip seal. In addition to sealing the surface cracks, a chip seal can be used to increase the surface friction of a smooth pavement. Multiple applications of the asphalt emulsion and stone are also used by some agencies, depending on the condition of the pavement surface. In addition, some states use multiple chip seal courses to upgrade a gravel or stabilized road surface to a hard surface roadway for light weight traffic. In New York, chip seals with a plain asphalt emulsion have lasted 3 to 4 years, depending on traffic (*28*). In Washington State, chip seals using a polymer-modified sealer have lasted as long as 5 to 7 years on high-volume roadways (*26*).

Thin Hot-Mix Asphalt Overlays: The performance and the constructibility of the surface treatments discussed above are especially sensitive to traffic volumes. When the traffic volumes are high and it is no longer possible to obtain satisfactory performance or to construct the surface treatment, a thin overlay consisting of approximately 30 mm or less (1¼ in.) of a hot-mix asphalt (HMA) concrete is applied. The service life of a thin overlay ranges from about 8 years to 11 years (*26*).

Composite Pavement

Preventive maintenance treatments for flexible pavements are also applicable to a composite pavement. In addition, the sawed and sealed transverse joints need to be resealed periodically to keep water from entering the pavement structure. The same crack sealing techniques used for flexible pavements are also applicable to composite pavements.

Rigid Pavement

Joint and Crack Sealing

The importance of properly sealed joints and cracks in concrete pavements cannot be overstated. Sealing of longitudinal lane/shoulder joints is considered equally as important as sealing of transverse joints. As was the case with flexible pavements, cracks should be routed and sealed. Properly sealed joints and cracks increase the life of the pavement by preventing the infiltration of incompressibles into the joint and cracks and by reducing the amount of moisture entering the pavement structure (*17*). The life of a PCC joint seal ranges from 2 years to 8 years and depends greatly on the care taken to clean and prepare the crack or joint opening, the type of joint material used, and the care taken to place the material.

Retrofit Load Transfer

The failure of the dowel or the load transfer device across the transverse joint for any reason leads to accelerated pavement pumping and slab cracking. Retrofit load transfer is restoring load transfer across joints in PCC or placing load transfer devices across any cracks that may have developed since the pavement was constructed. While a variety of devices have been tried, the most promising devices are smooth, round dowels for joints or deformed reinforcing bars for non-working cracks where there is not vertical movement. These devices are placed in slots in the pavements that are backfilled with concrete patching material. This is a relatively recent practice and there is limited experience with the technique. However, based on work done in Puerto Rico, FHWA reports that it appears an additional 10-15 years service life may be obtained for PCC pavements using this technique (*29*).

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APPENDIX B

Questionnaire

NCHRP Project 20-5
Topic 25-10

Cost Effective Preventive Pavement Maintenance

Questionnaire

1. GENERAL INFORMATION

Organization:____

Address:____

City:______________________State/Prov.______Zip_________

Person Compiling Response:____________________________

Title:___________________Org. Location__________________

Phone____________________Fax___________________________

2. PURPOSE AND DEFINITIONS

The purpose of this questionnaire is to obtain information on your agency's practices regarding pavement preventive maintenance practices and any cost effectiveness information which you may have developed. The following definitions are provided to establish a common understanding of the terms used in this questionnaire.

Pavement Preventive Maintenance: Planned maintenance activities done to prevent or delay future pavement deterioration. These activities are normally cyclical in nature and may correct minor defects as a secondary benefit.

Pavement Preventive Maintenance Treatment: The performance of a preventive maintenance activity at a specific point in time. Examples of preventive maintenance treatments are the replacement of joint sealer in Portland Cement Concrete (PCC) pavements and sealing cracks in Asphalt Concrete (AC) pavements.

Preventive Maintenance Strategy: A plan for applying a series of preventive maintenance treatments over the life of the pavement. It is an organized, systematic process to select and budget preventive maintenance activities over the life of the pavement so as to minimize life cycle costs.

Cost Effectiveness of Pavement Preventive Maintenance: Documentation of pavement preventive maintenance benefits as measured by the increased service life, decreased cost of demand maintenance, increased time to rehabilitation and increased level of pavement serviceability.

Agency __________________________

Life Cycle Cost Analysis: A cost analysis that includes all costs required to build and maintain a pavement over a specific period of time. The cost normally includes the construction cost, annual maintenance cost, the cost of future rehabilitation and the salvage value at the end of the analysis period. The analysis considers the time value of money and determines the single present worth or a uniform present worth of all the costs.

3. PREVENTIVE MAINTENANCE TREATMENTS

The purpose of this question is to obtain an indication of the types or categories of pavement preventive maintenance treatments used by your agency and an indication of the overall performance of those treatments. Your agency may have more that one specific treatment in each category. For instance, an agency may have four specific crack filling treatments depending on the circumstances. It may or may not rout the cracks before filling and it may use two different filler materials. The purpose of this question is **NOT** to obtain detail information on each treatment but rather to obtain information on the types of treatments used.

A. Please identify by a check mark the following types or categories of pavement preventive maintenance treatments used by your agency?

(1) **For Portland Cement Concrete Pavements**

_____Joint Spall Repair

_____Joint Sealer Replacement

_____Other (please describe)______________________

Agency ____________________________

(2) **For Asphalt Concrete Pavements**

_____Crack Filling (with or w/o routing)

_____Single Application Chip Seal (i.e., Single Surface Treatment)

_____Multiple Application Chip Seal-2 or more applications of asphalt and chips

_____Slurry Seal

_____Micro-surfacing

_____Thin HMA Overlays (1-1/4 inch or less)

_____Other (please describe)________________________

(3) **For Overlaid Pavements (AC over PCC)**

_____Fill Sawed and Sealed Joints in AC over old joints in PCC

_____Crack Filling (with or w/o routing)

_____Single Application Chip Seal (i.e., Single Surface Treatment)

_____Multiple Application Chip Seal-2 or more applications of asphalt and chips

_____Slurry Seal

_____Micro-surfacing

_____Thin HMA Overlays (1-1/4 inch or less)

_____Other (please describe)________________________

B. For each of the treatment categories checked in A above, please complete the appropriate attached Preventive Maintenance Treatment Category Worksheet. In completing the worksheet, please report on the treatment used in each category which provides the best overall performance for your agency.

Agency ____________________________

4. STRATEGIES

A. Does your agency have pavement preventive maintenance strategies as previously defined?
(Please circle) YES NO

B. If yes, what uses are made of the strategies in your agency. (Please check)

(1) To select pavement sections or treatments during the design process that provide the least life cycle costs._____

(2) To prepare Maintenance Organization's Budget._____

(3) To order materials._____

(4) To schedule work to be done by either agency forces or maintenance contractor._____

(5) Other (please describe) ________________________

C. Do the preventive maintenance strategies vary by functional class?
(Please circle) YES NO

D. Do the preventive maintenance strategies vary by traffic volume?
(Please circle) YES NO

E. If the answer to A above is yes, please describe the preventive maintenance strategies which your agency has. Normally, the analysis period for pavement life cycle costing includes at least one rehabilitation period. However, for the purposes of this questionnaire, it is sufficient to describe the strategy up to the time of rehabilitation.

Please use the attached 3 pages titled "Pavement Preventive Maintenance Strategy". A 3 page set has been provided for each type of pavement in 3 above. If your agency has more than one strategy for one type of pavement, please copy the appropriate set and provide information on each strategy. **An example is provided for guidance on how to complete the forms.**

NCHRP Project 20-5, Topic 25-10

Agency ______________________

5. PLANNING AND FUNDING PAVEMENT PREVENTIVE MAINTENANCE

The benefits gained by using a preventive maintenance strategy which minimizes life cycle cost to select a pavement or rehabilitation design, presupposes that the strategy is implemented.

A. Does your agency assume a preventive maintenance strategy during the design process to minimizing pavement life cycle costs ? (Please circle) YES NO

B. If yes,

(1) Does your agency identify or earmark monies in future years to fund the preventive maintenance treatments identified in the strategy? (Please circle) YES NO

(2) Are the maintenance funds appropriated to your agency, adequate to fund preventive maintenance? (Please circle) YES NO

(3) Does your agency decrease its capital program by transferring funds to maintenance to adequately fund the preventive maintenance program? (Please circle) YES NO

C. If your agency is not using pavement preventive maintenance strategies, please check the reasons why.

(1) The cost effectiveness of pavement preventive maintenance strategies has not been adequately demonstrated._____

(2) Agencies which provide funding (budget, legislature, etc.) have not accepted the demonstrated cost effectiveness of pavement preventive maintenance._____

(3) All the agencies agree with the benefits but there just isn't enough money available to fund the strategies._____

(4) Other (please describe)

____

____

____

NCHRP Project 20-5, Topic 25-10

Agency ______________________

6. FURTHER WORK NEEDED (Please check)

A. Additional research is needed to demonstrate the cost effectiveness of pavement preventive maintenance strategies._____

B. Presentations and literature needs to be prepared to convince the funding agencies of the benefits of pavement preventive maintenance._____

C. Other (Please describe)

____

____

____

****

Please Return to:

Donald N. Geoffroy, PE
22 Northgate Drive
Albany, NY 12203
Phone/Fax (518) 464-9551

If you have any questions, please call at the above number

A response by May 20, 1994 would be appreciated

THANK YOU FOR YOUR ASSISTANCE!

****

NCHRP Project 20-5, Topic 25-10

Agency___________________________

PAVEMENT PREVENTIVE MAINTENANCE CATEGORY WORKSHEET

Pavement Type: **PORTLAND CEMENT CONCRETE**
Preventive Maintenance Treatment Category: **JOINT SPALL REPAIR**

In completing this sheet, please report on the specific treatment which provides the best overall performance in this category.

1. Age of Pavement at the time of first application: Please circle

   <2 yrs   2-4 yrs   5-6 yrs   7-8 yrs   9-10 yrs   Other_____

2. Frequency of Application, if done cyclically: Please circle

   <2 yrs   2-4 yrs   5-6 yrs   7-8 yrs   9-10 yrs   Other_____

3. Cost of treatment per lane mile: Please circle

   <$1000 $1000-1499 $1500-1999 $2000-3999

   $4000-4999 $5000-6999 $7000-9999 $10,000-14,999

   $15,000-24,999 $25,000-49,999 $50,000-74,999

   $75,000-100,000   Over $100,000   Other $___________

4. Observed increase in pavement life obtained from the use of this treatment: Please circle

   <2 yrs   2-4 yrs   5-6 yrs   7-8 yrs   9-10 yrs   Other_____

5. Source(s) of the above information: Please check

   _____Pavement Management System

   _____Maintenance Management System

   _____Research Project conducted to determine benefits of preventive maintenance

   _____Estimate based on the observational experience of maintenance, material or pavement engineers

   _____Other (please describe)_______________________________
   ____

NCHRP Project 20-5, Topic 25-10

Agency:________________________

PAVEMENT PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **PORTLAND CEMENT CONCRETE**				
Year	Preventive Maintenance Treatments (check boxes)			
	Joint Spall Repair	Joint Sealer Replacement	Other (describe)	Other (describe)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

1. Time to Rehabilitation without the Strategy: Please Circle

   <10 yrs   10-12 yrs   13-15 yrs   16-20 yrs

   21-25 yrs   Over 25 yrs   Other _____yrs

NCHRP Project 20-5, Topic 25-10

Agency:________________________

2. Cost Effectiveness of Strategy (PCC)

(A) Increased time to rehabilitation (years): Please circle

<2 yrs   3-4 yrs   5-6 yrs   7-8 yrs   9-10 yrs

Over 10 yrs   Other_____yrs

(B) Reduction in the amount of time spent on pavement demand maintenance activities (e.g., unplanned, unscheduled pavement work which must be done for motorist safety, i.e., blowup repairs, pothole patching, etc): Please circle

<5 %   5-10 %   11-15 %   16-20 %   21-25 %

Over 25 %   Other_____%

(C) Reduction in the cost of pavement demand maintenance activities: Please circle

<5 %   5-10 %   11-15 %   16-20 %   21-25 %

Over 25 %   Other_____%

(D) Improvement in pavement serviceability, as measured by the Pavement Serviceability Index or a similiar index over a comparable time period: Please circle

<5 %   5-10 %   11-15 %   16-20 %   21-25 %

Over 25 %   Other_____%

NCHRP Project 20-5, Topic 25-10

Agency:________________________

PCC

Sources of Cost Effectiveness Information for the Strategy				
Source	Measures of Cost Effectiveness (check boxes)			
	Increased Time to Rehab.	Decreased Time for Demand Maintenance	Decreased Cost of Demand Maintenance	Increase Pavement Service
Pavement Management System				
Maintenance Management System				
Research Project done to determine benefits of Preventive Maintenance				
Estimate based on the observational experience of agency engineers				
Other (describe)				

APPENDIX C

Respondents to the Questionnaire

TABLE C-1
STATE, PROVINCE AND LOCAL DEPARTMENTS OF TRANSPORTATION RESPONDING TO THE QUESTIONNAIRE

STATES			
Name	Abbrev	Name	Abbrev
Alabama	AL	Nebraska	NB
Alaska	AK	Nevada	NV
Arizona	AZ	New Hampshire	NH
Arkansas	AR	New Jersey	NJ
California	CA	New Mexico	NM
Colorado	CO	New York	NY
Connecticut	CT	North Carolina	NC
Florida	FL	North Dakota	ND
Georgia	GA	Ohio	OH
Hawaii	HI	Oregon	OR
Idaho	ID	Pennsylvania	PA
Illinois	IL	Rhode Island	RI
Indiana	IN	South Carolina	SC
Iowa	IA	South Dakota	SD
Kansas	KS	Tennessee	TN
Kentucky	KY	Texas	TX
Louisiana	LA	Vermont	VT
Maine	ME	Virginia	VA
Maryland	MD	Washington	WA
Michigan	MI	West Virginia	WV
Minnesota	MN	Wisconsin	WI
Mississippi	MS	Wyoming	WY
Missouri	MO		

CANADIAN AGENCIES			
Name	Abbrev	Name	Abbrev
British Columbia	BC	Nova Scotia	NS
Ontario	ON	Prince Edward Is	PE

LOCAL	
Name	Abbrev
Contra Costa County, California	CCA
Town of Glastonbury, Connecticut	GCT
Village of Barrington, Illinois	BIL
Turnpike Authority, Massachusetts	MTA
City of Worcester, Massachusetts	WMA
Kalamazoo County, Michigan	KMI
Oakland County, Michigan	OMI
City of Kansas City, Missouri	KMO
Mecklenburg County, North Carolina	MNC
Salt Lake County, Utah	SUT
Clark County, Washington	CWA

APPENDIX D

Summary of Responses to the Questionnaire

TABLE D-1 RESPONSES TO QUESTION 3A(1).
TYPES OF PREVENTIVE MAINTENANCE TREATMENTS USED FOR PCC PAVEMENTS

State, Prov, and Local Agencies	Joint Spall Repair	Joint Sealer Replacement	Other*	State, Prov, and Local Agencies	Joint Spall Repair	Joint Sealer Replacement	Other*
AL	XP**	XP	1,4	NE	XP		
AZ		XP		NV	XP	XP	1,8
AR	XP	XP		NJ		X	
CA	XP	XP	1	NM	XP	XP	2,4,7
CO		X		NY	XP	XP	10
CT		XP		NC	XP	XP	
FL	X	X		ND	X	X	
GA	XP	X	2,3,4,6,8	OH	XP		
ID	XP	XP	3,4,7,8	ON		XP	
IL	X	X	Note 1	OR	X	X	
IN	XP	XP		PA		XP	
IA	XP	XP		RI	XP		
KS	XP			SC	XP	XP	
KY		X		SD	XP	XP	6,8,9,13
LA	XP			TN	XP	XP	6,8,9
ME	XP	XP		TX	XP	XP	11
MD	XP	XP	1,3	VA		XP	
MI		XP	1,5	WA		XP	1,7
MN	XP	XP		WI	XP	Note 2	
MS	X	X	12	WY	X	X	
MO	XP	XP	2,4,7,8	KMI	XP	XP	3
NE	XP			OMI		XP	
NV	XP	XP	1,8	CWA			11,14

* Numbers indicate treatments from the following list
** Indicates that the agency included a treatment worksheet providing cost and performance information, which is displayed in a subsequent table.

