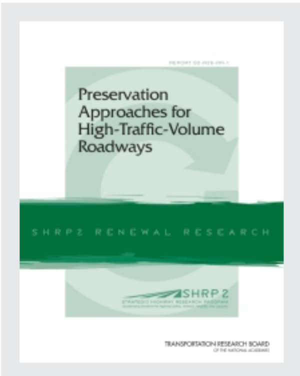

Preservation Approaches for High-Traffic-Volume Roadways

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SHRP 2 REPORT S2-R26-RR-1

Preservation Approaches for High-Traffic-Volume Roadways

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The research reported on herein was performed by Applied Pavement Technology (APTech), Inc. David Peshkin, Vice President of APTech, was the principal investigator. He was supported in the research by the following APTech engineers: James Krstulovich, Kelly Smith, Kurt Smith, Angela Wolters, and Katie Zimmerman. Also providing support were Jim Moulthrop and Cesar Alvarado of Fugro Consultants, Inc., and consultants Gerry Eller (formerly Executive Director of the Foundation for Pavement Preservation), Dr. R. Gary Hicks (Technical Director of the California Pavement Preservation Center), and Dean Testa (formerly Chief Construction Engineer with the Kansas Department of Transportation).

The authors gratefully acknowledge those individuals from state departments of transportation, industry organizations, and academia who participated in the project survey and provided important information and documentation for this project. The time and effort that they contributed were instrumental in the successful completion of this project.

FOREWORD

James W. Bryant, Jr., PhD, PE, *SHRP 2 Senior Program Officer, Renewal*

This research report documents the state of the practice of preservation treatment on asphalt and concrete pavements. Although the focus of the project was on treatments suitable for application on high-volume roadways, this report also discusses current practices for low-volume roadways. The information presented is derived from a detailed survey of transportation agencies and a review of national and international literature. In addition, the report provides a general framework for how best practices are identified. Finally, general guidelines were developed on the application of preservation treatments on high-volume roadways. Presented as a separate document, *Guidelines for the Preservation of High-Traffic-Volume Roadways* considers traffic volume, pavement condition, work-zone requirements, environmental conditions, and expected performance.

For several years, pavement preservation has been an important strategy to extend the life of roadways. As transportation agencies grapple with decreased capital budgets, pavement preservation will continue to be an important strategy. Relatively small investments for preservation activities, if properly timed and applied, can significantly increase infrastructure life. Several transportation agencies apply preservation strategies on lower-volume roadways; however, the application of these strategies on high-volume roadways has lagged behind.

The application of preservation strategies to high-traffic-volume roadways presents a complicated set of challenges. Many of the products and approaches that have been accepted for use on lower-traffic-volume roadways have not been accepted for use on high-traffic-volume roadways. Often, the use of a particular product or application has too great an impact on traffic or has not been successfully applied under high-traffic conditions. The purpose of this report is to provide guidance to more effectively match pavement condition and related considerations with suitable treatments for high-traffic-volume roadways.

CONTENTS

xi List of Abbreviations

1 Executive Summary

1 Introduction

2 Findings

5 Implementation of Guidelines

5 Conclusions

5 Recommendations

6 CHAPTER 1 Introduction

6 Background and Problem Statement

7 Research Objectives

7 Research Scope and Approach

7 Overview of Report

9 CHAPTER 2 Information Gathering and Review

9 Information Gathering

10 Analysis and Summary of Collected Information

33 CHAPTER 3 Development of Preservation Guidelines for High-Traffic-Volume Roadways

33 Preliminary Analysis of Treatment Feasibility: Consideration of Existing Pavement Conditions

42 Final Analysis of Treatment Feasibility: Consideration of Project Needs and Constraints

71 Selection of the Preferred Preservation Treatment

79 CHAPTER 4 Implementation of Preservation Guidelines

79 Barriers to Implementation

80 Keys to Implementation

82 CHAPTER 5 Conclusions and Recommendations

82 Conclusions

84 Recommendations

85 References

88 Glossary

93 Appendix A. Annotated Bibliography

106 Appendix B. Preservation Questionnaire Survey Form

126 Appendix C. Summary of Preservation Questionnaire Responses

174 Appendix D. Other Pavement Preservation Treatments

Online version of this report: www.trb.org/Main/Blurbs/165280.aspx.

LIST OF ABBREVIATIONS

AADT	average annual daily traffic
AADTT	average annual daily truck traffic
AAPT	Association of Asphalt Paving Technologists
AAR	alkali-aggregate reaction
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ACPA	American Concrete Pavement Association
ADT	average daily traffic
AI	Asphalt Institute
AP	analysis period
ARRA	Asphalt Recycling and Reclaiming Association
ARRB	Australian Road Research Board
ASCE	American Society of Civil Engineers
ASR	alkali-silica reaction
ASTM	American Society for Testing and Materials
BCR	benefit-cost ratio
B/C	benefit-to-cost
CFLHD	Central Federal Lands Highway Division
CIR	cold in-place recycling
CP Tech Center	National Concrete Pavement Technology Center
CPPC	California Pavement Preservation Center
DBR	dowel bar retrofit
DOT	department of transportation
EAC	equivalent annual cost
ESAL	equivalent single-axle load
FHWA	Federal Highway Administration
FI	freezing index
FP^2	Foundation for Pavement Preservation
FWD	falling weight deflectometer
HIR	hot in-place recycling
HMA	hot-mix asphalt
HMAOL	hot-mix asphalt overlay
HS	high severity
IC	initial construction
IGGA	International Grooving and Grinding Association
IPRF	Innovative Pavement Research Foundation
IRF	International Road Federation
IRI	international roughness index
ISO	International Organization for Standardization
ISSA	International Slurry Surfacing Association
LCCA	life-cycle cost analysis

LCPC	Laboratoire Central des Ponts et Chaussées (French public works research laboratory)
LS	low severity
LTPP	long-term pavement performance
LTR	load transfer restoration
M&R	maintenance and rehabilitation
MOT	ministry of transportation
MS	medium severity
NACE	National Association of County Engineers
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NCPP	National Center for Pavement Preservation
NHI	National Highway Institute
NHS	National Highway System
NPV	net present value
NTIS	National Technical Information Service
NTL	National Transportation Library
OGFC	open-graded friction course
PCA	Portland Cement Association
PCC	portland cement concrete
PCCOL	portland cement concrete overlay
PCI	pavement condition index
PCR	pavement condition rating
PIARC	World Road Association (formerly Permanent International Association of Road Congresses)
PM	preventive maintenance
PMAC	polymer-modified asphalt concrete
PMS	pavement management system
PSI	present serviceability index
PSR	present serviceability rating
PT	preservation treatment
QC/QA	quality control/quality assurance
RSL	remaining service life
SHA	state highway agency
SMA	stone matrix asphalt
SPS	Specific Pavement Study
SV	salvage value
TAC	Transportation Association of Canada
TI	traffic index
tpd	trucks per day
UTW	ultra-thin whitetopping
UV	ultraviolet
VOC	vehicle operating cost
vpd	vehicles per day

Executive Summary

Introduction

The practice of pavement preservation (i.e., preventive maintenance [PM] and some forms of minor rehabilitation and corrective maintenance) is a growing trend among transportation agencies throughout the United States. However, the practice of preservation on high-traffic-volume roadways is not nearly as common as it is on lower-traffic-volume roadways. The following are possible explanations for this:

- Agencies may associate the use of specific PM treatments solely with low-volume roads, thereby assuming that they are not appropriate for other uses.
- Agencies may have concerns over the liability and risk associated with failure (when a treatment fails on a higher-volume roadway, more people are affected and more people complain).
- The benefits of preservation on higher-traffic-volume roadways might not be as readily recognized or as well documented.
- Preservation treatments may not be as effective on higher-traffic-volume roadways. They may deteriorate in different ways from those applied on low-volume roadways because of the higher standards used in design and construction of higher-traffic-volume roadways.

Nonetheless, the preservation of high-traffic-volume roadways is as important as the preservation of lower-traffic-volume roadways, as many conditions hold true for both:

- Agency resources are limited and pavement preservation saves money in the long run.
- Preservation provides benefits to the traveling public, including safer and smoother roads.
- Preservation can be done more rapidly than rehabilitation, with fewer adverse effects on the traveling public.

Admittedly, there are also challenges to the use of preservation strategies on high-traffic-volume roadways (e.g., a smaller toolbox of treatments that can be used successfully, more difficult treatment construction because of shorter available closure times, less available information on treatment performance and life, increased risk, and less available guidance on preservation strategies). Nonetheless, it is believed that the benefits of practicing preservation on high-traffic-volume roadways outweigh the challenges and that it is worthwhile to take steps to increase or improve the practice of pavement preservation on these roadways.

The main objective of the research performed under SHRP 2 Renewal Project R26 was to develop guidelines on pavement preservation strategies for high-traffic-volume roadways that can be implemented and used by public agencies. A secondary objective was to identify promising pavement preservation strategies for application on high-traffic-volume roadways that might not commonly be used and to make recommendations for further research opportunities.

To accomplish these objectives, several sequential tasks were performed. First, an extensive literature search and review was undertaken to identify practices and experiences relating to preservation of high-traffic-volume roads. Next, a comprehensive survey of preservation practices was developed and distributed to all state highway agencies (SHAs) and selected other agencies to obtain information on current preservation practices for hot-mix asphalt (HMA)- and portland cement concrete (PCC)-surfaced pavements on high-traffic-volume roadways in rural and urban settings. Information from the compiled literature and the questionnaire survey was summarized and analyzed to identify the current state of the practice. Criteria were developed and applied to focus on preservation approaches that are currently successfully implemented and on others that have the potential to be successful but have not been regularly deployed. Detailed guidelines on pavement preservation strategies for high-traffic-volume roadways were then developed using the state of the practice and a comprehensive treatment selection framework and process.

Findings

Literature Review

Results of the literature review revealed several important items concerning pavement preservation practices in general and the use of preservation treatments on high-traffic-volume roads in particular. First, there are a variety of conventional preservation treatments (and several less widely used or new treatments) available for treating HMA- and PCC-surfaced roads, and these treatments have unique features and capabilities that can (a) effectively prevent the development of distresses or slow the development of existing distresses or (b) successfully restore the integrity and functionality of a pavement or restore important surface characteristics (e.g., friction and smoothness). The treatments entail the use of a variety of materials that can be placed in different fashions and in different thicknesses and that require different times until opening to traffic.

Second, according to a 2004 National Cooperative Highway Research Program (NCHRP) survey of SHAs (Peshkin and Hoerner 2005), pavement preservation is occurring as frequently, or even more frequently in the case of rural roads, on higher-volume roadways than on lower-volume roadways. The results from that survey suggested that the more important distinction is between rural and urban roadways for any traffic volume.

Third, besides proper design and good quality of construction and materials, the performance of preservation treatments—as measured by the extension in pavement service life imparted by the treatment—is impacted by three key factors. These factors include the following:

- Condition of the existing pavement;
- Level of traffic under which the treatment must function; and
- Climatic conditions to which the treatment is exposed.

Fourth, climatic conditions can also have an effect on the constructability of some preservation treatments. For example, some treatments, especially those based on asphalt emulsions, are best applied under restricted temperature and humidity conditions. Climate can directly affect curing time, which in turn impacts treatment feasibility and opening to traffic.

Finally, various international preservation practices were identified and reported. The proper context for these strategies must be fully understood, because the way in which each country chooses their preservation strategy depends on their standard road design, climate, traffic patterns, and the political and economic organization of the country.

Survey Results

Results of the preservation survey revealed several key findings as well. First and foremost, SHAs have different definitions regarding what constitutes a high-traffic-volume roadway. The criteria range from an average daily traffic (ADT) as low as 1,000 vehicles per day (vpd) to as high as 100,000 vpd, and several agencies have separate criteria for roads in rural settings and those in urban settings (or, sometimes National Highway System [NHS] versus non-NHS roadways). To provide a more consistent analysis of preservation treatment usage on roadways with different traffic levels, an analysis of the survey responses regarding the high-traffic-volume criterion was performed. Based on this analysis, high traffic volume was defined as an ADT of at least 5,000 and 10,000 vpd for rural and urban roadways, respectively.

The most commonly used preservation treatments (greater than 50% of responding agencies) according to these definitions of high-traffic-volume roadways were as follows:

- Rural HMA-surfaced roadways: Crack filling, crack sealing, thin HMA overlay, cold milling and thin HMA overlay, and drainage preservation.
- Urban HMA-surfaced roadways: Crack filling, crack sealing, cold milling and thin HMA overlay, and drainage preservation.
- Rural *and* urban PCC-surfaced roadways: Joint resealing, crack sealing, diamond grinding, partial-depth repair, full-depth repair, dowel bar retrofitting (i.e., load transfer restoration), and drainage preservation.

Treatments considered most inappropriate for use on high-traffic-volume facilities by survey respondents included fog seal, scrub seal, slurry seal, chip seal, and ultra-thin whitetopping for HMA-surfaced pavements and thin HMA overlay, ultra-thin bonded wearing course, and thin PCC overlays for PCC-surfaced pavements.