Other Treatments
1 Crack filling and sealing
2 Partial depth slab repair
3 Full-depth slab repair
4 Slab replacement
5 Full-depth joint repair
6 Undersealing
7 Slab jacking
8 Grinding
9 Install edge drains
10 Shoulder surface treatment
11 Hot-mix asphalt overlay
12 Crack seal repair
13 Saw and reseal joints
14 Cold mix open-graded overlays

Note 1: Maintenance program for mechanistically designed pavements.
Note 2: Does not seal PCC joints. Research from 1950 to 1985 indicates that it is not cost-effective (*47,48*).

TABLE D-2 RESPONSES TO QUESTION 3A(2).
TYPES OF PREVENTIVE MAINTENANCE TREATMENTS USED FOR AC PAVEMENTS

State/ Prov/ Local	Fill Cracks	Sing. Appl. Chip Seal	Multi. Appl. Chip Seal	Slurry Seal	Micro Surface	Thin HMA	Other (See footnote)
AL	XP*	XP	XP			XP	
AK	XP	XP				XP	
AZ	XP	XP					
AR	XP	XP		XP	XP		
BC	XP	XP	X	X	X		
CA	XP	XP		XP		XP	(1)
CO	X	X		X		X	
CT	XP	XP				XP	(2)
FL	X	X	X	X		X	
GA	XP	XP	XP	XP		XP	
ID	XP	XP			XP	XP	(3)
IL							(4)
IN	XP	XP			XP	XP	
IA	XP	XP	XP	X(5)		XP	
KS	XP	XP			XP	XP	
KY						X	
LA	XP	XP			X(6)	XP	
ME	XP					XP	
MD	XP	XP(7)	XP(7)	XP		XP	(8)
MI	XP	XP			XP	XP	
MN	XP	XP			X	XP	
MS	XP	XP	XP		XP	XP	(9)
MO	XP	XP			XP	XP	(10)
NE	X	X					
NV	XP	XP	XP			X	(11)
NH	XP	X	X			XP	
NJ	X				X		
NM	XP	XP			X(12)		(13)
NY	XP	XP	XP		XP	XP	(14)
NC	XP	XP	XP	XP	XP	XP	
ND	X	X			X(15)	X	
NS	XP	XP				XP	
OH	XP				XP	XP	
ON	XP				XP		(16)
OR	X	X	X				
PA	XP	XP	XP			XP	
PE	XP	XP	XP	XP	X	XP	
RI	XP						(17)
SC	XP	XP	XP				
SD	XP	XP	X		X(18)		
TN	XP	XP	X	XP	XP	XP	(19)
TX	XP	XP	XP		XP	X	(14)
VT	XP					XP	
VA	X			XP	XP		(14)
WA	XP	XP				XP	(20)
WI	XP	XP	XP		XP	XP	
WY	X	X			X	X	
CCA	XP	XP	XP	XP			(21)

State/ Prov/ Local	Fill Cracks	Sing. Appl. Chip Seal	Multi. Appl. Chip Seal	Slurry Seal	Micro Surface	Thin HMA	Other (See footnote)
GCT	XP	XP					(22)
BIL	X						
MTA	XP						
KMI	XP	XP		XP		XP	

State/ Prov/ Local	Fill Cracks	Sing. Appl. Chip Seal	Multi. Appl. Chip Seal	Slurry Seal	Micro Surface	Thin HMA	Other (See footnote)
OMI	XP					XP	
KMO	XP			XP			(23)
SUT	XP	XP		XP	XP		
CWA	XP	XP	X	XP	X		(24)

* Indicates that the agency included a treatment worksheet providing cost and performance information, which is displayed in a subsequent table.

FOOTNOTES FOR TABLE D-2

(1) 3/4-in. OGAC friction course with asphalt rubber or PBA-6
(2) Vendor-in-place 2-in. overlay
(3) Blade laid leveling course, rotomilling
(4) Maintenance program for mechanistically designed pavements
(5) Includes transverse joint leveling
(6) Plan to initiate in FY 94/95
(7) On shoulders only
(8) ½-in. rut mix
(9) Milling with ½-in. overlay
(10) Rotomilling and filling patches with HMA, rotomilling high spots and micro-milling to reduce rutting
(11) Flush seal, patching, sand seal
(12) Plan to do
(13) Heater re-mix, fog seal, and cold in-situ recycling
(14) 1½-in. HMA overlay
(15) Limited to test sections
(16) Hot mix patching
(17) 2-in. overlay
(18) As a corrective treatment
(19) Fog seal and inplace hot-mix recycling
(20) Fog seal
(21) Rejuvenation, cape seal, multichip crumb rubber asphalt
(22) 1½-in or more overlay with HMA or cold mix asphalt
(23) Cold mill 1½ in. and overlay with 1½-in. hot mix recycled asphalt
(24) Hot-mix overlays, cold-mix overlays

TABLE D-3
RESPONSES TO QUESTION 3A(3).
TYPES OF PREVENTIVE MAINTENANCE TREATMENTS USED FOR OVERLAID PAVEMENTS

State/ Prov/ Local	Fill Saw & SealJts	Fill Cracks	Sing. Appl. Chip Seal	Mult. Appl. Chip Seal	Slurry Seal	Micro Surf	Thin HMA	Other (See footnote)
AL	XP*	XP						
AK		XP						
AZ	XP	XP					XP	
AR	X	XP			XP	X		
CA	XP	XP	XP		XP		XP	(1)
CO	X	X						
CT	XP	XP	X				XP	(2)
FL	X	X		X			X	
GA		XP	XP	XP	X		XP	
IL								(3)
IN		XP				XP	XP	
IA	XP	XP	XP	XP	X(4)		XP	
KS		XP				XP		(5)
KY							X	
LA		XP	X			X(6)		
ME	X	XP					XP	
MD		XP	X(7)	X(7)	XP		XP	(8)
MI		XP	X			XP	X	
MN	XP	XP	XP				X	
MS		XP	XP			XP	XP	(9)
MO		XP	XP			XP	XP	(10)
NE		X						
NV	XP	XP	XP				XP	(11)
NH				X			X	
NJ	X	X				X		
NM		XP	XP					(12)
NY	XP	XP	XP	XP		XP	XP	(13)
NC		XP	XP	XP	XP	XP	XP	
ND		X	X				X	
OH		XP				XP	XP	(14)
ON	XP	XP				XP		(15)
OR		X	X	X				
PA		XP	XP	XP			XP	
RI	XP	XP						(16)
SC	XP	XP						
SD	XP	XP	XP	X		X(17)		
TN		XP					XP	
TX		XP	XP		X	XP	X	
VT	X	XP					XP	
VA							XP	(13)
WA		XP	XP				X	(18)
WI		XP	XP	XP		XP	XP	

State/ Prov/ Local	Fill Saw & SealJts	Fill Cracks	Sing. Appl. Chip Seal	Mult. Appl. Chip Seal	Slurry Seal	Micro Surf	Thin HMA	Other (See footnote)
WY		X	X				X	
CCA		XP	XP	XP				
GCT		XP	XP					(19)
BIL		X						
KMI	XP	XP	XP		XP			
OMI	XP	XP					XP	
KMO		XP			XP	XP	XP	(20)
SUT	X	X						
CWA		XP	XP	X				(21)

* Indicates that the agency included a treatment worksheet providing cost and performance information, which is displayed in a subsequent table.

FOOTNOTES FOR TABLE D-3

(1) 3/4 inch OGAC friction course with asphalt rubber or PBA-6
(2) Vendor-in-place 2 inch overlay
(3) Maintenance program for mechanistically designed pavements
(4) Includes transverse joint leveling
(5) AC Crack sealing
(6) Plan to initiate in FY 94/95
(7) On shoulders only
(8) 1/2 inch rut mix
(9) Milling with 1/2 inch overlay
(10) Rotomilling and filling patches with HMA, rotomilling high spots and micro-milling to reduce rutting
(11) Flush seal, sand seal
(12) Cold milling with AC Overlay and fog seal
(13) 1-1/2 inch HMA overlay
(14) Mill existing overlay and replace with HMA
(15) Hot-mix patching
(16) 2 inch overlay
(17) As a corrective treatment
(18) Fog seal
(19) 1-1/2 inch or more overlay with HMA or cold mix asphalt
(20) Cold mill 1-1/2 inch and overlay with 1-1/2 inch hot-mix recycled asphalt
(21) Hot-mix overlays, cold-mix overlays

PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS
COST AND PERFORMANCE INFORMATION

The following tables D-4 through D-18 contain the agencies' detail responses to Question 3B. The agency's source of the information in these tables are identified by the following code:

1. Pavement Management System
2. Maintenance Management System
3. Research Project conducted to determine benefits of preventive maintenance
4. Estimate based on the observational experience of the agency's maintenance, materials, and pavement engineers.

TABLE D-4
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Portland Cement Concrete**

Preventive Maintenance Treatment: **Joint Spall Repair**

State/ Prov/ Local	Pav't age at time of first appl. (yrs)	Freq of appl. (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	>20	7-8	50,000-74,999	7-8	4
AR	As needed		1,500-1,999	5-6	4
CA	All ages	5-6	Unknown	2-4	4
GA	10-11		2,000-3,999	7-8	2,4
ID	9-10	7-8	7,000-9,999	Unknown	4
IN	9-10	9-10	25,000-49,000	7-8	1,4
IA	9-10	Varies	7,000-9,999	7-8	4
KS	9-10		10,000-14,999	5-6	4
LA	7-8	Varies	1,000-1499	2-4	4
ME	As needed	-	<1,000	Unknown	4
MD	9-10	5-6	$132/sy	5-6	1,2,4
MN	12		10,000-14,999	7-8	4
MO	9-10	2-4	5,000-6,999	7-8	4
NE	As needed	Varies	<1,000	N/A	2
NV	5-6	2-4	10,000-14,999	2-4	1,2,4
NM	9-10	5-6	1,000-1,499	5-6	4
NY	9-10	9-10	5,000-6,999	Unknown	1,4
NC	9-10		7,000-9,999	9-10	4
OH	>10	Varies	$128/cy	2-4	4
RI	7-8	2-4	1,500-1,999	5-6	4
SC	2-4	9-10	Unknown	9-10	4
SD	15	9-10	25,000-49,999	15	1,3,4
TN	9-10	Varies		2-4	4
TX	10+		$100/sy	5-6	4
WI	7-8	5-6	1,500-1,999	5-6	1,2
KMI	2-4	5-6	2,000-3,999	9-10	2,4

TABLE D-5
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Portland Cement Concrete**

Preventive Maintenance Treatment: **Joint Sealer Replacement**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	>20	7-8	25,000-49,999	7-8	4
AZ	9-10	9-10	15,000-24,999	5-6	4
AR	9-10	5-6	1,500-1,999	5-6	4
CA	All Ages	5-6	Unknown	2-4	4
CT	9-10	7-8	5,000-6,999	7-8	4
ID	9-10	7-8	10,000-14,999	Unknown	4
IN	9-10	9-10	In spall repair	7-8	1,4
IA	2-4	7-8	5,000-6,999	Unknown	4
ME	As needed		<1,000	Unknown	4
MD	5-6	2-4	10,000-14,999	9-10	2,4
MI	10-15		15,000-24,999	9-10	4
MN	12		5,000-6,999	7-8	4
MO	9-10	2-4	1,500-1,900	5-6	4
NV	5-6	2-4	15,000-24,999	2-4	2,4
NM	20	9-10	2,000-3,999	9-10	4
NY	7-8	7-8	5,000-6,999	Unknown	1,4
NC	7-8	7-8	5,000-6,999	9-10	4
ON	9-10	5-6	5,000-6,999	2-4	1,4
PA	5-6	5-6	$9.20/gal	Unknown	1,2,4
SC	9-10	12-15	7,000-9,999	9-10	4
SD	9-10	9-10	7,000-9,999	5-6	1,3,4
TN	7-8	7-8	10,000-14,999	Unknown	4
TX	10+		50,000-74,999	5-6	4
VA	9-10	7-8	4,000-4,999	5-6	4
WA	5-6	5-6	<1,000	5-6	4
KMI	7-8	5-6	10,000-14,999	9-10	4
OMI	9-10	9-10	2,000-3,999	7-9	1,4

TABLE D-6
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment: **Crack Filling**

State/ Prov/ Local	Pav't age at time of first appl.(yrs)	Freq of appl.(yrs)	Cost per lane mile (dollars)	Observed increase in pav't life (yrs)	Source of Info (See List)
AL	9-10	7-8	10,000-14,999	2-4	4
AK	<2	5-6	2,000-3,999	2-4	1,4
AZ	5-6	2-4	1,000-1,499	2-4	1,2,4
AR	5-6	2-4	1,000-1,499	2-4	4
BC	3-25	Varies	Varies	5-6	4
CA	All ages	5-6	2,000-3,999	2-4	4
CT	7-8	5-6	15,000-24,999	5-6	1,2,4
GA	7-8	-	<1,000	2-4	2,4
ID	5-6	2-4	$1/lf of crack	7-8	4
IN	2-4	2-4	<1,000	2-4	2,4
IA	2-4	5-6	1,500-1,999	Unknown	4
KS	9-10	3-5	1,000-1,499	2-4	4
LA	5-6	2-4	1,500-1,999	2-4	1
ME	2-4	-	2,000-3,999	Unknown	1
MD	7-8	2-4	5,000-6,999	5-6	1,2,4
MI	2-4	-	Varies	5-6	4
MN	2-4	-	1,500-1,999	<2	4
MS	7-8	2-4	-	2-4	4
MO	2-4	<2	-	7-8	4
NV	2-4	<2	15,000-24,999	2-4	1,2,4
NH	5-6	5-6	-	-	-
NM	7-8	5-6	5,000-6,999	5-6	1
NY	2-4	2-4	1,500-1,999	Unknown	1,4
NC	5-6	7-8	2,000-3,999	7-8	4
NS	2-4	2-4	<1,000	5-6	4
OH	5-6	-	1,000-1,499	2-4	4
ON	2-4	2-4	2,000-3,999	2-4	1,3,4
PA	2-4	2-4	$7.40/gal	2-4	1,2,4
PE	5-6	-	-	2-4	4
RI	7-8	-	2,000-3,999	7-8	4
SC	10-20	5-6	Varies	5-6	4
SD	2-4	2-4	1,000-1,499	2-4	4
TN	Varies	Varies	2,000-3,999	2-4	4
TX	9-10	2-4	1,500-1,999	2-4	4
VT	2-4	-	1,000-1,499	5-6	2,4
WA	5-6	5-6	1,000-1,499	5-6	4
WI	2-4	5-6	1,000-1,499	2-4	1,3,4
CCA	7-8	2-4	2,000-3,999	2-4	4
GCT	9-10	2-4	<1,000	5-6	1
MTA	<2	2-4	1,500-1,999	2-4	4
KMI	2-4	5-6	5,000-6,999	9-10	4
OMI	9-10	9-10	2,000-3,999	5-6	1,4
KMO	2-4	-	1,500-1,999	5-6	4
SUT	2-4	2-4	1,000-1,499	2-4	1
CWA	7-8	2-4	2,000-3,999	2-4	4

TABLE D-7
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment: **Single Application Chip Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	7-8	7-8	5,000-6,999	2-4	4
AK	>15	-	15,000-14,999	2-4	1,4
AZ	7-8	7-8	7,000-9,999	7-8	1,2,4
AR	Varies	-	2,000-3,999	2-4	4
BC	Varies	9-10	15,000-24,999	7-8	4
CA	5-6	5-6	7,000-9,999	2-4	4
CT	11-15	2-4	15,000-24,999	7-8	1,2,4
GA	11-12	-	2,000-3,999	4-5	2,4
ID	<2	7-8	5,000-6,999	-	4
IN	7-8	5-6	2,000-3,999	5-6	2,4
IA	15-20	5-6	5,000-6,999	5-6	4
KS	9-20	3-5	2,000-3,999	2-4	4
LA	9-10	7-8	4,000-6,999	5-6	4
MD	9-10	5-6	4,000-4,999	5-6	4
MI	>10	-	5,000-6,999	5-6	4
MN	2-5	Varies	7,000-9,999	Unknown	3,4
MS	7-8	5-6	4,000-4,999	5-6	4
MO	12-14	9-10	4,000-4,999	2-4	4
NV	5-6	5-6	10,000-14,999	5-6	1,2,4
NM	9-10	5-6	1,000-1,499	5-6	1
NY	7-8	2-4	7,000-9,999	2-4	3,4
NC	7-8	5-6	5,000-6,999	5-6	4
NS	2-4	-	7,000-9,999	5-6	4
PA	5-6	5-6	4,000-4,999	5-6	1,2,4
PE	12+	7-8	7,000-9,999	7-8	4
SC	15-20	5-6	5,000-6,999	2-4	4
SD	2-4	7-8	4,000-4,999	2-4	4
TN	>10	Varies	10,000-14,999	2-4	4
TX	9-10	7-10+	7,000-9,999	7-8	2,4
WA	7-8	7-8	7,000-9,999	7-8	4
WI	5-6	5-6	5,000-6,999	5-6	4
CCA	7-8	5-6	4,000-4,999	5-6	1
GCT	10+	-	1,500-1,999	7-8	1
KMI	5-6	5-6	10,000-14,999	-	1,4
SUT	5-6	5-6	4,000-4,999	5-6	1
CWA	9-10	7-8	4,000-4999	7-8	1

TABLE D-8
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment:**Multiple Application Chip Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	7-8	7-8	7,000-9,999	5-6	4
GA	10-11	-	2,000-3,999	5-6	2,4
IA	15-20	7-8	10,000-14,999	7-8	4
MD	9-10	7-8	7,000-9,999	5-6	4
MS	7-8	5-6	4,000-4,999	5-6	4
NV	5-6	5-6	15,000-24,999	5-6	1,2,4
NY	7-8	2-4	10,000-14,999	2-4	4
NC	7-8	5-6	7,000-9,999	5-6	4
PA	7-8	5-6	7,000-9,999	5-6	1,2,4
PE	12+	7-8	15,000-24,999	7-8	4
SC	9-10	9-10	7,000-9,999	9-10	4
TX	10+	-	10,000-14,999	9-10	4
WI	5-6	5-6	7,000-9,999	5-6	4
CCA	7-8	5-6	5,000-6,999	5-6	1

TABLE D-9
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment: **Slurry Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AR	-	5-6	1,000-1,499	5-6	4
CA	5-6	2-4	10,000-14,999	2-4	-
GA	11-12	-	1,500-1,999	2-4	2,4
MD	9-10	5-6	4,000-4,999	5-6	1,2,4
NC	7-8	5-6	4,000-4,999	5-6	4
PE	9-10	7-8	7,000-9,999	7-8	4
TN	9-10	-	4,000-4,999	2-4	4
VA	Varies	5-6	2,000-3,999	2-4	4
CCA	7-8	5-6	7,000-9,999	5-6	1
KMI	7-8	-	7,000-9,999	2-4	4
KMO	4-5	-	5,000-6,999	5-6	4
SUT	5-6	5-6	4,000-4,999	5-6	1
CWA	5-6	5-6	5,000-6,999	5-6	4

TABLE D-10
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment: **Micro-Surfacing**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AR	-	5-6	1,000-1,499	5-6	4
ID	9-10	-	10,000-14,999	-	4
IN	9-10	-	10,000-14,999	2-6	1,4
KS	9-10	7-8	15,000-24,999	2-4	4
MI	>10	-	7,000-9.999	5-6	4
MS	7-8	-	7,000-9,999	-	-
MO	7-8	-	7,000-9,999	2-4	4
NY	7-8	5-6	25,000-49,999	_	4
NC	7-8	5-6	7,000-9,999	5-6	4
OH	9-10	-	7,000-9,999	5-6	4
ON	10-15	-	15,000-24,999	Hope for 5-7	3
TN	9-10	-	5,000-6,999	2-4	4
TX	10+	-	10,000-14,999	5-6	4
VA	7-10	5-6	15,000-24,999	5-6	3,4
WI	9-10	9-10	10,000-14,999	7-8	1,3,4
SUT	5-6	5-6	5,000-6,999	5-6	1

TABLE D-11
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Asphalt Concrete**

Preventive Maintenance Treatment: **Thin HMA Overlay**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	9-10	7-8	25,000-49,999	7-8	4
AK	15+	-	50,000-74,999	2-4	4
CA	5-6	2-4	15,000-24,999	2-4	4
CT	9-10	2-4	7,000-9,999	2-4	4
GA	11-12	11-12	15,000-24,999	9-10	2,4
ID	9-10	9-10	15,000-24,999	Unknown	4
IN	9-10	-	10,000-14,999	5-6	1,4
IA	9-10	9-10	15,000-24,999	9-10	4
KS	7-8	2-4	10,000-14,999	>2	4
LA	7-8	7-8	25,000-49,999	5-6	1
ME	9-10	9-10	4,000-4,999	2-4	4
MD	9-10	7-8	10,000-14,999 per/inch	7-8	1,2,4
MI	>10	-	15,0000-24,999	9-10	4
MN	15	-	15,000-24,999	-	4
MS	9-10	7-8	15,000-24,999	7-8	4
MO	9-10	-	10,000-14,999	5-6	4
NH	7-8	5-6	10,000-14,999	9-10	4
NY	7-8	9-10	25,000-49,999	9-10	1,4
NC	7-8	7-8	7,000-9,999	7-8	4
NS	9-10	2-4	10,000-14,999	5-6	4
OH	9-10	9-10	25,000-49,999	7-8	4
PA	7-8	9-10	15,000-24,999	7-8	1,2,4
PE	15+	-	15,000-24,999	5-6	4
TN	Varies	-	10,000-14,999	2-4	4
VT	9-10	-	15,000-24,999	7-8	1
WA	7-8	-	25,000-49,999	7-8	4
WI	>12	9-10	25,000-49,999	5-6	1,2,4
OMI	10-12	9-10	15,000-24,000	9-10	1,4
KMI	9-10	-	10,000-14,999	9-10	4

TABLE D-12
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Fill Sawed and Sealed Joints in AC over old joints in PCC**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	5-6	5-6	7,000-9,999	2-4	4
AZ	5-6	5-6	4,000-4,999	5-6	1,2,4
CA	5-6	5-6	2,000-3,999	2-4	4
CT	<2	-	2,000-3,999	11-15	1,2,4
IA	2-4	7-8	1,500-1,999	Unknown	4
MN	<2	-	5,000-6,999	Unknown	3,4
NV	5-6	2-4	25,000-49,999	2-4	2,4
NY	5-6	2-4	1,500-1,999	2-4	1,4
ON	2-4	2-4	10,000-14,999	5-6	1,4
RI	<2	-	4,000-4,999	9-10	4
SC	7-8	7-8	7,000-9,999	5-6	4
SD	<2	2-4	1,000-1,499	2-4	4
KMI	7-8	7-8	5,000-6,999	7-8	1,4
OMI	9-10	9-10	2,000-3,999	7-8	1,4

TABLE D-13
RESPONSES TO QUESTION 3B.PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Crack Filling**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AL	5-6	5-6	7,000-9,999	2-4	4
AK	<2	5-6	2,000-3,999	2-4	1,4
AZ	5-6	5-6	5,000-6,999	5-6	1,2,4
AR	5-6	5-6	1,000-1,499	2-4	4
CA	5-6	5-6	2,000-3,999	2-4	4
CT	7-8	2-4	10,000-14,999	5-6	1,2,4
GA	7-8	-	<1,000	2-4	2,4
IN	2-4	2-4	<1,000	2-4	2,4
IA	<2	<2	1,000-1,499	Unknown	4
KS	7-8	3-5	1,000-1,499	2-4	4
LA	5-6	5-6	5,000-6,999	2-4	1
ME	2-4	-	2,000-3,999	Unknown	1
MD	<2	2-4	5,000-6,999	2-4	1,2,4
MI	<2	-	2,000-3,999	5-6	4
MN	2-4	-	1,500-1,999	<2	3,4
MS	5-6	2-4	-	2-4	4
MO	2-4	2-4	1,500-1,999	7-8	4
NV	2-4	<2	15,000-24,999	2-4	1,2,4
NM	5-6	5-6	5,000-6,999	9-10	4
NY	2-4	2-4	1,500-1,999	Unknown	1,4
NC	5-6	7-8	2,000-3,999	7-8	4
OH	5-6	-	1,000-1,499	5-6	4
ON	2-4	2-4	2,000-3,999	5-6	4
PA	2-4	2-4	$7.40/gal	2-4	1,2,4
RI	7-8	-	2,000-3,999	7-8	4
SC	7-8	7-8	Varies	2-4	4
SD	2-4	2-4	1,000-1,499	2-4	4
TN	2-4	-	2,000-3,999	2-4	4
TX	10+	-	1,500-1,999	2-4	4
VT	2-4	-	1,000-1,499	5-6	2,4
WA	7-8	7-8	1,000-1,499	7-8	4
WI	2-4	5-6	1,500-1,999	2-4	1,2,4
CCA	7-8	2-4	2,000-3,999	2-4	4
GCT	2-4	2-4	<1,000	5-6	1
KMI	2-4	7-8	5,000-6,999	9-10	1
OMI	9-10	9-10	2,000-3,999	7-8	1,4
KMO	2-4	-	1,500-1,999	5-6	4
CWA	7-8	2-4	2,000-3,999	2-4	4

TABLE D-14
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Single Application Chip Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
CA	5-6	5-6	7,000-9,999	2-4	4
GA	12-13	-	2,000-3,999	4-5	2,4
IA	15-20	5-6	5,000-6,999	5-6	4
MN	2-5	-	7,000-9,999	Unknown	3,4
MS	7-8	5-6	4,000-4,999	5-6	4
MO	12-14	-	4,000-4,999	2-4	4
NV	5-6	2-4	10,000-14,999	5-6	1,2,4
NM	10-20	5-6	1,000-1,4999	5-6	2
NY	7-8	2-4	7,000-9,999	2-4	4
NC	7-8	5-6	5,000-6,999	5-6	4
PA	5-6	5-6	4,000-4,999	5-6	1,2,4
SD	2-4	5-6	4,000-4,999	2-4	4
TX	9-10	7-10+	7,000-9,999	7-8	4
WA	7-8	7-8	7,000-9,999	7-8	4
WI	2-4	5-6	2,000-3,999	2-4	1,2,4
CCA	7-8	5-6	4,000-4,999	5-6	1
GCT	10+	-	1,000-1,499	7-8	1
KMI	5-6	5-6	10,000-14,999	-	1,2
CWA	9-10	7-8	4,000-4,999	7-8	4

TABLE D-15
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement**

Preventive Maintenance Treatment:**Multiple Application Chip Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
GA	14-15	-	2,000-3,999	5-6	2,4
IA	15-20	5-6	5,000-6,999	5-6	4
NY	7-8	2-4	10,000-14,999	2-4	4
NC	7-8	5-6	7,000-9,999	5-6	4
PA	7-8	5-6	7,000-9,999	5-6	1,2,4
WI	5-6	5-6	4,000-4,999	5-6	1,2,4
CCA	7-8	5-6	5,000-6,999	5-6	1

TABLE D-16
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Slurry Seal**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AR	-	5-6	-	5-6	4
CA	5-6	5-6	10,000-14,999	2-4	4
MD	5-6	2-4	5,000-6,999	2-4	1,2,4
NC	7-8	5-6	4,000-4,999	5-6	4
KMI	9-10	9-10	15,000-24,999	9-10	4
KMO	4-5	-	5,000-6,999	5-6	4