The survey results indicated that the top three deficiencies addressed by preservation treatments on HMA-surfaced pavements are light and moderate surface distress (i.e., various forms of cracking), raveling, and friction loss. For PCC pavements, the top three pavement performance issues addressed related to smoothness or ride quality and surface distress (i.e., spalling and various forms of cracking), with some concern about noise issues.

Finally, the survey results showed that an overwhelming number of respondents reported using overnight or single-shift closures for treatment application. Ultra-thin whitetopping on HMA-surfaced pavements and thin PCC overlays on PCC pavements were the exceptions, as they generally require longer closure times to allow for proper curing.

Guidelines Development

The results of the literature review and preservation survey provided valuable insights regarding the following preservation treatment attributes.

Performance

- Effect of existing pavement condition (distress) and serviceability (smoothness) on treatment performance;
- Effect of traffic volume on treatment performance;
- Effect of climate and environment on treatment performance; and
- Effect of treatment on pavement condition, serviceability, safety (friction, surface drainage [splash/spray, cross slope]), and noise.

Constructability Issues

- Costs (agency and user);
- Complexity of construction;
- Availability of skilled and experienced or qualified contractors;
- Need for specialized equipment or materials;

- Availability of quality materials;
- Climatic and environmental constraints;
- Traffic disruption;
- Traffic control constraints; and
- Restrictions on available time for lane closures to complete the work.

The information gleaned from the literature review and the survey results was combined with additional information, concepts, and ideas to develop a comprehensive preservation treatment selection framework and process. This process, shown in Figure ES.1, serves as the basis for the guidelines developed in the study.

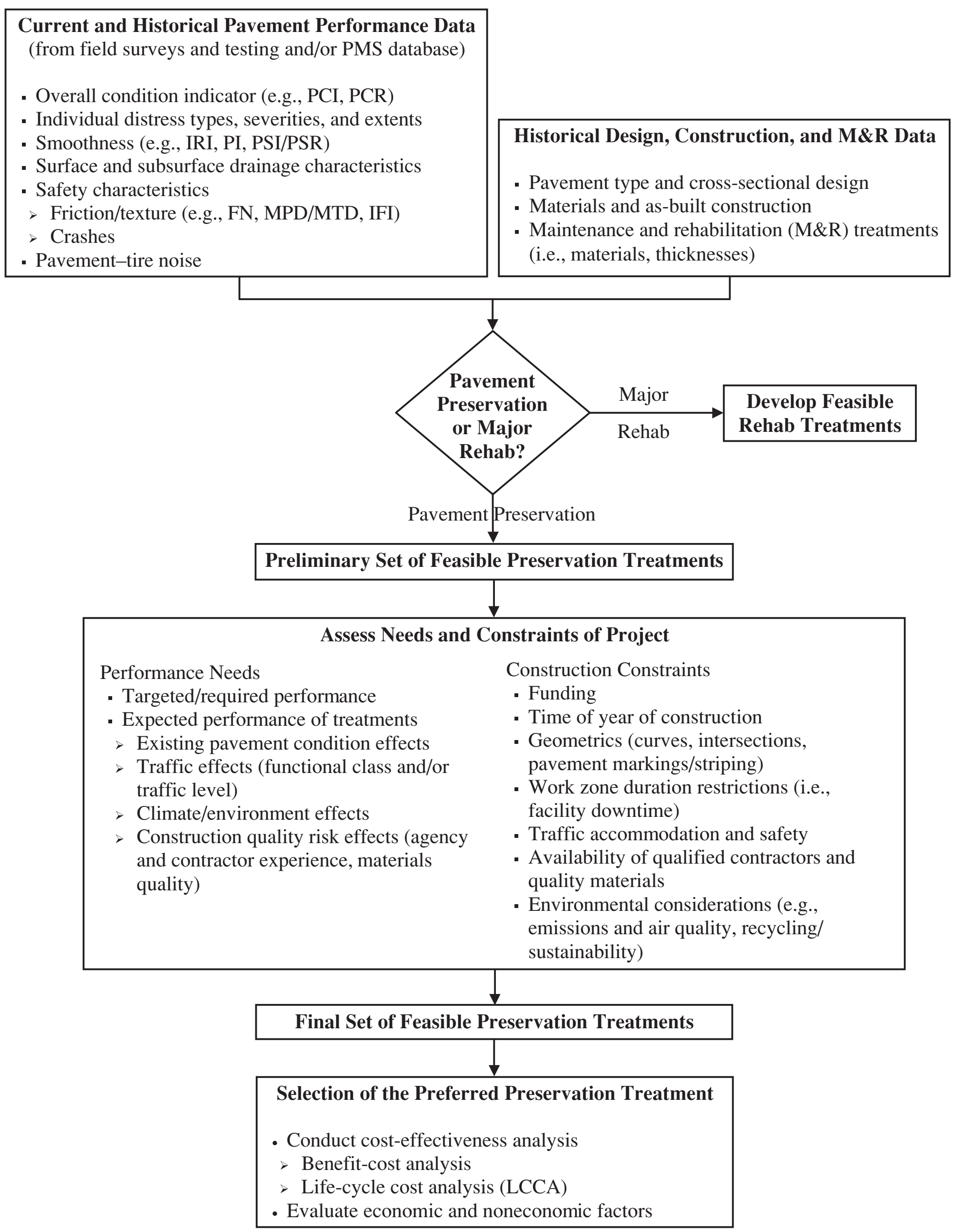


Figure ES.1. Process of selecting the preferred preservation treatment for high-traffic-volume roadways.

Implementation of Guidelines

Implementation and use of the preservation guidelines by highway agencies will certainly involve working through a variety of institutional and external issues. Several key implementation barriers, such as resistance to allowing the use of lower-volume preservation treatments on higher-volume roads and the ability to convince the traveling public of the benefits and importance of preserving high-traffic-volume roads, were also formulated and presented in this report.

Conclusions

Several major conclusions were developed in this study. The most notable conclusions are the following:

- Several preservation treatments are currently being extensively used or have been documented as successfully used on high-traffic-volume roadways.
- Successful selection of projects and preservation treatments for high-traffic-volume roadways requires that
  - Treatment functions be properly matched to pavement conditions;
  - Potential effects of traffic level and climatic conditions on expected treatment performance be properly assessed;
  - Project construction constraints be carefully examined in relation to the limitations of the treatments; and
  - Treatment cost-effectiveness and other factors be properly and methodically considered.

Recommendations

Key recommendations from this study include the following:

- Develop a more comprehensive treatment–pavement condition matching matrix;
- Improve estimates of treatment performance and unit costs; and
- Investigate more thoroughly the impact of pavement condition, traffic level, and climatic condition on treatment performance.

CHAPTER 1

Introduction

Background and Problem Statement

The practice of pavement preservation (i.e., preventive maintenance [PM] and some forms of minor rehabilitation and corrective maintenance) is a growing trend among transportation agencies around the United States. Where perhaps 20 years ago no agency could claim to formally practice pavement preservation, in the past decade alone a number of state highway agencies (SHAs) have created or formalized such programs. This list includes, but is not limited to, Rhode Island, Arizona, California, Nebraska, Missouri, North Carolina, Louisiana, Minnesota, South Carolina, and Nevada. At the same time, other agencies that might have been practicing preservation for a longer time (such as Texas and Washington State) have extended their programs to cover a greater proportion of their pavement network than ever before. In recent years, still other agencies (such as Illinois and Hawaii) have begun creating formal preservation programs.

The significance of this trend in SHAs and other public agencies can be seen in several ways. Some agencies—such as those in North Carolina, Louisiana, California, and Minnesota—have created a departmental position of pavement preservation engineer. Many agencies have developed, or are developing, formal guidelines for preservation, such as Ohio, Nebraska, Illinois, and California. Furthermore, Texas, Louisiana, and California have established pavement preservation centers, where researchers and practitioners work together to improve preservation practices. In addition to such centers, regional partnerships have also been formed to facilitate the exchange of ideas and best practices regarding pavement preservation.

Based on transportation agency practices in this area, the growing significance of preservation practices is indisputable. However, the practice of preservation on high-traffic-volume roadways is not nearly as common as it is on lower-volume roadways. There are several possible explanations for this. For example, treatments such as chip seals have long been associated with low-volume and low-speed roadways, and in many agencies, there is significant resistance to placing such treatments on roads with traffic volumes higher than a rather low number (say, between 500 and 2,000 vehicles per day [vpd]) because of liability concerns (e.g., cracked windshields, chipped paint) and a perception of lower quality (ride, materials, technique, and so on). Furthermore, the use of PM treatments in general has long been associated with lower-volume roads, where funding for higher-quality and higher-cost treatments, especially overlays, simply has not been available. As such, the use of PM treatments on high-volume roads is not considered.

There is also an implied liability problem associated with the failure of certain treatments on higher-volume roadways. When a treatment fails on a higher-volume roadway, by definition more people are affected and more people complain. There may also be a perception that high-traffic-volume roadways are more likely to fail due to load rather than develop the type of functional deficiencies that are best addressed by pavement preservation.

The potential benefit of preservation on higher-traffic-volume roadways might not be as readily recognized or as well documented. Also, because these pavements are typically designed and built to higher standards than lower-volume roadways, they may deteriorate in different ways, rendering typical PM treatments less effective. Nonetheless, the preservation of high-traffic-volume roadways is as important as the preservation of lower-traffic-volume roadways, because many conditions, such as the following, hold true for both:

- Agency resources are limited, and it makes sense to use available funding, personnel, and equipment in managing pavements wisely. In the long run, pavement preservation saves money.
- Preservation provides benefits to the traveling public, including safer and smoother roads.
- Preservation can be done more rapidly than rehabilitation, with fewer adverse effects on the traveling public.

Admittedly, there are also challenges to the use of preservation strategies on high-traffic-volume roadways, including the following:

- There is a smaller set of materials and procedures that can be employed successfully on high-traffic-volume roadways.
- Shorter available closure times for busy roadways make treatment construction more complicated.
- There is less available information on the life and performance of treatments used on high-traffic-volume roadways.
- There is an increased risk (because of the higher traffic volumes and speeds) should failure occur.
- Less guidance is available on the successful implementation of preservation strategies on high-traffic-volume roadways.

Nonetheless, it is believed that the benefits of practicing preservation on high-traffic-volume roadways outweigh the challenges, and it is worthwhile to take steps to increase or improve the practice of pavement preservation on these roadways.

This research was conducted to identify and advance practices that lead to higher-volume roadways being maintained in serviceable condition for longer periods of time before rehabilitation is needed, at a lower cost, in a safer manner, and with less disruption to the traveling public. The study was part of the second Strategic Highway Research Program (SHRP 2) Renewal focus area, which addresses the need to complete long-lasting highway projects with minimal disruption to the traveling public. SHRP 2 Renewal research has a focus of "applying new methods and materials for preserving, rehabilitating, and reconstructing roadways. . . . Alternative strategies for contracting, financing, and managing projects, and mitigating institutional barriers also are part of the emphasis on rapid renewal" (SHRP 2 2007).

Research Objectives

The main objective of this study was to develop guidelines on pavement preservation strategies for high-traffic-volume roadways that can be used and implemented by public agencies. A secondary objective was to identify promising pavement preservation strategies for application on high-traffic-volume roadways that might not commonly be used and to make recommendations for further research opportunities.

Research Scope and Approach

To accomplish the stated objectives, the project was divided into two phases of work consisting of the following tasks:

Phase I

1. Identify the state of the practice via a national and international literature search and survey.
2. Develop criteria to identify best practices; apply such criteria to the data obtained during the literature search and survey.
3. Submit an interim report summarizing the results obtained by completing Tasks 1 and 2.

Phase II

4. Develop guidelines for pavement preservation approaches for high-traffic-volume roadways.
5. Submit a draft final report that documents the entire research effort.
6. Submit a final report that addresses SHRP 2 comments on the draft final report.

In Phase I, an extensive literature search and review was undertaken, resulting in a comprehensive selection of references regarding pavement preservation practices from the last 5 years. In addition, a questionnaire was developed and distributed in September 2008 to all 50 SHAs, several large municipalities, seven Canadian provinces, international practitioners, and several industry representatives. The purpose of the questionnaire was to obtain information on current pavement preservation practices for high-traffic-volume roadways from North American and international practitioners.

Information from the compiled literature and the questionnaire survey was summarized and analyzed to identify the current state of practice for rural and urban high-traffic-volume roadways on both portland cement concrete (PCC)–surfaced and hot-mix asphalt (HMA)–surfaced pavements. Criteria were developed and applied to focus on preservation approaches that are currently successfully implemented and others that have the potential to be successful but have not been regularly deployed. Results of these activities, along with an updated Phase II work plan, were documented in a draft interim report.

In Phase II of the project, detailed guidelines on pavement preservation strategies for high-traffic-volume roadways were developed. These guidelines, entitled *Guidelines for the Preservation of High-Traffic-Volume Roadways,* evolved from the state of the practice identified in Phase I and incorporated various methodologies for evaluating treatment suitability at the project level, based on several decision factors. Recommended procedures for evaluating treatment cost-effectiveness were also incorporated.