TABLE D-17
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Micro-Surfacing**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
IN	9-10	-	10,000-14,999	4-6	1,4
KS	9-10	7-8	10.000-14,999	2-4	4
MI	>10	7-8	10,000-14,999	7-8	4
MS	7-8	-	7,000-9,999	Unknown	-
MO	9-10	-	7,000-9,999	2-4	4
NY	7-8	5-6	25,000-49,999	Unknown	4
NC	7-8	5-6	7,000-9,999	5-6	4
OH	9-10	-	7,000-9,999	5-6	4
ON	10-15	-	15,000-24,999	Hope for 5-7	3
TX	10+	-	10,000-14,999	5-6	4
WI	5-6	5-6	7,000-9,999	5-6	1,2,4

TABLE D-18
RESPONSES TO QUESTION 3B.
PREVENTIVE PAVEMENT MAINTENANCE TREATMENTS-COST AND PERFORMANCE INFORMATION

Pavement Type: **Overlaid Pavement (AC/PCC)**

Preventive Maintenance Treatment: **Thin HMA Overlay**

State/ Prov/ Local	Pav't age at the time of first application (yrs)	Freq of application (yrs)	Cost per lane mile (dollars)	Observed increase in pavement life (yrs)	Source of Information (See List)
AZ	9-10	9-10	15,000-24,999	7-8	1,2,4
CA	5-6	5-6	15,000-24,999	2-4	4
CT	9-10	2-4	7,000-9,999	2-4	4
GA	12-13	10-11	15,000-24,999	9-10	2,4
IN	9-10	-	10,000-14,999	5-6	1,4
IA	9-10	9-10	15,000-24,999	9-10	4
ME	9-10	9-10	4,000-4,999	2-4	4
MD	7-8	7-8	10,000-14,999 per inch	5-6	1,2,4
MS	9-10	5-6	15,000-24,999	5-6	4
MO	9-10	-	7,000-9,999	2-4	4
NV	5-6	5-6	25,000-49,999	2-4	1,2,4
NY	7-8	9-10	25,000-49,999	9-10	1,4
NC	7-8	7-8	7,000-9,999	7-8	4
OH	9-10	-	50,000-74,999	7-8	4
PA	7-8	9-10	15,000-24,999	7-8	1,2,4
TN	5-10	-	10,000-14,999	2-4	4
VT	9-10	7-8	25,000-49,999	5-6	2,4
VA	7-10	5-8	25,000-49,999	5-8	1,4
WI	9-10	9-10	25,000-49,999	5-6	1,2,4
OMI	10-12	9-10	15,000-24,999	9-10	1,4
KMO	9-10	-	10,000-14,999	9-10	4

TABLE D-19
RESPONSE TO QUESTION 4.
EXISTENCE OF A PAVEMENT PREVENTIVE MAINTENANCE STRATEGY, USES AND VARIATIONS BY FUNCTIONAL CLASS AND TRAFFIC VOLUMES

		Uses					Variations	
State/Prov/ Local	4A Have Strategy	4B(1) Pav't Design	4B(2) Maint Budget	4B(3) Order Mat'ls	4B(4) Sch'dW ork	4B(5) Other	4C Func Class	4D Traffic Volume
AL	NO							
AK	YES	X	X	X	X		NO	NO
AZ	NO							
AR	YES	X			X		YES	YES
BC	NO							
CA	YES		X		X		YES	YES
CO	NO							
CT	YES		X	X	X		YES	YES
FL	NO							
GA	NO							
HI	NO							
ID	YES	X		X			NO	NO
IL	YES							
IN	YES		X		X		YES	YES
IA	NO							
KS	YES			X	X		NO	NO
KY	NO							
LA	YES		X	X	X		NO	YES
ME	NO							
MD	YES	X	X	X	X		YES	YES
MI	YES					(1)	YES	YES
MN	NO							
MS	YES	X	X		X		YES	YES
MO	NO							
NE	NO							
NV	YES	X	X	X	X		NO	YES
NH	YES		X				YES	YES
NJ	YES					(2)	NO	NO
NM	YES	X	X	X	X		NO	NO
NY	YES	X					NO	NO
NC	YES	X					NO	YES

State/Prov/ Local	4A Have Strategy	Uses: 4B(1) Pav't Design	4B(2) Maint Budget	4B(3) Order Mat'ls	4B(4) Sch'dW ork	4B(5) Other	Variations: 4C Func Class	4D Traffic Volume
ND	YES		X				NO	NO
NS	NO							
OH	NO							
ON	YES		X		X		YES	YES
OR	NO							
PA	NO							
PE	NO							
RI	NO							
SC	NO							
SD	YES	X	X		X		YES	NO
TN	NO							
TX	NO							
VT	YES	X					YES	YES
VA	NO							
WA	YES	X	X	X	X		YES	YES
WV	NO							
WI	YES	X	X				YES	YES
WY	NO							
CCA	YES	X	X	X	X		YES	YES
GCT	NO							
BIL	NO							
MTA	YES		X	X	X		NO	YES
WMA	NO							
KMI	YES		X		X		YES	YES
OMI	YES	X			X		YES	YES
KMO	YES				X		YES	YES
MNC	NO							
SUT	YES	X	X	X	X		YES	YES
CWA	YES	X	X		X		YES	YES

FOOTNOTES

(1) To extend pavement life until major rehabilitation is completed
(2) Crack filling or micro-surfacing is used as needed, not formally scheduled

TABLE D-20
RESPONSES TO QUESTIONS 5C.
REASONS FOR NOT USING PAVEMENT PREVENTIVE MAINTENANCE

State/ Prov/ Local	5C(1) Cost effective not adequately demonstrated	5C(2) Funding agencies have not accepted demonstrated cost effectiveness	5C(3) All agree but there isn't enough money	5C(4) Other (See footnote)
AL			X	
AZ			X	
AR				(1)
BC		X		
CO			X	
CT			X	
FL			X	(2)
GA				(3)
IA				(4)
KS		X		(5)
KY	X			
LA	X	X		
ME			X	(6)
MI			X	(7)
MN	X			
MO				(8)
NE				(9)
NJ				(10)
NM	X			
ON			X	
OR	X			
PA			X	
RI		X		
SC				(11)
TN	X			(12)
TX		X	X	
VA		X	X	(13)
WV			X	

State/ Prov/ Local	5C(1) Cost effective not adequately demonstrated	5C(2) Funding agencies have not accepted demonstrated cost effectiveness	5C(3) All agree but there isn't enough money	5C(4) Other (See footnote)
WY	X		X	
GCT			X	
BIL				(14)
WMA		X		
KMI			X	
OMI			X	
KMO				

FOOTNOTES

(1) Preventive maintenance is not considered in our design strategy. However, preventive maintenance needs are assessed yearly for program planning and funding needs in each of our ten districts. District maintenance forces use preventive maintenance strategy to extend pavement life while balancing needs with cost effectiveness.

(2) Still in the process of development

(3) Preventive maintenance strategy is utilized on a project level basis, but not to the extent described in the definitions used in this survey. Development of a network wide preventive maintenance strategy is in progress and will be incorporated in the near future.

(4) Currently developing enhanced Pavement Management System that will fit with the planned Maintenance Management System. Hope to develop data that will allow us to implement preventive maintenance strategy.

(5) Design assumes Preventive Maintenance but do not do as much as is assumed.

(6) Require new thought process and planning which we are presently in the midst of completing but not yet implemented.

(7) Most preventive maintenance projects are accomplished through private contractors.

(8) We are presently developing pavement and maintenance management systems. We will not have a data base to support a preventive maintenance strategy until these systems are implemented.

(9) Have not developed any.

(10) While it is our practice to use preventive maintenance techniques, specific treatments or costs are not included in a life cycle cost analysis at this time. The maintenance management and pavement management systems are undergoing refinement and statewide implementation in accordance with ISTEA schedule. We would be very interested in getting data on cost, performance, and extension of pavement life.

(11) Limited funding is available. Preventive maintenance is performed as determined by observation of field engineers. Need, available funding, traffic, etc. are factors influencing p.m. performed. Crack sealing, chip seals and the like are usually incorporated into pavement rehabilitation or resurfacing programs.

(12) When the pavement management system is installed it will become a tool to formalize a "Pavement Maintenance Strategy". Currently Annual Work budgets are in Maintenance Management System. However, that system is not sophisticated enough to thoroughly track all preventive maintenance work envisioned by your definition.

(13) Administrators, legislators need to be educated on the benefits of preventive maintenance.

(14) The Village of Barrington is currently in the process of investigating the cost of implementing a twenty (20) year capital improvement program with a major focus on preventive maintenance strategies for our major roads. We currently fill cracks on both asphalt concrete and overlaid pavements on an as needed basis, the cost of which is approximately $0.90 /foot.

TABLE D-21
RESPONSE TO QUESTIONS 5A AND 5B.
PLANNING AND FUNDING PAVEMENT PREVENTIVE MAINTENANCE

		If yes		
State/ Prov/ Local	5A Assume prev maint strategy in pav't design ?	5B(1) Earmark funds in future years for prev maint?	5B(2) Are the maint funds adequate for prev maint?	5B(3) Transfer funds from capital to maint?
AL	NO			
AK	YES	YES	NO	NO
AZ	NO			
AR	NO			
BC	NO			
CA	NO			
CO	NO			
CT	YES	YES	NO	NO
FL	NO			
GA	NO			
HI	NO			
ID	YES	NO	NO	NO
IL	YES			
IN	YES	NO	NO	NO
IA	NO			
KS	YES	NO	NO	NO
KY	NO			
LA	NO			
ME	NO			
MD	YES	YES	NO	NO
MI	NO			
MN	NO			
MS	YES	YES	NO	NO
MO	NO			
NE	NO			
NV	YES	YES	YES	NO
NH	NO			
NJ	NO			
NM	YES	NO	NO	NO
NY	YES	NO	NO	YES
NC	YES	NO	NO	NO

State/ Prov/ Local	5A Assume prev maint strategy in pav't design ?	If yes 5B(1) Earmark funds in future years for prev maint?	5B(2) Are the maint funds adequate for prev maint?	5B(3) Transfer funds from capital to maint?
ND	NO			
NS	NO			
OH	NO			
ON	YES	NO	NO	NO
OR	NO			
PA	YES	NO	NO	NO
PE	YES	NO	NO	YES
RI	NO			
SC	NO			
SD	YES	NO	YES	NO
TN	NO			
TX	YES	YES	NO	NO
VT	YES	NO	NO	NO
VA	YES	NO		NO
WA	YES	YES	NO	NO
WV	NO			
WI	YES	YES	NO	NO
WY	YES	NO	NO	
CCA	YES	YES	NO	NO
GCT	NO			
BIL	NO			
MTA	YES	YES	YES	NO
WMA	NO			
KMI	YES	YES	NO	NO
OMI	NO			
KMO	NO			
MNC	NO			
SUT	YES	NO	NO	NO
CWA	NO			

TABLE D-22a
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Portland Cement Concrete**

Treatments and Codes: 1-Joint spall repair; 2-Joint sealer replacement; 3-Full-depth replacement patching; 4-Full-depth joint repair; 5-Partial depth repairs w/rotomill & fill w/HMA; 6-Crack fill

Year	State/Province/Local				
	CT	IN	IA	LA	MD
1					
2					
3					
4			2		
5					
6				1	2
7					
8					
9	2	1,2 **			2
10	2	1,2	1		1,3
11		1,2			
12		1,2	2		2
13					
14					
15					2
30			Rehab		

Cost-Effectiveness Information	State/Province/Local				
	CT	IN	IA	LA	MD
Time to rehab w/o strategy (yrs)	>10	21-25	21-25	13-15	13-15
Increase in time to rehab with strategy (yrs)	7-8 (PMS OE)*	7-8 (PMS OE)	9-10 (OE)	5-6 (OE)	5-6 (PMS OE)
Reduction in the time for demand maint, %	21-25 (PMS MMS OE)	Unknown	75 (OE)	16-20 (OE)	21-25 (MMS OE)
Reduction in the cost of demand maint, %	21-25 (PMS MMS)	Unknown	75 (OE)	11-15 (OE)	21-25 (MMS OE)
Improvement in PSI, %	16-20 (PMS OE)	11-15 (PMS OE)	11-15 (OE)	16-20 (OE)	>25 (MMS OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-22b
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Portland Cement Concrete**

Treatments and Codes: 1-Joint spall repair; 2-Joint sealer replacement; 3-Full-depth replacement patching; 4-Full-depth joint repair; 5-Partial depth repairs w/rotomill & fill w/ HMA; 6-Crack filling

Year	State/Province/Local				
	MI	MN	MO	NV	NM
1					
2				6	
3				1	
4				2,6	
5					1,2
6				1,6	
7	2				
8				2,6	
9			2	1	
10			1	6	2
11					
12		1,2	5	1,2,6	
13			2,3		
14			1,5		
15	4		3		2

Cost-Effectiveness Information	State/Province				
	MI	MN	MO	NV	NM
Time to rehab w/o strategy (yrs)	16-20	13-15	13-15	<10	16-20
Increase in time to rehab with strategy (yrs)	9-10	5-6 (OE)	9-10 (OE)	9-10 (PMS OE)	20
Reduction in the time for demand maint, %	16-20 (MMS)*	5-10 (OE)	>25 (OE)	5-10 (MMS OE)	>25
Reduction in the cost of demand maint, %	16-20 (MMS OE)	5-10 (OE)	>25 (OE)	16-20 (MMS OE)	>25 (MMS OE)
Improvement in PSI, %	16-20 (PMS OE)	11-15 (OE)	21-25 (OE)	16-20 (PMS MMS OE)	>25 (PMS RP)

* Source of the cost-effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-22c
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Portland Cement Concrete**

Treatments and Codes: 1-Joint spall repair; 2-Joint sealer replacement; 3-Full-depth replacement patching; 4-Full-depth joint repair; 5-Partial depth repairs w/rotomill & fill w/ HMA; 6-Crack filling

Year	State/Province/Local				
	NC	ON	PA	RI	TX
1					
2					
3					
4					
5			2		2
6					
7	2			1	
8					
9					
10	1	2		1	1,2
11					
12					
13				1	
14					
15		2			2
20		Rehab			

Cost-Effectiveness Information	State/Province				
	NC	ON	PA	RI	TX
Time to rehab w/o strategy (yrs)	13-15	13-15	13-15	13-15	21-25
Increase in time to rehab with strategy (yrs)	5-6	3-4 (PMS)	>10 (PMS OE)	7-8 (OE)	9-10 (OE)
Reduction in the time for demand maint, %	5-10 (OE)*	Unknown	21-25 (MMS)	11-15 (OE)	Unknown
Reduction in the cost of demand maint, %	5-10 (OE)	Unknown	11-15	11-15 (OE)	Unknown
Improvement in PSI, %	11-15 (OE)	5-10 (PMS OE)	5-10 (PMS MMS OE)	5-10 (OE)	Unknown

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-22d
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Portland Cement Concrete**

Treatments and Codes: 1-Joint spall repair; 2-Joint sealer replacement; 3-Full-depth replacement patching; 4-Full-depth joint repair; 5-Partial depth repairs w/rotomill & fill w/ HMA; 6-Crack filling

Year	State/Province/Local				
	VA	WA	KMI	OMI	KMO
1					
2					
3					
4					
5		2			
6					
7			1		
8	2				
9				2	
10		2			2,6
11					
12					
13					
14					
15		2			
16	2				

Cost-Effectiveness Information	State/Province/Local				
	VA	WA	KMI	OMI	KMO
Time to rehab w/o strategy (yrs)	16-20	21-25	25	>25	21-25
Increase in time to rehab with strategy (yrs)	5-6 (OE)*	>10 (OE)	9-10 (PMS)	7-8 (PMS)	9-10 (OE)
Reduction in the time for demand maint, %	11-15 (OE)	11-15 (OE)	>25 (OE)	21-25 (OE)	5-10 (OE)
Reduction in the cost of demand maint, %	5-10 (OE)	11-15 (OE)	21-25 (OE)	21-25 (OE)	5-10 (OE)
Improvement in PSI, %	5-10 (OE)	5-10 (OE)	>25 (OE)	16-20 (PMS)	5-10 (OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-23a
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single Appl Chip Seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot-mix patching; 12-2 inch overlay; 13-Rut filling; 14-1-1/2 inch overlay

Year	State/Province				
	AK	CT	IN(1)	IN(2)	IA
1	1				
2	1		1		1
3	1			1	
4	1		1		1
5	1			1	
6	1		2		1
7	1	1		1	
8	1	3	1		1
9	1			1, 3 or 5	
10	1		1		1
11	1	2	2	1	
12	1		1		1
13	1	1,4			
14	1		1	Rehab or	1
15	1			Rehab	
16	Rehab	Rehab Overlay	Rehab		
20					Rehab

Cost-Effectiveness Information	State/Province				
	AK	CT	IN(1)	IN(2)	IA
Time to rehab w/o strategy (yrs)	13-15	10-12	10-12	10-12	16-20
Increase in time to rehab with strategy (yrs)	2-3 (PMS RP OE)*	3-4 (OE)	5-6 (PMS)	3-4 (PMS OE)	3-4 (OE)
Reduction in the time for demand maint, %	5-10 (PMS OE)	5-10 (MMS)	5-10 (OE)	5-10 (OE)	75 (OE)
Reduction in the cost of demand maint, %	5-10 (PMS OE)	5-10 (MMS)	5-10 (OE)	5-10 (OE)	75 (OE)
Improvement in PSI, %		11-15 (MMS OE)	11-15 (PMS RP)	11-15 (PMS OE)	16-20 (OE)

TABLE D-23b
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single appl chip seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry Seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot-mix patching; 12-2 inch overlay; 13-Rut filling; 14-1-1/2 inch HMA overlay

Year	State/Province				
	LA	MD	MI	MN	MS
1				1	
2				1	
3				1	
4			1	1	
5				2	7
6				2	
7		1	1,2,5	2	1,2,5
8		3		2	
9	2			2	
10		1,6		2	3
11			1	2	
12				3	
13		1		3	
14			1,2,3,5	3	
15		3,6		3	

Cost Effectiveness Information	State/Province				
	LA	MD	MI	MN	MS
Time to rehab w/o strategy (yrs)	13-15	<10	13-15	16-20	10-12
Increase in time to rehab with strategy (yrs)	3-4 (OE)*	7-8 (PMS MMS OE)	5-6 (OE)	5-6 (OE)	5-6 (MMS OE)
Reduction in the time for demand maint, %	11-15 (OE)	21-25 (MMS OE)	21-25 (PMS MMS)	5-10 (OE)	21-25 (MMS OE)
Reduction in the cost of demand maint, %	11-15 (OE)	21-25 (MMS OE)	21-25 (PMS MMS)	11-15 (OE)	16-20 (MMS OE)
Improvement in PSI, %	16-20 (OE)	21-25 (OE)	16-20 (PMS OE)	5-10 (OE)	16-20 (MMS OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-23c
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single Appl Chip Seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot-mix patching; 12-2 inch overlay; 13-Rut fill; 14-1-1/2 inch overlay

Year	State/Province				
	MO	NV	NM	NC	ON
1					
2		1,9			
3	1				1
4		1,2,9		6	
5	1	7	1,2	1,5	
6		1,9			
7	1			2,3	1
8	5	1,9		6,7	
9	1	2			
10	3,8	1,7,9	2,10	5	
11	1				11
12	8	1,9		1,6	
13	1,2	2			
14	8	1,9			
15	1		2	2,3,7	Rehab
20	Rehab				

Cost-Effectiveness Information	State/Province				
	MO	NV	NM	NC	ON
Time to rehab w/o strategy (yrs)	10-12	10-12	<10	10-12	10-12
Increase in time to rehab with strategy (yrs)	5-6 (OE)*	7-8 (PMS OE)	5-6	5-6 (OE)	5-6 (PMS RP OE)
Reduction in the time for demand maint, %	>25 (OE)	21-25 (MMS OE)	>25	5-10 (OE)	Unknown
Reduction in the cost of demand maint, %	>25 (OE)	16-20 (MMS OE)	>25 (MMS RP OE)	5-10 (OE)	Unknown
Improvement in PSI, %	21-25 (OE)	16-20 (PMS MMS OE)	>25 (PMS)	11-15 (OE)	5-10 (PMS RP)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-23d
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single Appl Chip Seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot-mix patching; 12-2 inch overlay; 13-Rut filling; 14-1-1/2 inch HMA Overlay

Year	State/Province				
	PA	RI	SD	TX	VA
1					
2			1		
3			1		
4	1		2		
5			1	1	
6			1		
7		1	1	2	14
8	1,2,3,5,6,7		1		
9			1		
10			2	1	
11			1		
12	1,2,3,5,6,7		1		
13		12	1		
14			1	2,3,5,13	14
15			1	1	
16			Rehab		

Cost-Effectiveness Information	State/Province				
	PA	RI	SD	TX	VA
Time to rehab w/o strategy (yrs)	10-12	13-15	10-12	13-15	13-15
Increase in time to rehab with strategy (yrs)	9-10 (PMS OE)*	7-8 (OE)	5-6 (PMS RP OE)	In definite	5-6 (PMS)
Reduction in the time for demand maint, %	5-10 (PMS MMS OE)	16-20 (OE)	5-10 (OE)	50 (OE)	5-10 (OE)
Reduction in the cost of demand maint, %	5-10	11-15 (OE)	16-20 (OE)	50 (OE)	<5 (OE)
Improvement in PSI, %	21-25 (PMS MMS OE)	16-20 (OE)	11-15 (PMS OE)	>25 (OE)	16-20 (PMS)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-23e
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single Appl Chip Seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot- mix patching; 12-2 inch overlay; 13-Rut filling; 14-1-1/2 inch HMA overlay

Year	State/Province/Local				
	WA	CCA	MTA	KMI	OMI
1			1		
2				1	
3			1		
4					
5			1	2	
6	1				
7		1,2,6,7	1	6	
8	2				
9			1		1
10	3	1		2,3	
11				3	
12				3	3
13		1,2,6,7		3	
14				3,6	
15				2,3	

Cost-Effectiveness Information	State/Province/Local				
	WA	CCA	MTA	KMI	OMI
Time to rehab w/o strategy (yrs)	10-12	13-15	2-3	-	10-12
Increase in time to rehab with strategy (yrs)	5-6 (OE)*	>10 (PMS)	3-4 (PMS)	9-10	>10 (PMS)
Reduction in the time for demand maint, %	5-10 (OE)	>25 (OE)	5-10 (OE)	-	>25 (OE)
Reduction in the cost of demand maint, %	<5 (OE)	>25 (OE)	11-15 (OE)	-	>25 (OE)
Improvement in PSI, %	5-10 (OE)	>25 (PMS)	-	-	>25 (PMS)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-23f
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Asphalt Concrete**

Treatments and Codes: 1-Fill Cracks; 2-Single Appl Chip Seal; 3-Thin HMA; 4-Vendor-in-place paving; 5-Micro-surfacing; 6-Slurry seal; 7-Multi-appl chip seal; 8-Rotomill & fill w/HMA; 9-Flush seal; 10-Heater remix; 11-Hot-mix patching; 12-2 inch overlay; 13-Rut fill; 14-1-1/2 inch overlay

Year	State/Province/Local	
	KMO	SUT
1		
2		1
3		
4	1	
5	6	2,5,6
6		
7		1
8	1	
9		
10	8	2,5,6
11		
12	1	12
13		
14		
15		Rehab

Cost Effectiveness Information	State/Province	
	KMO	SUT
Time to rehab w/o strategy (yrs)	>25	13-15
Increase in time to rehab with strategy (yrs)	9-10 (OE)*	5-6 (PMS)
Reduction in the time for demand maint, %	16-20 (OE)	-
Reduction in the cost of demand maint, %	16-20 (OE)	-
Improvement in PSI, %	16-20 (OE)	-

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-24a
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Overlaid Pavements (AC/PCC)**

Treatments and Codes: 1-Fill cracks; 2-Micro-surface; 3-Thin HMA; 4-Slurry seal; 5-Fill saw & seal joints; 6-Seal cracks; 7-Single appl chip seal; 8-Multi-appl chip seal; 9-Hot mix patching; 10-Micro-surfacing; 11-2 inch overlay

Year	State/Province/Local				
	IN(1)	IA	MD	MI	MN
1					5
2	1	1	1	1	6 or
3					6 or
4	1	1			6 or
5					6,7 or
6	1	1	1	1	7 or
7			4		7 or
8	1	1	3		7 or
9	2,3				7 or
10	1	1	1	1	7 or
11			4		
12	1	1			3 or
13					3 or
14		1	1	1,2	3 or
15		Rehab	3,4		3

Cost-Effectiveness Information	State/Province/Local				
	IN	IA	MD	MI	MN
Time to rehab w/o strategy (yrs)	10-12	10-12	<10	13-15	13-15
Increase in time to rehab with strategy (yrs)	3-4 (PMS OE)*	3-4 (OE)	5-6 (PMS OE)	5-6 (OE)	5-6 (OE)
Reduction in the time for demand maint, %	5-10 (OE)	>75 (OE)	16-20 (MMS OE)	16-20 (PMS MMS)	5-10 (OE)
Reduction in the cost of demand maint, %	5-10 (OE)	>75 (OE)	16-20 (MMS OE)	16-20 (PMS MMS)	5-10 (OE)
Improvement in PSI, %	11-15 (PMS OE)	16-20 (OE)	16-20 (OE)	16-20 (PMS OE)	5-10 (OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

(1) Most are moderate to high volume roads.

TABLE D-24b
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Overlaid Pavements (AC/PCC)**

Treatments and Codes: 1-Fill cracks; 2-Micro-surface; 3-Thin HMA; 4-Slurry seal; 5-Fill saw & seal joints; 6-Seal cracks; 7-Single appl chip seal; 8-Multi-appl chip seal; 9-Hot-mix patching; 10-Micro-surfacing; 11-2 inch overlay

Year	State/Province/Local				
	MS	MO	NV	NM	NC
1					
2			1		
3		1			
4			1,5		
5	1		7	1,5	
6		1	1,8		1
7	2,7				
8			1,5		3,7,8
9		1			
10	3		1,7	1,5	
11					
12		1	1,5,8		
13					1
14					7,8
15		1		1	3
20		Rehab			

Cost-Effectiveness Information	State/Province/Local				
	MS	MO	NV	NM	NC
Time to rehab w/o strategy (yrs)	13-15	13-15	10-12	10-12	10-12
Increase in time to rehab with strategy (yrs)	5-6 (MMS OE)*	5-6 (OE)	7-8 (PMS OE)	5-6	3-4 (OE)
Reduction in the time for demand maint, %	16-20 (MMS OE)	>25 (OE)	16-20 (MMS OE)	>25	5-10 (OE)
Reduction in the cost of demand maint, %	16-20 (MMS OE)	>25 (OE)	16-20 (MMS OE)	>25 (MMS RP OE)	5-10 (OE)
Improvement in PSI, %	-	>25 (OE)	11-15 (PMS MMS OE)	>25 (PMS)	11-15 (OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-24c
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Overlaid Pavements (AC/PCC)**

Treatments and Codes: 1-Fill cracks; 2-Micro-surface; 3-Thin HMA; 4-Slurry seal; 5-Fill saw & seal joints; 6-Seal cracks; 7-Single appl chip seal; 8-Multi-appl chip seal; 9-Hot-mix patching; 10-Micro-surfacing; 11-2 inch overlay

Year	State/Province/Local				
	ON	PA	RI	TX	CCA
1			5		
2	5				
3	1				
4		1			
5				1	
6					
7	1		1	7	1,7,8
8		1,4,7,8,10			
9					
10				1	1
11	9				
12		1,3,7,8,10			
13			11		1,7,8
14				3,7,10	
15	Rehab			1	

Cost-Effectiveness Information	State/Province/Local				
	ON	PA	RI	TX	CCA
Time to rehab w/o strategy (yrs)	10-12	10-12	<10		13-15
Increase in time to rehab with strategy (yrs)	3-4 (PMS RP OE)*	7-8 (PMS MMS OE)	9-10 (OE)	In definite	>10 (PMS)
Reduction in the time for demand maint, %	Unknown	21-25 (PMS MMS OE)	16-20 (OE)	50 (OE)	>25 (OE)
Reduction in the cost of demand maint, %	Unknown	21-25 (PMS MMS OE)	21-25 (OE)	50 (OE)	>25 (OE)
Improvement in PSI, %	5-10 (PMS OE)	>25 (PMS MMS OE)	21-25 (OE)	>25 (OE)	>25 (PMS)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-24d
RESPONSE TO QUESTION 4E.
PREVENTIVE MAINTENANCE STRATEGY

Pavement Type: **Overlaid Pavements (AC/PCC)**

Treatments and Codes: 1-Fill cracks; 2-Micro-surface; 3-Thin HMA; 4-Slurry seal; 5-Fill saw & seal joints; 6-Seal cracks; 7-Single appl chip seal; 8-Multi-appl chip seal; 9-Hot-mix patching; 10-Micro-surfacing; 11-2 inch overlay

Year	State/Province/Local		
	KMI	OMI	KMO
1			
2			
3	5		
4			1
5	7		4
6			
7			
8	5		1
9		1,5	
10	7		
11			
12		3	1
13			
14	5		
15	7		

Cost-Effectiveness Information	State/Province/Local		
	KMI	OMI	KMI
Time to rehab w/o strategy (yrs)	-	13-15	21-25
Increase in time to rehab with strategy (yrs)	12-14 (PMS)*	>10 (PMS)	9-10 (OE)
Reduction in the time for demand maint, %	-	>25 (OE)	16-20 (OE)
Reduction in the cost of demand maint, %	>25 (OE)	>25 (OE)	16-20 (OE)
Improvement in PSI, %	>25 (OE)	>25 (PMS)	16-20 (OE)

* Source of the cost effectiveness information. PMS=Pavement Management System, MMS=Maintenance Management System, RP=Research Project, OE=Observational Experience.