Overview of Report

Including this introductory chapter, this report is presented in five chapters. Chapter 2 describes the information-gathering activities and presents a summary of the findings of those activities. Chapter 3 discusses the development of preservation treatment selection guidelines through a state-of-the-practice synthesis that provides support for the recommendations made in the guidelines. Chapter 4 discusses the application of the guidelines, focusing on potential impediments to implementation and successful ways of overcoming those impediments. Finally, Chapter 5 presents the study's conclusions and recommendations, including suggestions for future research of preservation-related policies and practices.

The report includes four appendices. Appendix A is an annotated bibliography covering the key source documents used in the study. Appendix B contains the questionnaire used to survey highway agencies about their preservation practices. Appendix C provides a detailed breakdown and discussion of the preservation survey responses. Appendix D is a short discussion of several new or limited-use pavement preservation treatments. The report also provides a glossary of terms. The detailed guidelines developed in this study are provided in a separate publication, *Guidelines for the Preservation of High-Traffic-Volume Roadways.*

CHAPTER 2

Information Gathering and Review

This chapter discusses the state of the practice with regard to preservation approaches for high-traffic-volume roadways. The content is based on two primary sources: a literature review and responses to a survey of the practices of state and other highway agencies. The chapter begins with a brief description of the information-gathering process and concludes with the state-of-the-practice synthesis organized around the following items:

- Types of preservation treatments used on high-traffic-volume roads;
- Special considerations for high-traffic-volume treatments;
- Performance of treatments on high-traffic-volume facilities; and
- Cost-effectiveness of preservation treatments.

Information Gathering

Literature Search

A comprehensive literature search was conducted at the outset of the study and focused on information pertaining to pavement preservation practices and experiences. This search, largely limited to work reported in the last 5 years, was national and international in scope and was performed primarily via the Internet and through manual searches of the libraries, files, and other resource materials of the individual project team members.

Among the key sources tapped in the literature search were the following:

- Transportation Research Information Services (TRIS) database.
- National Technical Information Service (NTIS) database.
- Engineering Index and Compendix.
- National Transportation Library (NTL).
- Transportation Research Board (TRB) and TRB Research in Progress database.
- American Association of State Highway and Transportation Officials (AASHTO).
- Federal Highway Administration (FHWA) and National Highway Institute (NHI).
- State department of transportation (DOT) research libraries.
- Pavement preservation centers:
  - Foundation for Pavement Preservation (FP^2);
  - National Center for Pavement Preservation (NCPP); and
  - California Pavement Preservation Center (CPPC).
- National pavement centers:
  - National Center for Asphalt Technology (NCAT); and
  - National Concrete Pavement Technology Center (CP Tech Center).
- Industry associations:
  - National Asphalt Pavement Association (NAPA);
  - Asphalt Institute (AI);
  - Association of Asphalt Paving Technologists (AAPT);
  - American Concrete Pavement Association (ACPA);
  - Portland Cement Association (PCA);
  - International Slurry Surfacing Association (ISSA);
  - Asphalt Recycling and Reclaiming Association (ARRA); and
  - International Grooving and Grinding Association (IGGA).
- American Society of Civil Engineers (ASCE).
- Innovative Pavement Research Foundation (IPRF).
- American Society for Testing and Materials (ASTM).
- International Organization for Standardization (ISO).
- Transportation Association of Canada (TAC).
- International Road Federation (IRF).
- World Road Association (PIARC).
- Australian Road Research Board (ARRB).
- Laboratoire Central des Ponts et Chaussées (LCPC; French public works research laboratory).

More than 100 documents were identified and compiled for use in this study, either in electronic or hardcopy form. Each of the selected documents was catalogued and reviewed in greater detail.

Appendix A contains an annotated bibliography of several key documents. Key aspects of the literature review are included in the summary provided later in this chapter.

Survey of Practice

The literature search was supplemented with an electronic questionnaire distributed to SHAs, Canadian provinces, highway agencies of several large cities, international practitioners, and several industry representatives. The purpose of this survey was to identify pavement preservation practices on rural and urban roadways, distinguished by surface type—HMA or PCC—and high traffic levels (as defined by the reporting agency). The survey focused on the following topics:

- Successful techniques for pavement preservation on high-traffic-volume roadways currently in use;
- Potentially successful techniques for pavement preservation approaches that are not yet fully deployed;
- Challenges and solutions to implementation on high-traffic-volume roadways; and
- Special considerations for quality control and quality assurance (QC/QA).

Recognizing that the definition of "high-traffic-volume roadways" is perhaps as much or more a matter of perception as it is a matter of policy, the survey also asked the respondents to define what traffic volumes fell in that category for them.

The questionnaire included the preservation treatments shown in Table 2.1. It called for respondents to link these treatments to roadways, differentiating by traffic volume and rural-versus-urban route, as well as matching closure time scenarios to treatment, indicating which pavement performance issues are addressed by each treatment, and which contracting mechanisms are used to ensure quality. Furthermore, it sought feedback concerning why certain treatments are not used by the responding agency (e.g., lack of experience, bias against, previous failures, cost, safety issues, and so on).

To reduce the time required to fill out the 24-page questionnaire, it was developed and administered using InstantSurvey, an online software tool that creates, distributes, manages, and analyzes online surveys. The time period required for completing the survey was approximately 8 weeks.

The complete survey is provided in Appendix B, and a detailed breakdown of the responses is provided in Appendix C. Key aspects of the survey results are included in the summary provided later in this chapter.

Table 2.1. Common Pavement Preservation Treatments

HMA-Surfaced Pavements	PCC-Surfaced Pavements
Crack fill	Joint resealing
Crack seal	Crack sealing
Cape seal	Diamond grinding
Fog seal	Diamond grooving
Scrub seal	Pavement patching Partial depth Full depth
Slurry seal	Dowel bar retrofit (i.e., load transfer restoration)
Rejuvenators	Thin PCC overlay
Microsurfacing Single course Multiple course	Ultra-thin bonded wearing course
Chip seal Single course Multiple course With polymer-modified binder	Thin HMA overlay (<1.5 in.)
Ultra-thin bonded wearing course	Drainage preservation
Thin HMA overlay (<1.5 in.)	
Cold milling and thin HMA overlay	
Ultra-thin HMA overlay (<0.75 in.)	
In-place HMA recycling Hot (<1.95 in.) Cold (<4.0 in.)	
Profile milling (diamond grinding)	
Ultra-thin whitetopping	
Drainage preservation	

Note: 1 in. = 25.4 mm

Analysis and Summary of Collected Information

Literature Review

This section provides a summary of the pertinent literature reviewed in the first phase of the study. The information presented is intended to familiarize the reader with the key aspects regarding the use of preservation treatments on high-traffic-volume roadways. The information was used in conjunction with information from additional pieces of literature collected in the second phase of the study to aid the development of the preservation guidelines featured in *Guidelines for the Preservation of High-Traffic-Volume Roadways.*

Pavement Preservation Overview

One definition of pavement preservation is that it is a planned system of treating pavements at the optimum time to maximize

Table 2.2. Classification of Pavement Activities by Purpose

Type of Activity	Purpose of Activity				
	Increase Capacity	Increase Strength	Slow Aging	Restore Surface Characteristics	Improve or Restore Functionality
New construction	X	X	X	X	X
Reconstruction	X	X	X	X	X
Major (heavy) rehabilitation		X	X	X	X
Structural overlay		X	X	X	X
Minor (light) rehabilitation			X	X	X
Preventive maintenance			X	X	X
Routine maintenance					X
Corrective (reactive) maintenance					X
Catastrophic maintenance					X

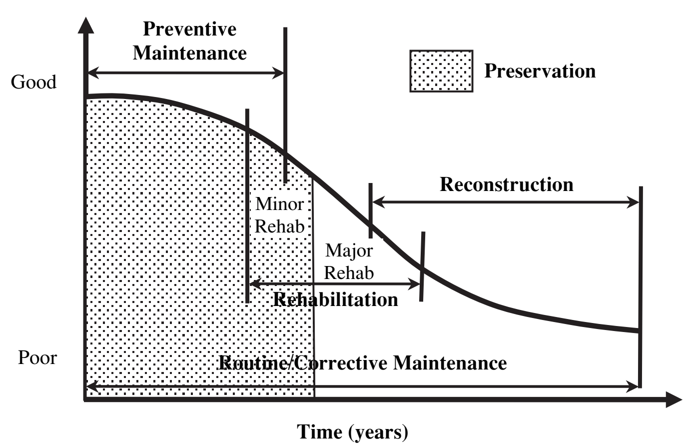
Source: Adapted from Geiger 2005.

their useful life, thus enhancing pavement longevity at the lowest cost (Kuennen 2006b). It represents a proactive approach to maintaining existing highway pavements that enables highway agencies to reduce costly, time-consuming rehabilitation and reconstruction projects and the associated traffic disruptions (Geiger 2005).

Table 2.2 illustrates various pavement activities and their primary purpose. The three shaded rows represent pavement preservation, indicating that it is composed of PM, some forms of minor (nonstructural) rehabilitation, and some forms of routine maintenance (Geiger 2005). The darker shading indicates that PM is the primary component of pavement preservation. The general philosophy of pavement preservation is to apply preventive (actions intended to prevent, stop, or slow down deterioration), restorative (actions intended to improve conditions or restore conditions to acceptable levels), or limited corrective (actions intended to fix defects or reestablish structural integrity) treatments to pavements that are in relatively good condition and have little or no structural deterioration. Application of the right treatment at the right time and in the right manner can help prolong the service life of the pavement. Incidentally, this is especially important for high-traffic-volume roadways where construction delays have a large impact on users.

One of the keys to an effective pavement preservation program on high-volume roadways is understanding pavement performance. The typical life cycle of a pavement and the general categories of treatments that are appropriate at different times of the life of the pavement are presented in Figure 2.1. PM is used early in the life of the pavement, while the pavement is still in good condition. When a pavement has deteriorated so that more extensive cracking and other distresses are present, the use of PM is no longer appropriate, but it could be too soon to trigger major rehabilitation. Pavements at this condition level receive minor rehabilitation treatments, such as thin overlays or surface recycling, that restore functional qualities and, to a limited extent, structural integrity. The use of PM treatments and minor rehabilitation techniques along with routine maintenance are good options for a pavement that is still in relatively good condition.

If PM or minor rehabilitation is not used during the life of the pavement, the pavement will deteriorate to the point that major rehabilitation (structural restoration, such as full-depth repairs or thick overlays, or even reconstruction) is necessary. When a pavement develops significant levels of distress, pavement preservation activities are no longer viable treatment options. If PM or minor rehabilitation is used on a pavement that is highly deteriorated, the life of the chosen treatment can be greatly reduced, especially on pavements with high traffic volumes.



Source: Adapted from Peshkin et al. 2007.

Figure 2.1. Relationship between pavement condition and different categories of pavement treatment.

Preservation Treatments

There is a broad range of treatments that may be used in the preservation of pavements. While many may focus on a specific treatment and its role in preservation, it is not the treatment alone that defines preservation. Considering Table 2.2 and Figure 2.1, both the purpose and timing of the treatment help define a preservation treatment. With that caveat, descriptions of treatments that are commonly used in pavement preservation are provided in the *Guidelines for the Preservation of High-Traffic-Volume Roadways.*

In addition to the treatments listed in the *Guidelines for the Preservation of High-Traffic-Volume Roadways,* drainage preservation is a treatment that can be carried out on both HMA- and PCC-surfaced pavements. This activity consists of cleaning silt, debris, and vegetation at underdrain outlets and replacing damaged or destroyed outlets. Although not directly applied to the pavement structure, it is considered by many to be an essential tool in the preservation of the pavement, as it helps to ensure adequate drainage of the structure.

A few other types of preservation treatments were identified and examined as part of the literature review. These treatments fall under one or another of the following categories: (a) lengthy existence but limited overall use; (b) lengthy existence but use limited to one or two agencies; (c) international use, with recent trials in the United States; or (d) new or innovative, with recent trials in the United States. Known details regarding each of these treatments are provided below.

Each preservation treatment has unique capabilities and functions that enable them to accomplish the following:

- Prevent or delay the occurrence of new distresses or slow the development of existing distresses; or
- Restore the integrity and functionality or serviceability of the pavement or improve its surface characteristics.

The primary means by which the treatments can achieve these goals are summarized in Tables 2.3 and 2.4.

Preservation Treatments and Existing Pavement Condition

The condition of a pavement has a significant impact on the ability of treatments to fulfill their respective goals, and so their effectiveness is fairly variable. By the same token, a treatment will not be very effective if the pavement condition is too good, although that "problem" is rarely encountered.

While it is difficult to establish optimal timings (in terms of the overall condition of the existing pavement) for the application of individual treatments, the timings of treatments grouped according to similar goals and purposes are easier to construct. Preventive treatments like joint or crack sealing and surface seals are most appropriate for pavements in good to very good condition, while preventive or restorative measures like thin HMA overlays, proprietary surfacings, and patching are most appropriate for pavements in fair to good condition. More extensive restorative treatments like mill-and-HMA overlay, ultra-thin whitetopping, thin PCC overlays, and partial-depth recycling (i.e., hot in-place recycling [HIR] and cold in-place recycling [CIR] confined to surface, intermediate, or upper-base layers) are most appropriate for pavements in fair condition.