TABLE D-25
RESPONSES TO QUESTION 6.
FURTHER WORK NEEDED

State/ Prov/ Local	6A Demonstrate the cost effectiveness of preventive maintenance	6B Presentations and literature on the benefits of preventive maintenance	6C Other (See footnote)
AK	X	X	
AZ		X	
BC		X	
CA	X	X	
CO	X	X	
CT		X	
FL		X	
GA	X		
ID			
IN	X	X	
IA	X		
KS		X	
LA	X	X	
MD	X	X	
MI		X	
MN	X	X	
MS		X	
MO			(1)
NV	X	X	(2)
NH	X	X	
NJ	X		(3)
NM		X	
NY	X		
NC	X		
NS			
OH	X		
ON		X	
OR	X		
PA		X	(4)
SD	X		
TN	X	X	
TX			(5)
VT	X		
VA	X	X	
WA		X	
WV	X		
WI	X	X	
WY	X	X	(6)
CCA	X	X	(7)
BIL	X	X	
KMI	X		
OMI	X	X	

FOOTNOTES

(1) Management system needs to be developed as soon as possible to provide data for preventive maintenance strategy.
(2) Reports needed to outline the preventive maintenance process, including performance curves and life cycle cost analysis procedure, then follow-up review.
(3) Cost and pavement performance data are needed.
(4) Maintenance funds must be kept separate from capital project appropriations or be secured from diversion of funds due to political changes.
(5) Research needed to define ESAL/truck loaded routes.
(6) It is generally accepted by all that preventive maintenance is cost effective. However, funding is never sufficient to perform the treatment at the proper time.
(7) Research, presentations, and literature aimed at increasing public awareness of the benefits of pavement preventive maintenance.
(8) Further research is not necessary, but we need more money.

APPENDIX E

Examples of Preventive Maintenance Strategies From State DOTs' Publications

FULL-DEPTH AC PAVEMENT

Effective July 1, 1991
Maintenance and Rehabilitation Activity Schedule
Traffic Factor Less Than 15.0 (Rural)
Traffic Factor Less Than 10.0 (Urban)

ACTIVITY	CURRENT FREQUENCY	REVISION	REMARKS
LONGITUDINAL SHOULDER CRACKS Rout and Seal with 3405	50% at 11, 21 and 33 years	100% at 3, 12, 21, 31 years	Based on field observations and Department's experience.
C_L CRACKS Rout and Seal with 3405	50% at 11, 21 and 33 years	100% at 3, 12, 21, 31 years 100% at 23 and 31 years	For single lane paving* For full-width paving*
THERMAL/TRANS-VERSE CRACKS (Assume 100 ft. Spacing) Rout and Seal with 3405	20% at 1 and 2 years 60% at 3 years 100% at 11, 21, and 33 years	15% at 3 years 50% at 6 years 100% at 12, 21, and 31 years	Based an field observations. Projecting field observations. Insufficient information available to support a revision in percentages. Years changed to conform to other sealing schedules (one contract).
Random cracks (Assume 100 Lin. Ft. per station) Rout and Seal with 3405	50% at 11, 21, and 33 years	50% at 12, 21, and 31 years	Insufficient information available to support a revision. Years changed to conform to other sealing schedules (one contract).
PAVEMENT PATCHING (4 ft. Bituminous)	0.5% at 5 years 3% at 10 and 32 years 4% at 20 years	No Specified Length	Insufficient information available to support a revision Deleted (4 ft. bituminous) since patches will be random locations and lengths.
Shoulder Patching (Bituminous)	6% at 10, 20 and 32 years	2% at 10 years 4% at 20 years 3% at 32 years	Based on field observations, improved subgrade and underdrains. Projecting field observations.
Policy Overlay Mill 3/4" and Lay 3 1/4" (Interstate) 2" (Primary) AC Surface (Estimate) (Thickness Minus 3/4" on Shoulders)	At 20 years		Current Department Policy
Routine Maintenance	$1010 per year/2-lane mile		Insufficient information available to support a revision.
			3405 Refers to ASTM D 3405

*Paving width is job specific.

FIGURE E-1 Illinois DOT strategy for full-depth mechanistically designed AC pavements, traffic factor 1 *(1)*.

FULL-DEPTH AC PAVEMENT
Effective July 1, 1991
Maintenance and Rehabilitation Activity Schedule
Traffic Factor Greater than 15.0 and Less than 24.5 (Rural)
Traffic Factor Greater than 10.0 and Less than 16.3 (Urban)

ACTIVITY	CURRENT FREQUENCY	REVISION	REMARKS
LONGITUDINAL SHOULDER CRACKS Rout and Seal with 3405	50% at 11, 21 and 33 years	100% at 3, 11, 21, 33 years	Based on field observations and Department's experience.
C_L CRACKS Rout and Seal with 3405	50% at 11, 21 and 33 years	100% at 3, 11, 21, and 33 years 100% at 13, 21 and 33 years	For single lane paving[*] For full-width paving[*]
THERMAL/TRANS-VERSE CRACKS (Assume 100 ft. Spacing) Rout and Seal with 3405	20% at 1 and 2 years 60% at 3 years 100% at 11, 21, and 33 years	15% at 3 years 50% at 6 years 100% at 11, 21, and 33 years	Based on field observations. Projecting field observations. Insufficient information available to support a revision in percentages.
Random cracks (Assume 100 Lin. Ft. per station) Rout and Seal with 3405	50% at 11, 21, and 33 years		Insufficient information available to support a revision.
PAVEMENT PATCHING (4 ft. Bituminous)	0.5% at 5 years 3% at 10 and 32 years 4% at 20 years	No Specified Length	No information available to support changing percent Deleted (4 ft. bituminous) since patches will be random locations and lengths.
Shoulder Patching (Bituminous)	6% at 10, 20 and 32 years	2% at 10 years 4% at 20 years 3% at 32 years	Based on field observations, improved subgrade and underdrains. Projecting field observations.
Policy Overlay Mill 3/4" and Lay 3 1/4" (Interstate) 2" (Primary) AC Surface (Estimate) (Full thickness on pavement; Thickness Minus 3/4" on Shoulders)	At 20 years		Current Department Policy
Routine Maintenance	$1010 per year/2-lane mile		Insufficient information available to support a revision. 3405 Refers to ASTM D 3405

[*]Paving width is job specific.

FIGURE E-2 Illinois DOT strategy for full-depth mechanistically designed AC pavements, traffic factor 2 *(1)*.

FULL-DEPTH AC PAVEMENT
Effective July 1, 1991
Maintenance and Rehabilitation Activity Schedule
Traffic Factor Greater than 24.5 and Less than 34.0 (Rural)
Traffic Factor Greater than 16.3 and Less than 22.7 (Urban)

ACTIVITY	CURRENT FREQUENCY	REVISION	REMARKS
LONGITUDINAL SHOULDER CRACKS Rout and Seal with 3405	50% at 8, 15, 21 and 31 years	100% at 3, 8, 15, 21, 31 years	Based on field observations and Department's experience.
C_L CRACKS Rout and Seal with 3405	50% at 8, 15, 21 and 31 years	100% at 3, 8, 15, 21, and 31 years 100% at 10, 21 and 31 years	For single lane paving* For full-width paving*
THERMAL/TRANS-VERSE CRACKS (Assume 100 ft. Spacing) Rout and Seal with 3405	20% at 1 and 2 years 60% at 3 years 100% at 8, 15, 21, and 31 years	15% at 3 years 50% at 8, 12, and 15 years 100% at 21 and 31 years	Based on field observations. Projecting field observations. Insufficient information available to support a revision to years 21 and 31.
Random cracks (Assume 100 Lin. Ft. per station) Rout and Seal with 3405	50% at 8, 15, and 31 years	50% at 8, 15, 21, and 31 years	Insufficient information available to support a revision. Year 21 inadvertently omitted from current model.
PAVEMENT PATCHING (4 ft. Bituminous)	0.5% at 5 years 3% at 7 and 30 years 4% at 20 years	No Specified Length	Insufficient information available to support changing percent Deleted (4 ft. bituminous) since patches will be random locations and lengths.
Shoulder Patching (Bituminous)	6% at 7, 20 and 30 years	2% at 7 years 4% at 20 years 3% at 30 years	Based on field observations, improved subgrade and underdrains. Projecting field observations.
Surface Corrections Mill 3/4" and Lay 1 1/2" AC surface	At 7 and 30 years	3/4" on shoulder	Clarification. Included in current economic analysis.
Policy Overlay Mill 3/4" and Lay 3 1/4" (Interstate) 2" (Primary) AC Surface (Estimate) (Full thickness on pavement; Thickness Minus 3/4" on Shoulders)	At 20 years		Current Department Policy
Routine Maintenance	$1010 per year/2-lane mile		Insufficient information available to support a revision.
			3405 Refers to ASTM D 3405

*Paving width is job specific.

FIGURE E-3 Illinois DOT strategy for full-depth mechanistically designed AC pavements, traffic factor 3 *(1)*.

FULL-DEPTH AC PAVEMENT
Effective July 1, 1991
Maintenance and Rehabilitation Activity Schedule
Traffic Factor Greater than 34 (Rural)
Traffic Factor Greater than 22.7 (Urban)

ACTIVITY	CURRENT FREQUENCY	REVISION	REMARKS
LONGITUDINAL SHOULDER CRACKS Rout and Seal with 3405	50% at 6, 14, 21, 29 and 37 years	100% at 3, 6, 14, 21, 29, and 37 years	Based on field observations and Department's experience.
C_L CRACKS Rout and Seal with 3405	50% at 6, 14, 21, 29, and 37 years	100% at 3, 6, 14, 21, 29, and 37 years 100% at 8, 14, 21, 29 and 37 years	For single lane paving* For full-width paving*
THERMAL/TRANS-VERSE CRACKS (Assume 100 ft. Spacing) Rout and Seal with 3405	20% at 1 and 2 years 60% at 3 years 100% at 6, 14, 21, 29, and 37 years	15% at 3 years 50% at 6 years 100% at 14, 21, 29, and 37 years	Based on field observations. Projecting field observations. Insufficient information available to support a revision at years 14, 21, 29 and 37.
Random cracks (Assume 100 Lin. Ft. per station) Rout and Seal with 3405	50% at 6, 14, 29, and 37 years	50% at 6, 14, 21, 29, and 37 years	Insufficient information available to support a revision. Year 21 inadvertently omitted from current model.
PAVEMENT PATCHING (4 ft. Bituminous)	0.5% at 5 years 2% at 13, 28, and 36 years 4% at 20 years	No Specified Length	Insufficient information available to support revising percent Deleted (4 ft. bituminous) since patches will be random locations and lengths.
Shoulder Patching (Bituminous)	4% at 5, 13, 20, and 28 years	1% at 5 years 2% at 13, 20, 28, and 36 years 3% at 30 years	Based on field observations, improved subgrade and underdrains. Projecting field observations.
Surface Corrections Mill 3/4" and Lay 1 1/2" AC surface	At 5, 13, 28, and 36 years	3/4" on shoulder	Clarification. Included in current economic analysis.
Policy Overlay Mill 3/4" and Lay 3 1/4" (Interstate) 2" (Primary) AC Surface (Estimate) (Full thickness on pavement; Thickness Minus 3/4" on Shoulders)	At 20 years		Current Department Policy
Routine Maintenance	$1010 per year/2-lane mile		Insufficient information available to support a revision.
			3405 Refers to ASTM D 3405

*Paving width is job specific.

FIGURE E-4 Illinois DOT strategy for full-depth mechanistically designed AC pavements, traffic factor 4 *(1)*.

E. Preventative Maintenance

The following chart is a list of maintenance treatments used on a freeway facility depending on the type of pavement structure.

SCHEME	DESIGN LIFE (YRS)	YEAR OF TREATMENT	MAINTENANCE TREATMENT
SCHEME A CONCRETE	20	10 15 20	Reseal 10% of all joints Reseal 20% of all joints REHABILITATION
	25	10 15 20 25	Reseal 10% of all joints Reseal 20% of all joints Reseal 20% of all joints REHABILITATION
SCHEME B COMPOSITE	18	3 7 11 15 18 21 25 29	Rout and Seal 70% of transverse joints Rout and Seal 30% of transverse joints and 30% of longitudinal joints Rout and Seal 70% of longitudinal joints Reseal 30% of sealed cracks REHABILITATION Rout and Seal 70% of transverse joints Rout and Seal 30% of transverse joints and 30% of longitudinal joints Rout and Seal 70% of longitudinal joints
SCHEME C FULL DEPTH	15	3 7 11 15 18 22 27	Rout and Seal 250 m of transverse cracks and 250 m centreline cracks Rout and Seal 250 m of centreline and 520 m of transverse cracking Mill 25 mm and patch with 25 mm OFC (5%) REHABILITATION Rout and Seal 250 m of transverse cracks and 250 m centreline cracks Rout and Seal 250 m of centreline and 520 m of transverse cracking REHABILITATION
SCHEME D DEEP STRENGTH	15	3 7 11 15 18 22 27	Rout and Seal 250 m of centreline cracks and 750 m transverse cracks Rout and Seal 250 m of centreline and 520 m of transverse cracking Mill 25 mm and patch with 25 mm OFC (5%) REHABILITATION Rout and Seal 250 m of transverse cracks and 750 m centreline cracks Rout and Seal 250 m of centreline and 520 m of transverse cracking REHABILITATION

FIGURE E-5 Preventive maintenance strategies used by the Province of Ontario on freeways.

Single-Course Overlay (1" to 1-1/2")

1. Treatment Guidelines

Conditions For Use

1. Low-severity cracking.
2. Infrequent corrugations, settlements, heaves, slippage cracks, ravelling, and/or high-severity cracking.
3. Medium-severity wheelpath rutting and/or widening dropoff.

Constructability

1. Advantages
   a. Can be done one lane at a time.
   b. Overnight lane closures not required.
   c. Common rehabilitation technique.

2. Disadvantages
   a. Crack filling, shimming wheel ruts are required to achieve service life.

Performance

1. Restores ride, friction, and cross-slope.
2. Maintenance required early in overlay life to fill or seal reflective cracks. Full-width transverse cracks are sealed after first year, others filled after second year.

Expected Failure Modes

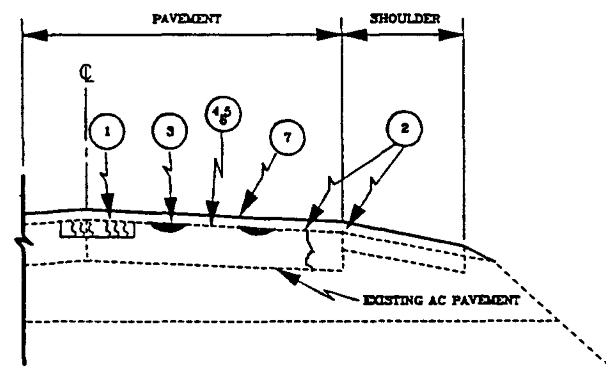
1. Reflective cracking, oxidation, cracking, potholes, ravelling, and rutting.

Expected Service Life

8 years with full-width transverse crack sealing at 5-year intervals and other cracks filled at 2-year intervals.

FIGURE E-6 Example of preventive maintenance treatment guidelines provided to designers by NYSDOT *(2)*.

2. Typical Section



1. **Mill and patch high-severity cracks with asphalt concrete.**
2. **Clean and fill cracks and pavement/shoulder joint.**
3. **Shim wheel ruts.**
4. **Clean pavement.**
5. **Tack coat**
6. **Truing-and-leveling**
7. **Asphalt concrete top course (1" to 1-1/2").**

FIGURE E-7 Example of typical section that accompanies guidelines in Figure E-6 *(2)*.

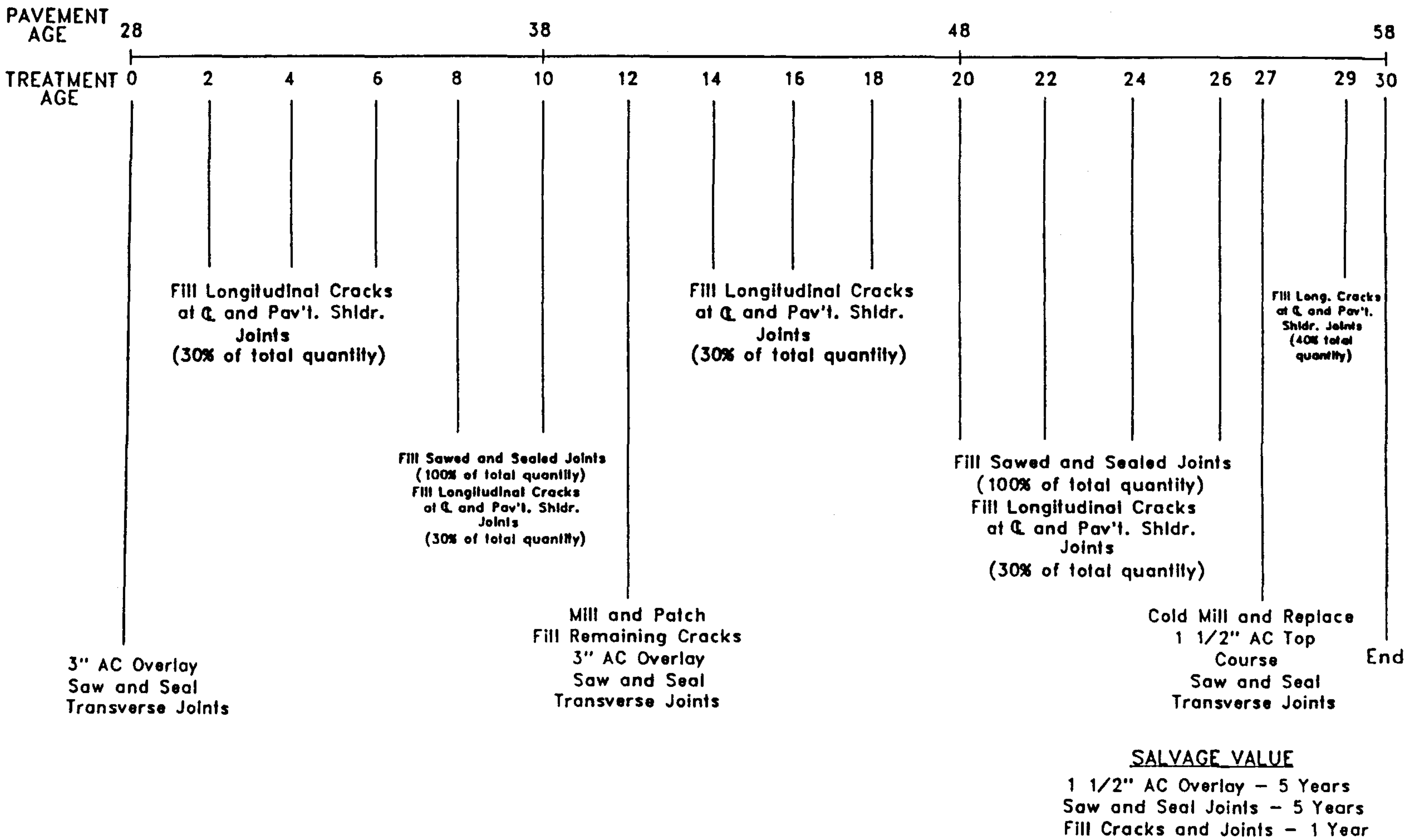


FIGURE E-8 Example of a preventive maintenance strategy provided to designers by NYSDOT *(2)*.

REFERENCES

1. *Mechanistic Pavement Design,* Illinois Department of Transportation.
2. Pavement Rehabilitation Manual, Volume II: Treatment Selection, Materials Bureau, New York State Department of Transportation, Albany (1991).

APPENDIX F

Simulation of Pavement Management Strategies

The following simulation was provided by Dr. Donald M. Walker, Director, Wisconsin Transportation Information Center at the University of Wisconsin-Madison.

The Wisconsin Department of Transportation, in cooperation with the Transportation Information Center, has developed a pavement management system for use by local agencies to comply with the now optional Pavement Management System requirements of ISTEA. The system is based on a pavement condition rating system with a scale of 1 to 10, where a new pavement has a rating of 10 and a failed pavement has a rating of 1. The software package that implements the system is condition of the roadway system. It also projects 5 years of deterioration. The user can select projects with a priority called Roadware. It has the capability to provide cost estimates for rehabilitation or maintenance given the existing scheme that essentially selects the worst first (assigning high priority to high-volume roads). The user may also select projects using a different strategy (such as preventive maintenance projects first). The user must enter the annual budget expenditures. The The evaluation of the effectiveness of different strategies is

A	PROJECT SELECTION: DO NOTHING		
YEAR	COST	BACKLOG	CR
1	$0	$2,436,580	5.88
2	$0	$2,437,638	5.39
3	$0	$3,591,228	4.98
4	$0	$5,058,285	4.65
5	$0	$5,128,415	4.31
TOTALS	$0	$5,128,415	3.98

B	PROJECT SELECTION: DO EVERYTHING		
YEAR	COST	BACKLOG	CR
1	$2,436,580	$0	5.88
2	$1,220	$0	7.87
3	$4,388	$0	7.49
4	$151,856	$0	7.16
5	$156,221	$0	7.26
TOTALS	$2,750,265	$0	7.07

C	PROJECT SELECTION: DO PM's ONLY		
YEAR	COST	BACKLOG	CR
1	$265,326	$2,171,254	5.88
2	$1,704	$2,170,608	6.39
3	$162	$2,174,834	6.01
4	$150,798	$3,610,060	5.67
5	$65,792	$3,610,060	5.78
TOTALS	$483,782	$3,610,060	5.58

FIGURE F-1 Tables A, B, and C of strategies.

D	PROJECT SELECTION: Roadware Priority		
YEAR	COST	BACKLOG	CR
1	$799,973	$1,636,607	5.88
2	$799,876	$837,789	5.95
3	$799,974	$962,478	6.25
4	$799,960	$236,869	6.54
5	$349,179	$0	6.77
TOTALS	$3,548,962	$0	7.03

E	PROJECT SELECTION:- DO PM's first,		
$800,000/yr	then do resurfacing and reconstruction		
YEAR	COST	BACKLOG	CR
1	$799,905	$1,636,675	5.88
2	$799,678	$838,055	6.74
3	$798,955	$43,970	6.92
4	$239,924	$0	7.23
5	$88,588	$0	7.40
TOTALS	$2,727,050	$0	7.18

F	PROJECT SELECTION: - NO PM's		
$800,000/yr	Do only resurfacing and reconstruction		
YEAR	COST	BACKLOG	CR
1	$799,790	$1,636,790	5.88
2	$799,633	$838,215	5.94
3	$799,917	$1,191,888	6.09
4	$798,352	$470,685	6.36
5	$307,217	$264,792	6.57
TOTALS	$3,504,909	$264,792	6.45

FIGURE F-2 Tables D, E, and F of strategies.

accomplished through a comparison of the backlog and system condition rating (CR). The backlog is simply the total of all of the maintenance and rehabilitation work required on the system at any given point in time. The system condition rating is the weighted average of the condition rating of all of the segments in the system.

The roadway system used for this simulation is a small city network of 68 miles of roads divided into approximately 400 individual segments. Tables A through F are shown in Figures F-1 and F-2.

- Table A is the do-nothing strategy. It shows in year 1 that the total backlog of work required is $2.4 million and the system condition rating is 5.88. If no maintenance or repair work is completed, at the end of 5 years the total backlog increases to $5.1 million and the condition rating deteriorates to 3.98.
- Table B is the strategy that does everything as it is needed. This shows an expenditure in year 1 of $2.4 million. As the pavements deteriorate throughout the 5 years, small expenditures are made in the subsequent years for a total of $2.7 million and a resulting system condition rating of 7.70. This demonstrates the effectiveness of timely investment in pavement rehabilitation vs. allowing deterioration to continue.
- Table C illustrates a strategy of doing only preventive maintenance (crack sealing and seal coating). The total expenditure is $483,000 over 5 years. The condition rating remains essentially uniform throughout the period but the backlog of rehabilitation work increases to $3.6 million.
- Table D represents an annual expenditure of $800,000 a year with the worst-first project selection strategy. The total investment over 5 years is $3.5 million and the condition rating increases to 7.03.
- Table E again demonstrates an annual investment of $800,000 with a strategy that uses the money first for preventive maintenance and the remaining funds each year are applied to the high-priority (worst-first) projects. The results of this strategy are startling. The total investment is reduced to $2.7 million, the backlog is totally eliminated, and the improved condition rating is the highest.
- Table F shows the effect of the annual investment applied to only structural overlays and total reconstruction. The total investment is greater than the preventive maintenance strategy and the end pavement condition level is not as good.

The results of all the strategies are compared in Table F-1 which is also Table 4 in Chapter 2.

The above simulation demonstrates that the most cost-effective strategy, which also results in the highest pavement condition rating, is to perform preventive maintenance on those pavements when and where preventive maintenance treatments are appropriate and then to resurface and reconstruct pavements where the condition has deteriorated below the point where preventive maintenance is effective. The least cost-effective strategy is to allow a pavement to deteriorate until it needs to be resurfaced or reconstructed.

TABLE F-1

BENEFITS OF PREVENTIVE MAINTENANCE OF PAVEMENTS ON A SMALL CITY NETWORK AFTER 5 YEARS

Pavement Management Strategy	Expenditure (Mil $)	Cost of Work Backlogged (Mil $)	Pavement Condition Rating
Do-Nothing	0	$5.1	3.98
Preventive Maintenance Only	$0.5	$3.6	5.58
Preventive Maintenance first then Resurface & Reconstruction	$2.7	0	7.18
Do-Everything	$2.7	0	7.07
Worst-First	$3.5	0	7.03
Resurface & Reconstruction, no Preventive Maintenance	$3.5	$0.3	6.45

APPENDIX G

A Process to Demonstrate the Cost-Effectiveness of Preventive Maintenance

The following describes a process to assess the impact of alternative pavement management strategies on a highway network that does not require detailed knowledge of each segment of the network. The description was adapted from a presentation made by Ray Gerke at the Seventh AASHTO/TRB Maintenance Management Conference held in Orlando, Florida from July 18 to 21, 1994 (*1*). The process uses the condition transition matrix presented in the paper and adds a methodology that can be used to estimate the condition transition matrices for the initial network condition with and without preventive maintenance.

The cost-effectiveness of preventive maintenance is demonstrated by comparing the end condition of the highway network after 5 years using a preventive maintenance strategy and a worst-first strategy. The example is typical of the conditions experienced in a state or local transportation agency.

The following assumptions and limitations were made in this example:

- The present pavement condition of the network can be characterized by a network pavement performance curve and a simple matrix.
- The performance of the network with no work being done can be approximated as the average of the performance of the individual segments.
- The effect of the preventive maintenance strategy on the network can be approximated by the effect of the strategy on an individual segment.
- The distribution of the Very Good, Good, Fair, Mediocre, and Poor pavements in the hypothetical network reflects the distribution in the nation's urban and rural arterials network in 1990 as reported by FHWA on page 12 of "Our Nations Highways: Selected Facts and Figures," Publication No. FHWA-PL-92-004.
- The preventive maintenance strategy selected will increase the time before an asphalt pavement needs to be rehabilitated from 10 to 14 years, reflecting an increase in pavement life of 4 years. These values are typical of those reported by the agencies responding to the questionnaire.
- A preventive maintenance treatment, by definition, does not increase the pavement condition rating. Therefore, there is no increase in the Present Serviceability Index (PSI) when a preventive maintenance treatment is applied.
- The cost of the preventive maintenance treatments and the cost to rehabilitate a pavement are typical of those reported by the agencies responding to the questionnaire.