The selection of appropriate preservation treatments is based not only upon the overall condition of the roadway, but also the specific visible distresses. For instance, if transverse cracking in an HMA-surfaced pavement is frequent but there is not a high degree of edge deterioration, the pavement may be best treated with a surface treatment. If the cracks are low to moderate in frequency but have typically progressed to a point of high edge deterioration, then crack repair or patching may be needed. In the case of pavements with transverse thermal or reflection cracks that are moderate in density and have little or no deterioration, the cracks can be treated effectively through sealing operations. For pavements with a substantial amount of nonworking cracks (primarily longitudinal, but also transverse) with different size openings and relatively low levels of deterioration, an appropriate treatment is crack filling.

Thin HMA overlays are used on all types of roadways for functional improvements. The pavement to be restored using thin HMA overlays should be in good to fair condition. This type of treatment is particularly suitable for high-volume roads in urban areas where longer life and relatively low-noise surfaces are desired. Similarly, slurry seals do not usually perform well if the underlying pavement contains extensive cracks. According to the South Dakota DOT, slurry seals should not be used on deteriorated pavements. Chip seals, on the other hand, can be applied during the majority of a pavement's life (Johnson 2000). However, the ideal benefits of chip sealing are achieved when the treatment is applied early. For instance, chip sealing can be used when the pavement has just begun to oxidize, and should not be applied to pavements with distress such as high-severity cracking, raveling, potholes, or rutting.

Additionally, for the use of thin HMA overlays, cracking should be of low to moderate severity and ideally should have been crack-sealed 6 to 12 months prior to the thin overlay application. Raveling should be of low to moderate severity, with depressions caused by stripping of the surface no greater than 0.25 in. (6 mm) deep. In addition, it is recommended to mill the surface before an overlay application when segregation, raveling, or block cracking are present (Hein and Croteau 2004). If rutting is evident, the pavement can also receive a leveling course instead of milling.

Also identified in the literature search, ultra-thin bonded wearing course applications are typically used to seal the surface

Table 2.3. Primary Capabilities and Functions of Preservation Treatments for HMA-Surfaced Pavements

	Prevention		Restoration				
Treatment	**Seal/Waterproof Pavement**	**Rejuvenate Surface/ Inhibit Oxidation**	**Eliminate Surface Defects[a]**	**Eliminate Stable Ruts**	**Improve Texture for Friction**	**Improve Profile (Lateral Surface Drainage and Ride)**	**Improve Texture for Noise**
Crack filling	√		√				
Crack sealing	√		√				
Cold milling			√			√	
Profile milling				√	√	√	
Rejuvenation		√					
Fog seal	√	√					
Scrub seal	√	√			√		
Slurry seal	√	√			√		
Microsurfacing	√	√		√	√	√	
Sand seal	√	√			√		
Chip seal	√		√		√	√ (minor)	
Ultra-thin HMAOL	√		√		√	√	√
Ultra-thin bonded wearing course	√		√		√	√	√
Thin HMAOL							
Dense-graded	√		√	√	√	√	√
Open-graded (OGFC)[b]					√		
Gap-graded (SMA)				√	√	√	√
Mill and thin HMAOL	√		√	√	√	√	√
Hot in-place recycling							
Surface recycling		√	√	√		√	
Remixing		√	√	√		√	
Repaving			√	√	√	√	
Cold in-place recycling		√	√	√		√	
Ultra-thin whitetopping			√	√	√	√	

Source: Modified from KYTC 2009.

Note: HMAOL = Hot-mix asphalt overlay; OGFC = Open-graded friction course; SMA = Stone matrix asphalt.

[a] Surface defects include weathering/raveling, bleeding, polishing, surface cracks, and so on.

[b] Improves splash/spray.

Table 2.4. Primary Capabilities and Functions of Preservation Treatments for PCC-Surfaced Pavements

	Prevention		Restoration			
Treatment	**Seal/Waterproof Pavement**	**Prevent Intrusion of Incompressibles**	**Remove/Control Faulting**	**Improve Texture for Friction**	**Improve Profile (Lateral Surface Drainage and Ride)**	**Improve Texture for Noise**
Crack sealing	√	√				
Joint resealing	√	√				
Diamond grinding			√	√	√	√
Diamond grooving				√		
Partial-depth patching	√	√	√		√	
Full-depth patching	√	√	√[a]		√[a]	
Dowel bar retrofit			√		√	
Ultra-thin bonded wearing course	√	√		√	√	√
Thin HMAOL	√	√		√	√	√
Thin PCCOL	√	√		√	√	√

Source: Modified from KYTC 2009.
Note: HMAOL = Hot-mix asphalt overlay; PCCOL = Portland cement concrete overlay.
[a] In conjunction with diamond grinding.

to minimize weathering, raveling, and oxidation. Candidate roads for this treatment usually should have ruts less than 0.5 in. deep, moderate to no cracking, and minor to no bleeding. In contrast, slurry seals are used to seal the surface of the existing asphalt pavement, retard surface raveling, seal small cracks, and improve surface friction. As with other surface treatments, slurry seals should not be used where sealing the pavement would cause a stripping problem or where the underlying pavement is cracked (Wade et al. 2001).

Other preventive treatments include fog seals, which can be considered a candidate treatment to address raveling, and oxidation. However, a fog seal generally lasts only 1 to 2 years. Microsurfacing is primarily used as a surface seal to address rutting and loss of friction; this treatment also limits damage from water, oxidation, and ultraviolet (UV) rays, which cause weathering, raveling, and surface cracking.

A detailed analysis of the long-term pavement performance (LTPP) data from the four treatments used at SHRP Specific Pavement Study (SPS)-3 sites through 2001 indicated that thin HMA overlays were most effective—followed by chip seals and then slurry seals—in addressing roughness, rutting, and fatigue cracking (Hall et al. 2002). Slurry seals showed no effect on long-term roughness. The thin overlays, as expected, were the only treatment to affect long-term rutting. The study concluded that, with respect to roughness, rutting, and cracking on PCC pavements in the SPS-6 study, HMA overlay had the best effect, followed by diamond grinding, full-depth repair, and joint and crack sealing. No added benefit was associated with drainage improvement, dowel bar retrofitting, and undersealing.

Regarding the use of diamond grinding on concrete pavements, the pavement should not have corner breaks, spalling, or popouts. The visible surface distress may include low-severity cracking, faults not exceeding 0.25 in. (6 mm), and moderate to severe polishing. Pavements with moderate to advanced material-related distresses, such as alkali-silica reaction (ASR) and D-cracking, are not good candidates for diamond grinding (Shuler 2006).

Use of Preservation Treatments on High-Traffic-Volume Facilities

While it is generally observed that the practice of pavement preservation and the use of PM are growing among transportation agencies, the majority of constructed preservation projects, in terms of treated lane miles, occur on lower-volume roadways. One explanation for this is that typical PM treatments, such as chip seals and other thin surface treatments, have historically been used on low-volume roads. However, there are many indications that this is changing.

A 2004 survey conducted under the National Cooperative Highway Research Program (NCHRP) 20-07 revealed that most agencies practice pavement preservation on all types of facilities (Peshkin and Hoerner 2005). This conclusion was drawn from responses to the following question, “On what facility types does your agency currently apply preven-

Table 2.5. Summary of Facility Characteristics Associated with Projects Selected as Candidates for Pavement Preservation Projects

Roadway Classification	General ADT Range Associated with Different Roadway Classifications (vehicles per day [vpd])	Number of Respondents Using Preservation	
		Rural	Urban
Freeway	30,000 and above	29 of 35 (83%)	26 of 35 (74%)
Arterial	12,000 to 40,000	29 of 35 (83%)	27 of 35 (77%)
Collector road	2,000 to 12,000	29 of 35 (83%)	27 of 35 (77%)
Local road	≤2,000	24 of 35 (69%)	22 of 35 (63%)

Source: Peshkin and Hoerner 2005.

tive maintenance treatments?" The responses are shown in Table 2.5.

Results from this survey seemed to indicate that pavement preservation is occurring as frequently, or even more frequently in the case of rural roads, on higher-volume roadways as on lower-volume roadways. These results suggested that the more important distinction is between rural and urban roadways for any traffic volume.

Although in general there may be a common association between typical preservation treatments and their use on low-volume roads, some departments of transportation (DOTs) are finding it effective to apply such treatments to high-volume roads. The DOTs identified in the literature as having performed preservation work on high-traffic-volume roadways (ADT ≥ 2,500 vpd) include Alabama, Arkansas, California, Colorado, Florida, Georgia, Idaho, Montana, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, Utah, Virginia, and Washington State. International agencies proactive in the use of preservation treatments on high-volume roads include the United Kingdom, South Africa, Spain, France, and Australia.

While chip seals have seen the greatest use on low-volume roadways (with a typical ADT less than 1,000 vpd), California allows them to be used on roads with average annual daily traffic (AADT) up to 30,000 vpd (Romero and Anderson 2005). The United Kingdom "commonly" uses chip seals on roads with ADT greater than 20,000 vpd, as do Colorado and Montana (Cuelho et al. 2006). In Washington State, chip seals were used on the Tacoma Narrows Bridge, which has an ADT of 178,000 vpd (Kuennen 2006a).

Following the successes of other states, a study conducted for the Utah DOT recommended that chip seal usage extend to "certain roads with AADT up to 20,000 vehicles," while continuing the existing practice of using chip seals on highway sections with AADT less than 5,000 vpd (Romero and Anderson 2005). On the other hand, while the Colorado DOT's maintenance superintendents believe chip seals "can be used on high-volume roads (AADT up to 10,000 vpd)," one region restricts their use to roads with AADT less than 1,200 vpd, and Ohio limits their use to roads with less than 2,500 vpd AADT (Galehouse 2004; Ohio DOT 2001).

In other states, such as Utah, there was some concern about cost and relative performance of chip seals; following a life-cycle study of chip seals, it was recommended that policies be modified to specify open-graded friction courses (OGFCs) for high-speed (greater than 55 mph [88 kph]), high-volume roads (AADT greater than 25,000 vpd), similar to practices in Georgia, Nevada, and Oklahoma (Romero and Anderson 2005). OGFCs have also found success on high-volume roads in Florida (at 10 to 12 years) and Oregon (up to 8 years and 2.5 million equivalent single-axle loads [ESALs]) (Huddleston et al. 1993; Page 1993). At the same time, Connecticut and South Carolina limit the use of OGFCs, and other states, including Illinois, Michigan, and Washington, have discontinued their use because of poor performance.

Microsurfacing has been successful on high-volume roads in Texas, Kansas, Oklahoma, Pennsylvania, and Arkansas. Oklahoma found that microsurfacing provides adequate performance for "at least 4 years under traffic volumes up to 70,000 ADT" (Raza 1994). Virginia has applied microsurfacing treatments to stretches of Interstate with AADTs ranging from 14,000 up to 26,000 vpd, preserving "performance qualities for several years," whereas Michigan confirms this level of performance, typically assuming service life for a single-course microsurfacing treatment of 3 to 5 years or up to 6 years for multiple courses (Morian et al. 2005; Peshkin and Hoerner 2005). Indiana has determined that "severe climatic conditions," as opposed to traffic volume, have a greater effect on performance of microsurfacing treatments (Labi et al. 2007).

Cold in-place recycling (CIR), has found success in Pennsylvania, where projects have outperformed their expected service life of 10 years by an average of 3 additional years (Morian et al. 2004). In Nevada, with regular crack sealing and judicious use of CIR, projects can achieve full life expectancy of 15 to 20 years (Bemanian et al. 2006). In Quebec, Canada, Bergeron (2005) compared CIR practices with typical asphalt resurfacing for highways with AADT of 20,000 vpd to determine the difference in net present value and benefit-cost ratio. The additional performance of CIR compared with asphalt resurfacing resulted in higher benefit-cost ratios, even though the net present values were higher for CIR. Bergeron also found that CIR net present values for national and regional roads (with an AADT of 12,000) were less and had even higher benefit-cost ratios.

Ultra-thin bonded wearing courses (also referred to as ultra-thin friction courses) are a relatively new preservation treatment but are generally considered appropriate for high-volume roads. The literature identifies performance studies in two southern states, Alabama and Louisiana. Alabama has had success using ultra-thin bonded wearing course on several high-volume roads including US 280 (13,000 ADT), AL 21 (7,500 ADT), I-65 (60,000 ADT), and I-29 (165,000 ADT) (Koch 2001). Missouri's first experiment using this treatment was damaged by freeze-thaw and snowplowing (MoDOT 1999). This treatment has also been placed in several cold-weather states, including Colorado, Michigan, New York, Ohio, Pennsylvania, and Wisconsin (Koch 2001). Anecdotal reports are that it has been successful.

Special Considerations for High-Traffic-Volume Treatments

A common concern regarding preservation treatment performance on high-volume roads is the issue of treatment durability, or obtaining a cost-effective service life from the preservation treatment, given the traffic level. As previously asserted, effective preservation requires the appropriate treatment for a given pavement section, as well as proper timing (Geoffroy 1996). For high-volume facilities, choosing the appropriate treatment may require additional considerations. For example, as noted, chip seals see their most common application as wearing courses on low-volume roads, but they have proven successful as surface treatments for high-volume roads. Using a chip seal on a high-volume road may require using a higher-quality aggregate or polymer-modified binder, which has been effective for California and Washington State, with both reporting 5 to 7 years of serviceable life (Shuler 1998; Geoffroy 1996).

Gransberg's (2005) synthesis of chip sealing best practices found that all nine agencies (culled from 72 individual responses from 42 states and 12 cities and counties) reporting superior results from chip sealing applications do the following:

- Use polymer or crumb-rubber modified binders;
- Use pavement condition ratings as triggers, then select roads of moderate or less distress level with structural cross-section rated fair or better; and
- Follow chip sealing applications with routine crack or fog sealing.

Specifically regarding high-volume roads, Gransberg concluded:

- Chip seals can be successfully used on high-volume roads if the agency's policy is to install it on roads before pavement distress becomes severe or the structural integrity of the underlying pavement is breached.
- Both hot asphalt cement and emulsified asphalt binders can be used successfully on high-volume roads. Binders modified by polymers or crumb rubber seem to reinforce success.

Some other recommendations for applying chip seals to high-volume facilities include applying a "choke" aggregate to prevent dislodging larger aggregate chips or applying a fog or flush seal over the chip seal (Shuler 1998; Wade et al. 2001). One region in Colorado applies fog seals within 2 to 10 days of placement on a "majority" of chip seals (Galehouse 2004). However, it should be noted that additional time may be required to allow emulsions to break (Wade et al. 2001).

Several additional considerations are recommended to extend the applicability of chip seal treatments to higher-traffic-volume roadways. These include the following (Beatty et al. 2002; Shuler 1998):

- Precoat aggregate to improve adhesion, an approach popular in South Africa and Australia.
- Limit excess chips to 5% to 10%.
- Sweep excess chips prior to opening to traffic.
- Once opened to traffic, control speeds (via signage or a pilot car) to reduce whip-off and to promote embedment.

In Canada, it has been confirmed that the structural integrity of the seal is "dependent on the embedment of the aggregate in the binder/substrate" because chip seals are leaner on high-volume roads to avoid bleeding (Croteau et al. 2005).

Performance of Treatments on High-Traffic-Volume Facilities

Performance is varied for different preservation treatments on high-volume roadways. California reports "good performance" from chip seals on facilities with up to 30,000 ADT, and "good performance" from crack sealing, slurry sealing, and microsurfacing, as well as applying OGFCs and thin HMA overlays for facilities with greater than 30,000 ADT. On the other hand, California does not recommend fog sealing on facilities with greater than 5,000 ADT, and has typically experienced "fair performance" with fog seals on facilities with less than 5,000 ADT (Shatnawi et al. 2006).

Texas monitored performance of different PM treatments on the SPS-3 sections (crack sealing, chip seals, slurry seals, and thin overlays), concluding that chip seals performed the best under a "wide range" of pavement conditions, as well as scoring the best on high- and low-volume sections. Considering initial cost, chip seal is a better choice on high-traffic roads, especially where rutting is not a concern. If rutting is a major problem, then a thin HMA overlay was determined to be the most effective option (Chen et al. 2003).

Slurry seals have typical reported service lives of 3 to 5 years on roads with "moderate to heavy traffic," effectively reducing crack development and raveling, as well as being "marginally effective" in preventing reflective cracking (Morian et al. 1997; Raza 1992). Flush seals are reported to survive "approximately 2 to 7 years" for traffic up to 5,000 ADT and up to 5 years for higher volumes (NCHRP 1997).

Microsurfacing provided good rut resistance for 3 to 7 years in Kansas, Pennsylvania, Oklahoma, and Arkansas. Oklahoma and Pennsylvania also note good surface friction for up to 5.5 years of service (Raza 1994; Wade et al. 2001). However, in North Carolina, it was reported that once the microsurfaced sections failed, they "deteriorated quickly" due to the pavement's diminished structural integrity under heavy traffic loading (Morian et al. 2005).

OGFCs have reported service lives of 10 to 12 years on Florida Interstates and up to 8 years in Oregon (Huddleston et al. 1993; Page 1993). Reported average service lives for CIR treatments range from 5 to almost 13 years in Ohio and Pennsylvania (Hicks et al. 2000; Morian et al. 2004). Ultra-thin bonded wearing courses are generally reported to achieve service lives of between 7 and 12 years (Gilbert et al. 2004; Peshkin and Hoerner 2005).

Illinois reports successful service lives of 7 to 10 years using thin HMA overlays (1 to 1.5 in. [25 to 38 mm]) when correctly targeting specific pavement condition criteria, while one district in Indiana expects a 10- to 15-year pavement life extension using thin HMA overlays (Cuelho et al. 2006; Reed 1994). Iowa DOT has also found best performance from thin HMA overlays compared to chip seals, fog seals, cape seals, slurry seals, and even microsurfacing (Jahren et al. 2003). Washington State DOT most commonly uses thin HMA overlays for pavement preservation, reserving chip seal applications for lower-traffic areas (Li et al. 2008).

In Colorado, it was noted that deicer compounds leave residue in pavement cracks, preventing adequate sidewall adhesion and, consequently, loss of crack sealant. Seasonal limitations were recommended, including waiting "at least two rainfall events" before commencing crack-filling operations (Galehouse 2004). In Utah, OGFCs have on average survived 7 years, early failures being related to raveling, stripping, and potholing (Romero and Anderson 2005).

The literature gives some indication of how extensively practitioners are making efforts to establish PM practices and policies for their high-traffic-volume roadways with varying degrees of success. The performance of treatments varies significantly from agency to agency, and there are gaps in the shared knowledge pool, especially regarding PM practices on PCC roadways. Furthermore, "success" is a relative concept, where what some agencies describe as successful is not considered as successful by others. Variations in traffic, climate, and materials may account for some of these relative differences. In any case, the full extent of each agency's PM program is difficult to gauge from the literature. In the next section, the review of the questionnaire responses illuminates state and provincial PM practices and can be viewed as a supplement to the information reported in the literature.

Preservation Treatments and Climate

Climate is commonly defined as the weather of a given region averaged over a long period of time (AMS 2008). It encompasses the statistics of temperature, humidity, atmospheric pressure, wind, rainfall, and numerous other meteorological elements, and is affected by latitude, terrain, altitude, ice or snow cover, as well as nearby water bodies and their currents.

Climatic conditions impact preservation treatment usage in at least two ways: determining construction timing, and affecting treatment performance. Brief discussions of these impacts are provided in the following sections.

Climatic Effects on Construction Timing

Some treatments, especially those based on asphalt emulsions, are best applied under restricted temperature and humidity conditions. Climate can directly affect curing time, which in turn impacts treatment feasibility and opening to traffic. For example, crack sealing techniques are best applied when temperatures are moderately cool (i.e., spring and fall in the northern half of the United States). Accordingly, the Ohio DOT recommends that crack sealing, in contrast to most other PM strategies, be performed in cooler weather when the pavement has contracted, thus moderately expanding crack openings such that on very hot or cold days, the sealant will not bulge excessively or risk pulling away (Cuelho et al. 2006). Because crack filling treats nonworking cracks that are not significantly affected by temperature fluctuations, crack filling can be applied any time of the year when weather conditions are appropriate (i.e., no rain or snow).

Fog seals, according to the South Dakota DOT, are not recommended for high-volume roadways because of the length of time required for slow setting emulsions to break, which reduces the amount of surface friction immediately after application (Wade et al. 2001).

The use of a slurry seal may not be appropriate for high-volume roads where traffic must be allowed very soon after application. In warm weather, slurry seals require at least 2 hours to cure, resulting in potential traffic delays. On the other hand, microsurfacing cures and develops strength faster than conventional slurry seals and can be opened to rolling traffic in about an hour; therefore it is more applicable for a variety of environments.

In the case of chip seals, cold-applied seals must be placed during the day and in warm temperatures, while hot-applied chip seals can be placed at night and in cooler temperatures. Generally, the construction season runs from May to September to take advantage of the warmest months for the northern states (Gransberg 2005). Good performance related to favorable climatic conditions during placement and also, importantly, favorable climatic conditions during the weeks following placement. The major cause of pavement failure is weather related, such as when rain or extreme temperatures occur shortly after construction (Croteau et al. 2005).

Although thin HMA overlays can be placed successfully in a variety of climatic conditions, application in cooler temperatures can impact the ability to achieve specified density. This is particular true for ultra-thin HMA overlays.

Climatic Effects on Treatment Performance

Whereas some preservation treatments, such as diamond grinding on PCC pavements, may not be too affected by differences in climate, most treatments do experience climate-related performance effects. For example, the Indiana DOT has determined that severe climatic conditions, as opposed to traffic volume, have a greater effect on performance of certain treatments, such as microsurfacing (Labi et al. 2007).

Results of the SHRP SPS-3 study indicated that chip seals performed well across all climate zones and very well in wet nonfreeze zones (Morian et al. 1998). Moreover, slurry seals showed very good performance in nonfreeze climates, but poor performance in freeze climates. Similarly, crack seals showed good performance in nonfreeze climates, but significantly reduced performance in freeze climates.

International Pavement Preservation Practices

In addition to information on preservation practices within the United States, some information was obtained about international practices. The proper context for each treatment strategy must be understood because the way in which each country chooses its preservation strategy depends on its standard road design, climate, traffic patterns, and political and economic organization. Information collected from Saudi Arabia, India, France, South Africa, and Australia is provided in the following descriptions. Note, however, that these are large, diverse countries and that what is reported may not be representative of an entire country's practice.

Saudi Arabia reported using sulfur asphalt, crack sealing, slurry seals, microsurfacing, and thin overlays as part of its preservation activities. Sulfur asphalt is a mixture of asphalt binder and a sulfur compound that makes a stiffer product. This product is more resistant to rutting, even with inferior aggregates, but due to its stiffer and more brittle nature, it can be susceptible to fatigue cracking and is less resistant to water damage and stripping than conventional asphalt. The temperature must be closely monitored during mixing to ensure the proper blend of asphalt and sulfur. The price and availability of sulfur varies, making it difficult to predict prices and feasibility. Its uses are similar to any other asphalt overlay, except that layer thickness may be decreased when rutting is the primary concern. Rut-resistant solutions are important in the country's hot climate.

India has included in its pavement preservation strategies the use of stone matrix asphalt (SMA), microsurfacing, and cold in-place recycling. SMA is a type of HMA that uses a modified aggregate gradation. This gap-graded gradation creates a stable skeleton of top-size aggregate particles, whereas the fine materials mix with the binder to create a stiff mastic to hold the aggregate skeleton together. Fibers are sometimes included. This stone-on-stone contact makes a highly rut-resistant material. Similar to the practices in Saudi Arabia, India has placed important emphasis on the development of rut-resistant asphalt mixes due to the hot climate.

France reports on an overall pavement strategy that is focused on building strong and stiff underlying pavements and performing surface repaving every 10 to 15 years. As is common for many European countries, many of the roads and maintenance contracts in France are privatized, so the work may be performed and funded by private entities rather than by the government. Seals and thin overlays are used for improving skid resistance, reducing noise, and enhancing ride smoothness between major repaving projects. Open-graded mixes are commonly used for noise reduction. In material design, aggregate quality is emphasized, and both hot asphalt mixes and emulsions are used for surface work. A new development, called a "bio-binder," which is asphalt cut back with vegetable oil to make a binder that is workable at normal temperatures, has been used on several projects, though full details of its performance are not known.

South Africa uses a variety of surface seals, especially chip seals, even on high-volume roads. An important part of the process is that the aggregate is precoated to reduce loss and stripping. Like France, South Africa emphasizes aggregate quality by limiting fines and securing quality aggregate regardless of cost. Also, like France, it builds strong and thick pavement sections, so that structural distresses are minimized and the use of chip seals address surface distresses only. Emulsions are used only for fog seals or rejuvenators; otherwise, hot asphalt is used. Crumb rubber is used in both HMA and surface treatments.

Australia places a heavy emphasis on preservation, particularly keeping water away from the subgrade. Most roads have a very thick subbase, a strong unbonded base course, and an asphalt concrete wearing surface. An example of a PM process in Australia includes milling and placement of a stress-absorbing membrane, followed by an asphalt concrete overlay. Emphasis is placed on crack sealing with polymer-modified binder to prevent water intrusion. Another PM technique is a tack coat that is followed by a geotextile and then a chip seal. Most Australian states dedicate more funding to PM than to reconstruction. For example, the state of Victoria dedicates 90% of its program to prevention and 10% to reconstruction.