Step 1 Classify the System By Pavement Performance and Condition

The purpose of the analysis is to compare the cost-effectiveness of alternative pavement maintenance strategies on the *network*. Ideally, transportation agencies would have a performance model for their entire network. In many agencies, that doesn't exist. Therefore, it is necessary to identify groups or families of pavements with similar performance characteristics and use that information to estimate the performance of the network. Factors that an agency should consider in grouping the highway segments into categories with similar pavement performance characteristics are: pavement type, volume of trucks, physiographic provinces, and geographic regions, (i.e., an urban region with PCC pavement network with a large volume of heavy trucks). The performance of the pavements should be similar but need not be identical. The objective is to categorize the agency's network into a manageable number of categories with similar performance characteristics for analysis purposes. The pavement sections in each category are then sorted by condition. For the purposes of this analysis, four or five levels of pavement condition are sufficient. The following analysis is performed for each category of pavements and results are combined to present the impact of a preventive maintenance strategy on the agency's network.

Table G-1 illustrates this analysis for a small hypothetical agency with a highway system of 1,000 lane miles of asphalt concrete pavement. The entire system has similar performance characteristics and only one category is needed to demonstrate the cost-effectiveness of a network preventive maintenance strategy. The pavement sections were grouped into the five levels of pavement condition shown in Table G-1. For this analysis, the five levels of pavement condition used by the FHWA on page 12 of "Our Nation's Highways: Selected Facts and Figures," were selected because they may be more meaningful to executive management and other decision makers not familiar with technical pavement condition terminology, such as PSI.

Step 2 Establish Network Pavement Performance Characteristics With No Maintenance or Rehabilitation (Do Nothing)

Analyze the performance history of the highway segments in each pavement condition rating level that have not been worked on recently and determine the average number of years that the sections remain in each pavement condition rating level, (i.e., for the segments in the network, how many years were they rated Very Good, rated Good, rated Fair, etc). If the network is very large, it is not necessary to use every section. Determine the averages using a representative random sample. The purpose of the analysis is to determine the performance characteristics of the network when no work is done and not the performance of an individual section of pavement. Table G-2 illustrates the results of this analysis for the hypothetical agency.

The network pavement performance curve resulting from these averages is shown as the lower curve in Figure G-1. Based on the averages determined in Table G-2, the network

TABLE G-1

INITIAL NETWORK CONDITION

Condition Rating	PSI Range	Description	Number of Lane Miles
Very Good	>=4.0	New or almost new pavement; will not require improvement for some time.	200
Good	3.5-4.0	In decent condition; will not require improvement in the near future.	280
Fair	2.5-3.5	Will likely need improvement in the near future.	370
Mediocre	2.0-2.5	Needs near-term improvement to preserve usability.	100
Poor	<=2.0	Needs immediate improvement to restore serviceability.	50

TABLE G-2

NETWORK PERFORMANCE WITH NO MAINTENANCE OR REHABILITATION

Condition Rating	PSI Range	Average No. of Years with Condition Rating
Very Good	>=4.0	5
Good	3.5-4.0	2
Fair	2.5-3.5	2
Mediocre	2.0-2.5	1
Poor	<=2.0	

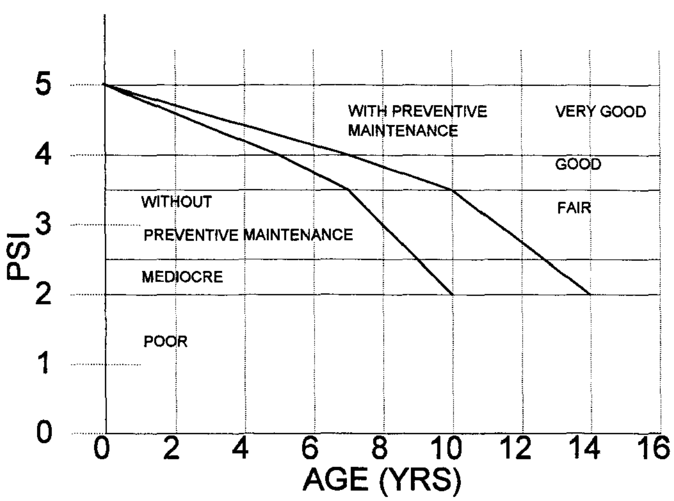


FIGURE G-1 Network pavement performance curves.

pavement performance factors in Table G-3 are developed. If the pavement sections remain in a Very Good condition for an average of 5 years, then 20 percent of the sections drop down to Good each year and 80 percent remain at the Very Good level. Likewise, 50 percent of the sections in a Good condition drop down to Fair and 50 percent remain at the Good level.

Step 3 Develop Proposed Network Preventive Maintenance Strategy

A preventive maintenance strategy is developed based on the observed improvements in pavement performance and increases in the time required for rehabilitation on selected sections of the network where different preventive maintenance treatments were used. An agency may also use the experience reported by neighboring agencies in arriving at its proposed strategy. For this example, the proposed network pavement preventive maintenance strategy is shown in Table G-4.

Step 4 Establish Network Pavement Performance Factors with Preventive Maintenance

Because there is no historical database that can be analyzed to determine the percentage of the highway network in each pavement condition rating level that remains the same and the percentage that drops from year to year with preventive maintenance, the network percentages have to be estimated based on the observed improvement in the performance of pavement sections. The pavement and maintenance engineers for the agency have observed that sealing cracks and a single application chip seal, on the average, add 2 years to the pavement at the Very Good condition rating level and if repeated when the pavement is rated Good, add about another 2 years before the pavement reaches a Poor condition rating level, at which time it needs to be rehabilitated. Overall, the proposed preventive

TABLE G-3

NETWORK PAVEMENT PERFORMANCE FACTORS WITH DO-NOTHING STRATEGY

From Condition Level	To Condition Level After One Year (Percent)				
	Very Good	Good	Fair	Mediocre	Poor
Very Good	80.0	20.0	-	-	-
Good	-	50.0	50.0	-	-
Fair	-	-	50.0	50.0	-
Mediocre	-	-	-	0.0	100.0
Poor	-	-	-	-	100.0

TABLE G-4

PROPOSED NETWORK PREVENTIVE MAINTENANCE STRATEGY

Pavement Condition	Preventive Maintenance Treatment	Year of Application	Cost of Treatment (per lane mile)
Very Good	Crack Filling	3	$2,500
Very Good	Single Application Chip Seal	5	$6,000
Good	Crack Filling	8	$2,500
Fair	Single Application Chip Seal	10	$6,000

maintenance strategy, on the average, extends the performance of the pavement network 4 years before rehabilitation is required. A simple method and, as reported in the literature, a reasonable assumption is that the pavement performance curve is a straight line. However, for this example, it is assumed that the network pavement performance is curvilinear. The length of time that a pavement is assumed to remain in each pavement condition level is shown in Table G-5. The network pavement performance curve with preventive maintenance is shown as the upper curve in Figure G-1.

TABLE G-5

NETWORK PERFORMANCE WITH PREVENTIVE MAINTENANCE

Condition Rating	PSI Range	Average No. of Years in Condition Rating
Very Good	>=4.0	7
Good	3.5-4.0	3
Fair	2.5-3.5	2.7
Mediocre	2.0-2.5	1.3
Poor	<=2.0	

Using the same approach as described above for the do-nothing alternative, the network pavement performance factors (shown in Table G-6) with the preventive maintenance strategy are determined.

Step 5 Determine the Funding Required

The funding analysis can be done in one of two ways. One way is to determine how much money would be needed to achieve an agreed on network end condition after a specified number of years. The second approach, more common in state and local transportation agencies, is to do "what if" analyses. Given a certain funding level and funding strategy, what will the network end conditions be after a specified number of years. The second approach will be used in this example. The analysis will be done for an annual budget of $8 million and the analysis will compare the network end condition after 5 years with a do-nothing strategy, a worst-first funding strategy, and a preventive maintenance strategy. The analysis will also compare the funding required for the worst-first and the funding level for the preventive maintenance strategy to obtain approximately the same pavement network end condition after 5 years.

TABLE G-6

NETWORK PAVEMENT PERFORMANCE FACTORS WITH THE PREVENTIVE MAINTENANCE STRATEGY

From Condition Level	To Condition Level After One Year (Percent)				
	Very Good	Good	Fair	Mediocre	Poor
Very Good	85.7	14.3	-	-	-
Good	-	66.7	33.3	-	
Fair	-	-	63.0	37.0	-
Mediocre	-	-	-	23.1	76.9
Poor	-	-	-	-	100.0

TABLE G-7

PAVEMENT NETWORK END CONDITION WITH DO-NOTHING STRATEGY

	Lane Miles					
Pavement Condition	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Very Good	200	0.8(200)=160	128	102	82	66
Good	280	0.2(200)+0.5(280)= 180	122	87	64	48
Fair	370	0.5(280)+ 0.5(370)=325	253	187	137	100
Mediocre	100	0.5(370)=185	163	126	94	68
Poor	50	1.0(100)+1.0(50)=150	335	498	624	717

TABLE G-8

PAVEMENT NETWORK END CONDITION WITH WORST-FIRST FUNDING STRATEGY

	Lane Miles						
		Year 1					
Pavement Condition	Year 0	Before Rehab	After Rehab	Year 2	Year 3	Year 4	Year 5
Very Good	200	160	160+80=240	272	298	318	334
Good	280	180	180	138	123	121	124
Fair	370	325	325	253	195	159	140
Mediocre	100	185	185	163	126	98	80
Poor	50	150	150-80=70	175	258	304	321

TABLE G-9

EXPENDITURE OF FUNDS WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $8 MILLION ANNUALLY

Pave Age	Pave Cond.	Lane Miles Year 0	Prevent Maint. Treat	Unit Costs	Total Costs
3	Very Good	200	Crack Seal	$2,500	(200/7)(2500) =$ 71,400
5	Very Good	200	Chip Seal	$6,000	(200/7)(6000) =$ 171,400
8	Good	280	Crack Seal	$2,500	(280/3)(2500) =$ 233,300
10	Fair	370	Chip Seal	$6,000	(370/2.7)(6000) =$ 822,200
Cost of Prevent Maint in Year 0					$ 1,298,300
Available for Rehabilitation					$ 6,701,700
Number of Lane Miles Rehabilitated					67.0

TABLE G-10

PAVEMENT NETWORK END CONDITION WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $8 MILLION ANNUALLY

	Lane Miles						
		Year 1					
Pavement Condition	Year 0	Before Rehab	After Rehab	Year 2	Year 3	Year 4	Year 5
Very Good	200	0.857(200)= 171	238	272	303	329	352
Good	280	0.143(200)+ 0.667(280)= 215	215	178	157	148	146
Fair	370	0.333(280)+ 0.63(370)= 326	326	277	234	200	175
Mediocre	100	0.37(370)+ 0.231(100)= 160	160	158	139	119	101
Poor	50	0.769(100)+ 1.0(50)= 127	60	115	167	205	225

Step 6 Analysis

Do-Nothing Strategy

Table G-7 shows the results of the analysis for the do-nothing strategy. This analysis shows the pavement network end condition after 5 years. The analysis is performed by multiplying the mileage in Table G-1 by the factors in Table G-3. The computations are shown for the first year to illustrate the process.

Worst-First Funding Strategy

Table G-8 shows the results of the analysis for the worst-first funding strategy with an annual budget of $8 million. The first step in the analysis is identical to the computations for the do-nothing analysis in Table G-7 above. The mileage in Table G-1 is multiplied by the factors in Table G-3. Then, the number of lane miles of poor pavement to be rehabilitated is determined by dividing the annual budget ($8 million) by

TABLE G-11

PAVEMENT NETWORK END CONDITION WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $6.4 MILLION ANNUALLY

	Lane Miles					
Pavement Condition	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Very Good	200	222	243	262	279	294
Good	280	215	175	152	138	132
Fair	370	326	277	233	197	170
Mediocre	100	160	158	139	118	100
Poor	50	76	147	215	267	303

TABLE G-12

COMPARISON OF THE EFFECT OF ALTERNATIVE STRATEGIES ON NETWORK CONDITION AFTER 5 YEARS

	Lane Miles				
		Year 5 Network End Condition			
				Preventive Maintenance Annual Funding Level	
Pavement Condition	Year 0	Do Nothing	Worst-First $8 Million Annually	$8 Million	$6.4 Million
Very Good	200	66	334	352	294
Good	280	48	124	146	132
Fair	370	100	140	175	170
Mediocre	100	68	80	101	100
Poor	50	717	321	225	303

the cost to rehabilitate one lane mile ($100,000). The number of lane miles rehabilitated is 80. The number of lane miles rated Poor is then decreased by 80 and the number rated Very Good is increased by 80. When there are more lane miles rehabilitated than there are lane miles rated Poor, the number of lane miles of pavements rated Mediocre is decreased by the difference between the number rehabilitated and the number rated Poor. The computations are shown for the first year to illustrate the process.

Preventive Maintenance Strategies

Table G-10 shows the results of the analysis for the preventive maintenance strategy with an annual budget of $8 million. The first step, as shown in Table G-9 for the first year, is to spend that portion of the annual budget needed for the preventive maintenance treatments required by the strategy starting with the pavements rated Very Good, then Good, and Fair. The second single application chip seal, at year 10, is at the end of the Good condition level or the beginning of the Fair condition level. For the purposes of computing the cost of the preventive maintenance strategy in this example, the second chip seal was applied to the pavements in a Fair condition. In this instance, this resulted in a slightly higher cost for the preventive maintenance strategy. Any remaining funds are then available to rehabilitate pavements rated Poor and the number of lane miles rehabilitated is computed. The second step is to multiply the mileage in Table G-1 by the pavement network deterioration factors for the preventive maintenance strategy in Table G-6. The third step is to add the number of lane miles of pavements rated Poor and Mediocre that were rehabilitated to the lane miles of pavement rated Very Good and subtract the same number from the number rated Poor and Mediocre.

There is a significant improvement in the pavement network end condition with the preventive maintenance strategy over the worst-first strategy. Frequently, policy makers want to compare the funding required for each strategy to obtain approximately the same network end condition. Table G-11 shows the results of the analysis for the preventive maintenance strategy annually funded at $6.4 million.

A side-by-side comparison of the network end conditions for the worst-first and preventive maintenance strategies funded at $8 million annually as illustrated in Table G-12 shows the improvement in the condition of the pavement network obtained over 5 years using the preventive maintenance strategy. The number of lane miles of the pavement rated Very Good increased from 334 to 353 while the number of lane miles of pavement rated Poor decreased from 321 to 225. Furthermore, the network condition after 5 years is approximately the same (the total lane miles rated Poor and Mediocre is 401 vs 403) for the worst-first strategy funded at $8 million annually and the preventive maintenance strategy funded at $6.4 million annually for an annual savings of $1.6 million, or 20 percent.

REFERENCE

1. Sparks, G.A., R. Gerke, and D. Kaweski, "Integrating Maintenance Management and Pavement Management Systems," in *Preprints*, Seventh AASHTO/TRB Maintenance Management Conference, Transportation Research Board, National Research Council, Washington, DC (July 18–21, 1994), Preprint C.

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