Review of Survey Results

As shown in Table 2.6, 50 highway agencies responded to the pavement preservation questionnaire; the FHWA's Central Federal Lands Highway Division (FHWA-CFLHD), National Association of County Engineers (NACE), and National Asphalt Pavement Association (NAPA) also provided responses.

A review of the survey responses revealed that there was a wide range of experience in pavement preservation practices.

Table 2.6. Summary of Survey Respondents

State Highway Agencies		*Canadian Provinces*
Alaska	Montana	Alberta
Arizona	Nebraska	British Columbia
Arkansas	Nevada	Manitoba
California	New Hampshire	New Brunswick
Colorado	New Mexico	Ontario
Connecticut	New York	Quebec
Florida	North Carolina	Saskatchewan
Georgia	Ohio	
Hawaii	Oklahoma	*Cities*
Illinois	Pennsylvania	Phoenix, Ariz.
Indiana	Rhode Island	San Diego, Calif.
Iowa	South Carolina	
Kansas	South Dakota	*Toll Authorities*
Kentucky	Tennessee	Texas Turnpike
Louisiana	Texas	
Maine	Utah (3)[a]	
Michigan	Virginia	
Minnesota	Washington	
Mississippi (4)[a]	Wisconsin	
Missouri	Wyoming	

[a] Agencies that submitted multiple responses from various districts within the state have the number of responses indicated in parentheses.

Among the 28 agencies that responded to the experience question, one-half reported having more than 10 years of experience and one-quarter reported having more than 20 years' experience.

Treatment Selection Considerations

In identifying the important considerations in selecting preservation treatments, respondents collectively reported the following hierarchy:

- High Priority
  1. Safety concerns (76%)
  2. Treatment cost (74%)
  3. Durability/expected life of treatment (64%)
- Medium Priority
  1. Availability of experienced contractor (60%)
  2. Work zone considerations (59%)
  3. Tied: Risk associated with treatment failure; closure time (57%)
- Low Priority
  1. Availability of alternate route(s) (40%; however, one in four of all respondents considered this issue unimportant)
  2. Noise issues (39%)
  3. Public perception (36%)

Traffic volume was considered of high priority by just over half of respondents and of medium priority by approximately 40%. This implied that if pavement preservation is indeed practiced on high-traffic-volume roads, many agencies have established standard practices using preservation treatments for that application.

Responses regarding the most successful treatments indicated that they have low cost, good durability and long life expectancy, and fast application (important in getting work crews quickly out of harm's way and in minimizing impact on road users). These responses show the influence of the noted priority factors on treatment selection. On the other hand, the common complaints against the least successful preservation treatments that agencies have used were related to high cost and poor performance.

Traffic Level and Treatment Use

An important consideration affecting which preservation treatments are used on high-traffic-volume roadways is how the agency defines "high" traffic volumes. While some respondents wanted the researchers to provide a definition for high traffic volumes, it was recognized that different agencies use markedly different definitions and that it would be better for respondents themselves to provide this value. Accordingly, in order to better characterize the range of volumes considered, the questionnaire asked respondents to provide their own values for low (less than or equal to . . .), medium (a range), and high (greater than or equal to . . .) traffic volumes for both rural and urban roadways. In order to make further distinctions concerning treatment use on high-traffic-volume roadways, the agency-defined criteria for high traffic volume were exclusively examined. These criteria were grouped into one of three categories for both rural and urban roadways—"low" (ADT < 10,000 vpd), "medium" (ADT = 10,000 to 19,999 vpd), and "high" (ADT ≥ 20,000 vpd). A summary of the high-traffic-volume criteria grouped according to these three categories is provided in Table 2.7.

The high-traffic-volume criteria reported by agencies were initially analyzed for trends concerning the use of the preservation treatments. Some key findings from this initial analysis are summarized in Tables 2.8 and 2.9, respectively. Each table lists the most-used treatments on HMA- and PCC-surfaced roadways, based on the three categories of high-traffic-volume criteria.

In addition to the information included in Tables 2.8 and 2.9, the following specific details were noted from the responses regarding high-volume traffic:

- Those agencies falling in the "high" criteria category reported *not* using the following treatments: cape seal, scrub seal,

Table 2.7. Responding Agencies' High-Traffic-Volume Criteria and Criteria Categories

High-Traffic-Volume Criteria Categories		
Low Criterion (ADT < 10,000 vpd)	**Medium Criterion (ADT = 10,000 to 19,999 vpd)**	**High Criterion (ADT ≥ 20,000 vpd)**
Louisiana DOT (7,000)	Alaska DOT (10,000)	Connecticut DOT (30,000)
Michigan DOT (3,400 est.)	Hawaii DOT (10,000)	Rhode Island DOT (30,000)
Missouri DOT (1,000)	Maine DOT (10,000)	South Carolina DOT (20,000)
Montana DOT (6,000)	Minnesota DOT (10,000)	British Columbia (100,000)
New York DOT (4,000/lane)	New Hampshire (10,000)	
Pennsylvania DOT (2,000)	Oklahoma DOT (10,000)	
South Dakota DOT (1,500)	Ontario (10,000)	
Washington DOT (5,000)		
Alberta (5,000)		
FHWA-CFLHD (4,000)		
For agencies that make a distinction between rural and urban traffic volume categorizations:		
Georgia DOT (5,000 rural/8,000 urban)	Wyoming DOT (10,000 rural/15,000 urban)	Virginia DOT (20,000 rural/40,000 urban)
Iowa DOT (3,500 rural)	Iowa DOT (11,500 urban)	
	Florida DOT (10,000 rural)	Florida DOT (40,000 urban)
Kansas DOT (3,000 rural)		Kansas DOT (20,000 urban)
Kentucky DOT (5,000 rural)	Kentucky DOT (10,000 urban)	
Mississippi DOT, Newton (3,000–7,000 rural)		Mississippi DOT, Newton (20,000 urban)
Mississippi DOT, Batesville (2,000 rural)	Mississippi DOT, Batesville (10,000 urban)	
Mississippi DOT, Tupelo (3,000–7,000 rural)		Mississippi DOT, Tupelo (20,000 urban)
	Nevada DOT (10,000 rural)	Nevada DOT (100,000 urban)
New Mexico DOT (5,000 rural)	New Mexico DOT (15,000 urban)	
North Carolina DOT (5,000 rural)	North Carolina DOT (10,000 urban)	
Tennessee DOT (5,000 rural)	Tennessee DOT (10,000 urban)	
Texas DOT (1,000 rural)	Texas DOT (10,000 urban)	
Manitoba (4,000 rural)	Manitoba (10,000 urban)	
Quebec (8,000 rural)		Quebec (20,000 urban)

Table 2.8. Initial Analysis of Most-Used Preservation Treatments for HMA-Surfaced High-Volume Roadways

Rural			Urban		
Low	**Medium**	**High**	**Low**	**Medium**	**High**
≥60% SHAs and provinces report using:					
Crack fill Crack seal Thin HMA overlay Drainage preservation	Crack fill Crack seal Ultra-thin bonded wearing course Cold mill and overlay Drainage preservation	Crack fill Crack seal Thin HMA overlay Drainage preservation	Crack fill Crack seal Single-course microsurfacing Ultra-thin bonded wearing course Drainage preservation	Crack fill Crack seal Multiple-course microsurfacing Cold mill and overlay Drainage preservation	Crack fill Crack seal Drainage preservation
≥50% SHAs and provinces additionally report using:					
Single-course microsurfacing Thin bonded wearing course Cold mill and overlay	Thin HMA overlay Profile milling			Thin bonded wearing course	

single- and multiple-course chip seals, cold in-place recycling, and ultra-thin whitetopping. Nor did they report using any "other" specific treatments (Figures 2.2 and 2.3).

- No agencies reported currently using scrub seal.
- Two SHAs with "high" volume designations, Nevada and Utah, reported using fog seal.
- As shown in Figures 2.2 and 2.3, for all agencies reporting traffic volume designations, crack fill and crack seal are used by at least 60% of reporting agencies. Additionally, on rural roads, thin HMA overlays and drainage prevention are used by at least 60% of agencies (see Figure 2.2), while on urban roads, drainage preservation is used by at

Table 2.9. Initial Analysis of Most-Used Preservation Treatments for PCC-Surfaced High-Volume Roadways

Rural			Urban		
Low	**Medium**	**High**	**Low**	**Medium**	**High**
≥80% DOTs and provinces report using:					
Joint reseal Diamond grinding Full-depth patching	Diamond grinding Full-depth patching Dowel bar retrofit	Joint reseal Crack seal Diamond grinding Full-depth patching	Joint reseal Crack seal Diamond grinding Partial-depth patching Full-depth patching	Joint reseal Crack seal Diamond grinding Full-depth patching	Joint reseal Diamond grinding Full-depth patching
≥70% DOTs and provinces additionally report using:					
Crack seal Partial-depth patching	Crack seal Partial-depth patching Drainage preservation	At 67%: Partial-depth patching Thin HMA overlay Drainage preservation	Dowel bar retrofit Drainage preservation	At 64%: Partial-depth patching Dowel bar retrofit Drainage preservation	Crack seal At 63%: Partial-depth patching At 50%: Dowel bar retrofit Drainage preservation

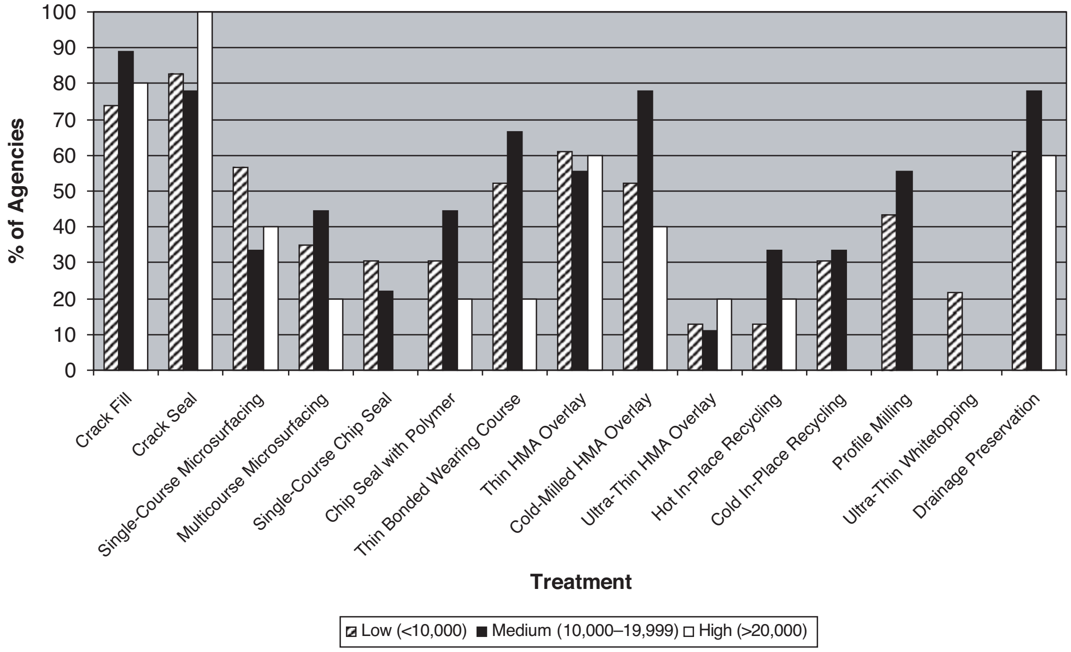


Figure 2.2. Treatment use on rural HMA-surfaced roadways, by category of high-traffic-volume criteria.

least 60% (see Figure 2.3). Also shown in Figure 2.3, the combination treatment of cold milling and thin HMA overlay (<1.5 in.) is used on urban roads by at least 40% of reporting agencies.

- For PCC pavements (Figures 2.4 and 2.5), those agencies with "high" traffic volume designations reported *not* using thin PCC overlays on urban roads. Nor did they report using any "other" treatments on either rural or urban roads.
- For all agencies reporting "high" traffic volume designations, joint seal, diamond grinding, and full-depth patching are used on PCC pavements by at least 80% of reporting agen-

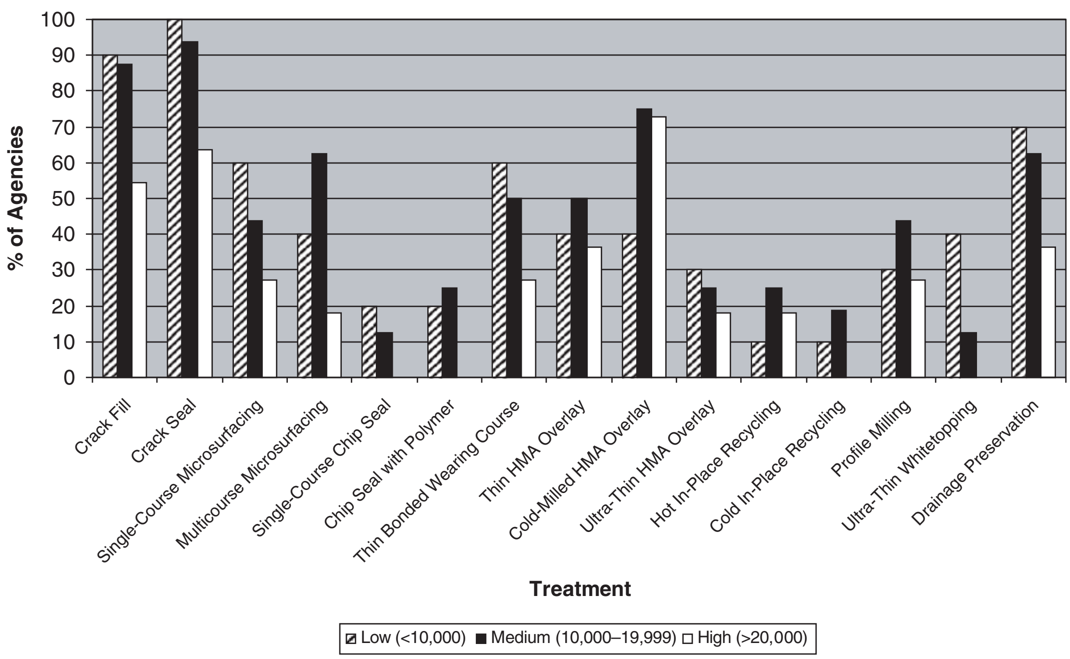


Figure 2.3. Treatment use on urban HMA-surfaced roadways, by category of high-traffic-volume criteria.

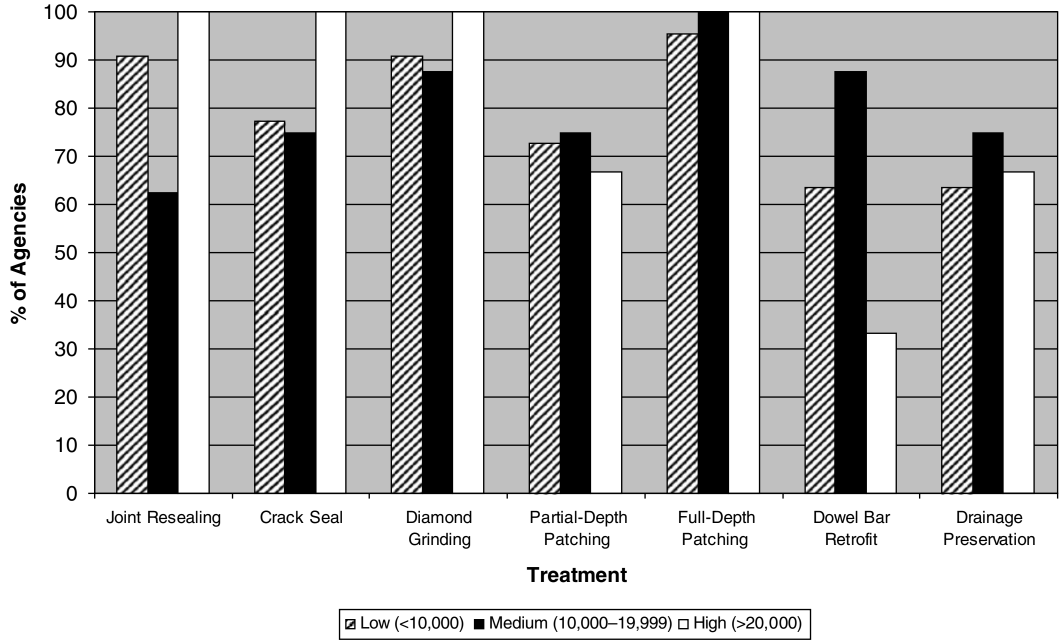


Figure 2.4. Treatment use on rural PCC-surfaced roadways, by category of high-traffic-volume criteria.

cies (see Figures 2.4 and 2.5). Crack seal is used on rural PCC roads by 100% of reporting agencies (see Figure 2.4).

With some differences noted between the treatment usage trends for low-, medium-, and high-traffic-volume criteria categories, an analysis was conducted to generate a numeric definition of high-traffic-volume ADT for rural and urban roadways. Using descriptive statistical analyses, histograms of ADT criterion levels for rural and urban roadways were created (see Figures 2.6 and 2.7) and then analyzed to identify the ADT level at which at least 50% of reporting agencies are represented. From this analysis, it was determined that high

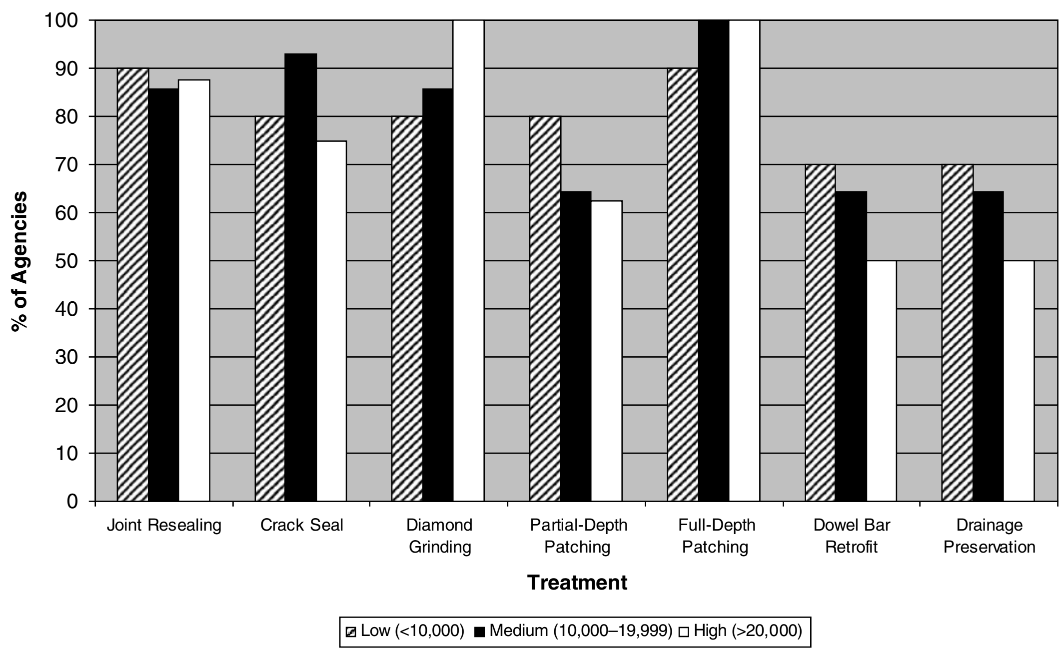


Figure 2.5. Treatment use on urban PCC-surfaced roadways, by category of high-traffic-volume criteria.

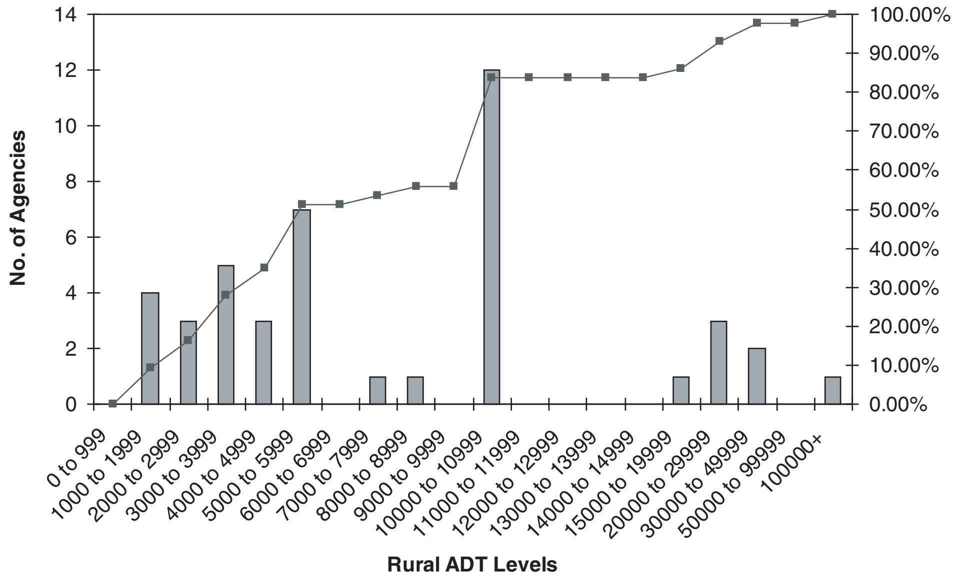


Figure 2.6. Histogram and cumulative percentage of high-traffic-volume ADT on rural roadways.

traffic volume should be defined as an ADT of at least 5,000 and 10,000 vpd for rural and urban roadways, respectively. Modifications were then made to Table 2.7 to reflect the responding agencies whose high-traffic-volume criteria meet these new definitions. The results of this recategorization of agencies are shown in Table 2.10. However, it is recognized that this categorization is still somewhat arbitrary, as for some the high value may be low and for others the high may be too high.

With the new high-volume traffic values serving as the basis for further treatment analysis, the evaluation of the "most used" treatments described previously was revisited. Table 2.11 and Figures 2.8 and 2.9 show the results of this analysis for HMA-surfaced roadways.

Key findings from this analysis are summarized as follows:

- As shown in Figures 2.8 and 2.9, crack fill and crack seal are used by at least 75% of reporting agencies. Additionally, on rural roads, drainage preservation and combined cold milling and thin HMA overlay are used by at least 70% and 60% of agencies, respectively (see Figure 2.8). On urban roads, drainage preservation and combined cold milling

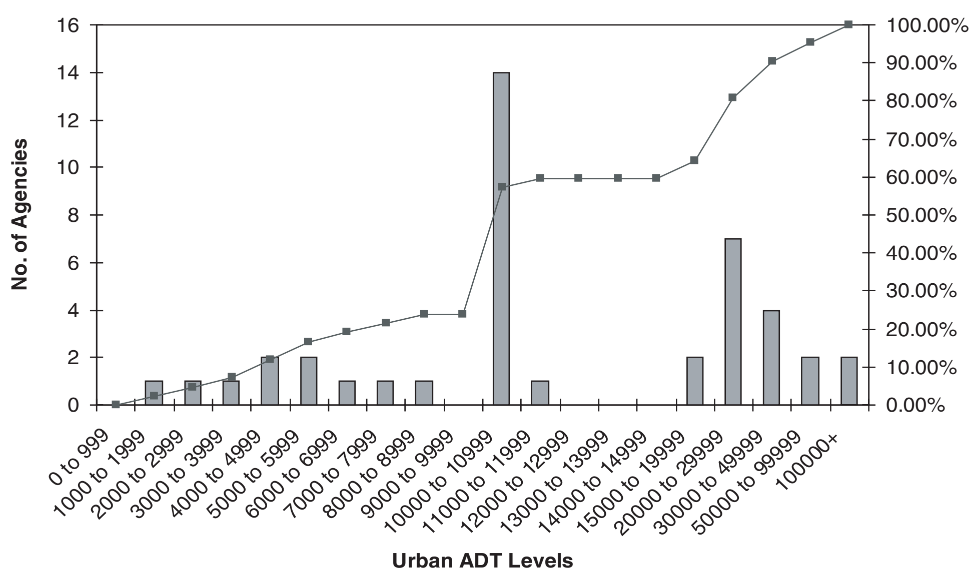


Figure 2.7. Histogram and cumulative percentage of high-traffic-volume ADT on urban roadways.

Table 2.10. Recategorization of Agencies Based on New Definitions of Rural and Urban High-Traffic-Volume Levels

New High-Traffic-Volume Criteria Categories	
Rural (ADT ≥ 5,000 vpd)	**Urban (ADT ≥ 10,000 vpd)**
Louisiana DOT (7,000)	Alaska DOT (10,000)
Washington DOT (5,000)	Connecticut DOT (30,000)
Alberta (5,000)	Hawaii DOT (10,000)
	Maine DOT (10,000)
	Minnesota DOT (10,000)
	New Hampshire (10,000)
	Oklahoma DOT (10,000)
	Rhode Island DOT (30,000)
	South Carolina DOT (20,000)
	British Columbia (100,000)
	Ontario (10,000)
For agencies that make a distinction between rural and urban traffic volume categorizations:	
Georgia DOT (5,000 rural)	
Wyoming DOT (10,000 rural)	Wyoming DOT (15,000 urban)
Virginia DOT (20,000 rural)	Virginia DOT (40,000 urban)
	Iowa DOT (11,500 urban)
Florida DOT (10,000 rural)	Florida DOT (40,000 urban)
	Kansas DOT (20,000 urban)
Kentucky DOT (5,000 rural)	Kentucky DOT (10,000 urban)
Mississippi DOT, Newton (3,000–7,000 rural)	Mississippi DOT, Newton (20,000 urban)
	Mississippi DOT, Batesville (10,000 urban)
Mississippi DOT, Tupelo (3,000–7,000 rural)	Mississippi DOT, Tupelo (20,000 urban)
Nevada DOT (10,000 rural)	Nevada DOT (100,000 urban)
New Mexico DOT (5,000 rural)	New Mexico DOT (15,000 urban)
North Carolina DOT (5,000 rural)	North Carolina DOT (10,000 urban)
Tennessee DOT (5,000 rural)	Tennessee DOT (10,000 urban)
	Texas DOT (10,000 urban)
	Manitoba (10,000 urban)
Quebec (8,000 rural)	Quebec (20,000 urban)

Categorizations by agencies not included in trend analysis:
Organizations: NAPA (10,000); NACE (15,000 rural/60,000 urban).
Other: Colorado DOT categorizes by ESALs. Caltrans categorizes by traffic index (TI): TI ≤ 18 rural and TI ≤ 15 urban, where $TI = 9.0 \times (ESAL \div 10^6)^{0.119}$. Utah DOT (Region 4) categorizes by Interstate or non-Interstate (25,000 ADT and 2,500 ADT, respectively). City of Phoenix, Ariz., categorizes by 20,000 ADT rural, 50,000 ADT urban.

Table 2.11. Revised Analysis of Most-Used Preservation Treatments for HMA-Surfaced High-Volume Roadways

Commonly Used Preservation Treatments on HMA-Surfaced High-Volume Roadways	
Rural (ADT ≥ 5,000 vpd)	**Urban (ADT ≥ 10,000 vpd)**
≥60% SHAs and provinces report using:	
Crack fill	Crack fill
Crack seal	Crack seal
Cold mill and thin HMA overlay	Cold mill and thin HMA overlay
Drainage preservation	Drainage preservation
≥50% additionally report using:	
Thin HMA overlay	

and thin HMA overlay are used by at least 60% and 70%, respectively (see Figure 2.9). Also shown in Figure 2.9, single- and multiple-course microsurfacing, ultra-thin bonded wearing course, and thin HMA overlays (<1.5 in. [<38 mm]) are used on urban roads by at least 40% of respondents.

- Cape seal, scrub seal, and rejuvenator are not used by many reporting agencies. In addition, on urban roads, fog seals and multiple-course chip seals are not used by many agencies. Therefore, they are not included in Figures 2.8 and 2.9.
- Only one agency, Nevada DOT, reported using scrub seal on rural or urban roadways with ADT ≥ 5,000 and ≥ 10,000 vpd, respectively.
- A handful of agencies—Hawaii, Minnesota, Montana, and Alberta (Canada)—noted using "other" preservation treatments.
    - Hawaii reported only doing 1.5-in. (38-mm) HMA mill and fill as a preservation technique for rural and urban roadways.
    - Minnesota requires that all chip seal applications receive a fog seal.
    - Montana applies thin HMA overlays (< 2.375 in. [< 60 mm]) on rural roadways.
    - Alberta uses a combination of profile milling and thin overlay on rural roadways.

Similar analyses were performed for treatments used on PCC pavements. The high-traffic-volume results were analyzed for trends concerning treatment use, as well as treatment use in relation to pavement performance issues. The findings of this analysis are summarized in Table 2.12 and Figures 2.10 and 2.11.

Key findings from the analysis of PCC treatments are summarized as follows:

- As shown in Figures 2.10 and 2.11, for both rural and urban roadways, joint resealing, diamond grinding, and full-depth patching are used by at least 70% of agencies.
- Fewer than 40% of reporting agencies use diamond grooving, thin PCC overlays, or ultra-thin bonded wearing courses on both rural and urban roads.
- Dowel bar retrofitting and drainage preservation are used on urban roads by at least 50% of reporting agencies (see Figure 2.11).

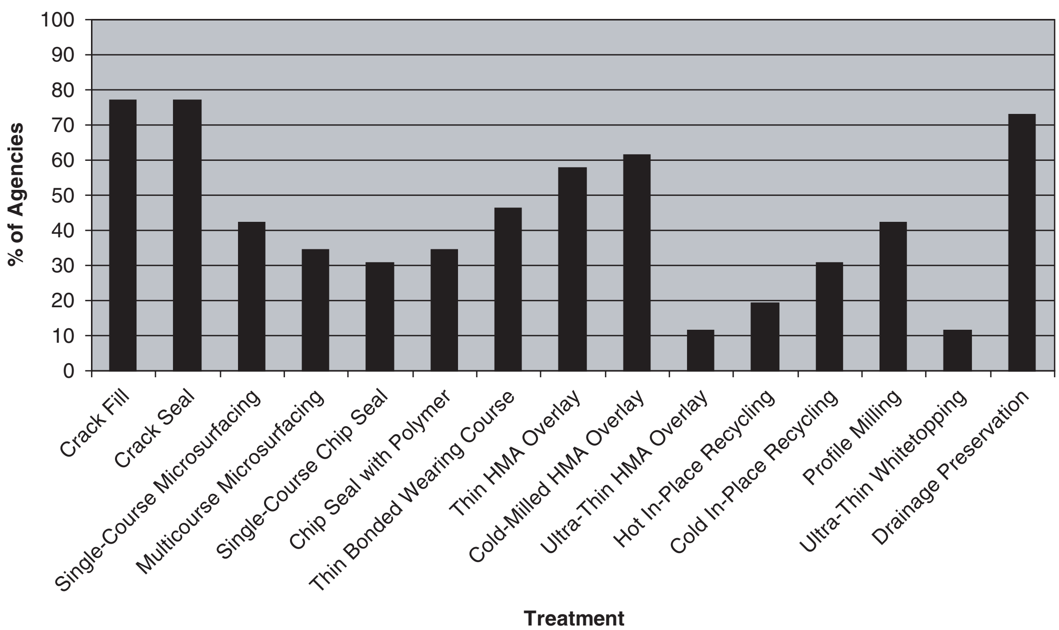


Figure 2.8. Treatment use on rural HMA-surfaced roadways, based on revised definition of rural high traffic volume (ADT ≥ 5,000 vpd).

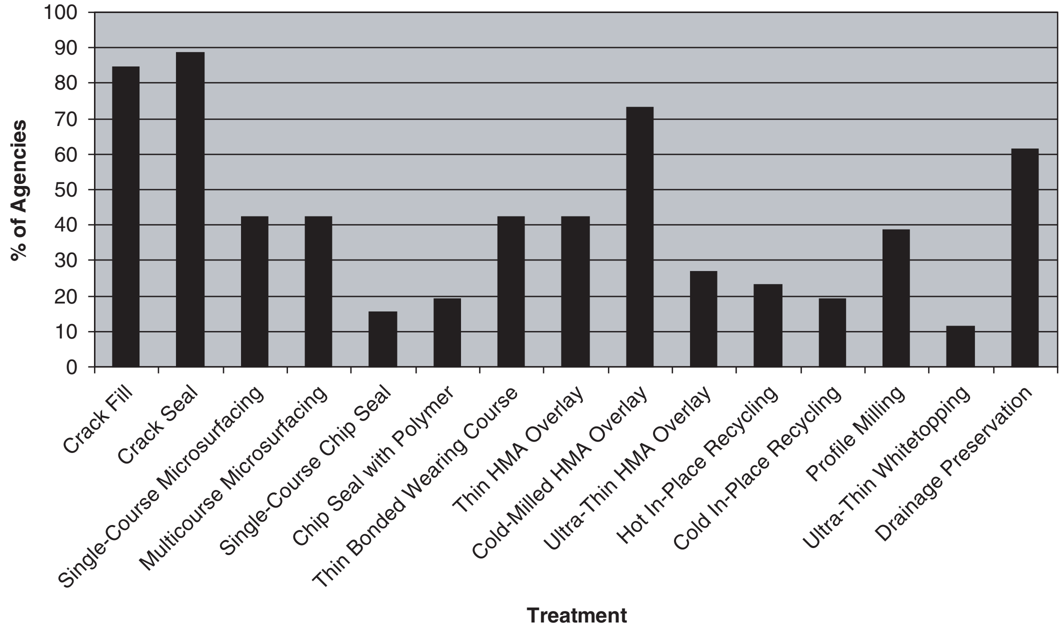


Figure 2.9. Treatment use on urban HMA-surfaced roadways, based on revised definition of urban high traffic volume (ADT ≥ 10,000 vpd).

- Only the Maine DOT reported using an "other" treatment on PCC. Maine once applied an ultra-thin bonded wearing course on a PCC pavement, which has since been rubblized and paved with HMA.

In general, 60% of agencies report using a different set of treatments for rural high-traffic-volume roadways than on rural low-traffic-volume roads, while a slightly lower margin of the majority reports using a different set of treatments for urban high-traffic-volume roadways from those for urban low-traffic-volume roadways.

Of the treatments used on HMA-surfaced pavements, the majority (80%) of respondents indicated that chip seals are not considered applicable for rural or urban high-traffic-volume roadways. Common issues were related to loose rock damage, flushing, dust, bleeding, raveling, noise concerns, and short life expectancy. However, when asked to rank the top three treatments used, approximately 40% of agencies included chip seals within the top three treatments used on rural and urban high-traffic-volume roadways. Washington State, Wyoming, Alaska, Maine, Alberta (Canada), and British Columbia (Canada) report using chip seals on high-traffic-volume rural roadways; Nevada, North Carolina, and Rhode Island report using chip seals on both rural and urban high-traffic-volume roads. Minnesota and New Hampshire report using chip seals with polymer-modified binders on high-traffic-volume urban roads.

The most common and successful treatments used on high-traffic-volume roadways appear to be thin HMA overlays, cold milling and thin HMA overlay, and micro-surfacing, with crack seal also being successful on high-traffic rural roadways. As shown in Table 2.13, the least popular treatments are fog seal, scrub seal, and slurry seal, with just over half of respondents indicating these treatments are not considered for use on high-traffic-volume rural and urban roadways.

Of the treatments used on PCC pavements, the majority (approximately two-thirds) of respondents indicated ultra-thin

Table 2.12. Revised Analysis of Most-Used Preservation Treatments for PCC-Surfaced High-Volume Roadways

Commonly Used Preservation Treatments on PCC High-Volume Roadways	
Rural (ADT ≥ 5,000 vpd)	**Urban (ADT ≥ 10,000 vpd)**
≥70% SHAs and provinces report using:	
Joint reseal	Joint reseal
Diamond grinding	Crack seal
Full-depth patching	Diamond grinding
	Full-depth patching
≥50% additionally report using:	
Crack seal	Partial-depth patching
Partial-depth patching	Dowel bar retrofit
Dowel bar retrofit	Drainage preservation
Drainage preservation	

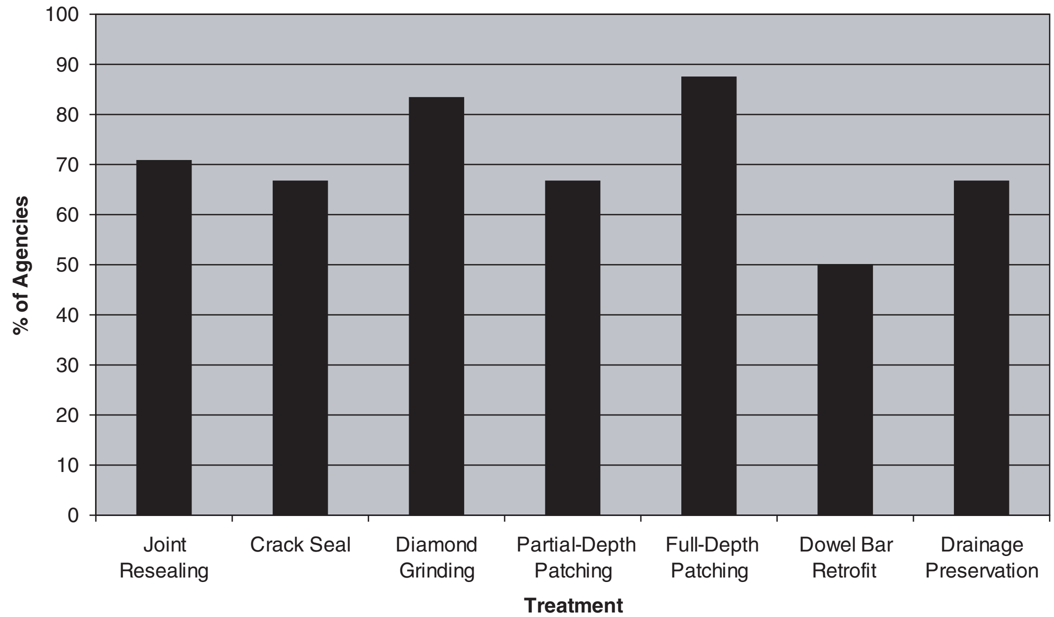


Figure 2.10. Treatment use on rural PCC-surfaced roadways, based on revised definition of rural high traffic volume (ADT ≥ 5,000 vpd).

bonded wearing courses and thin overlays (either HMA or PCC) are not considered applicable for rural or urban (although by a lower margin) high-traffic-volume roadways, as shown in Table 2.14.

For the most part, truck traffic does not influence treatment use by reporting agencies. At most, nearly one-third of respondents report being less likely to use single-course chip seal on roadways with high truck traffic, and just over a quarter of respondents would be more likely to apply load-transfer restoration to such roads.

Based on responses, agencies appear to have well-established policies regarding treatment use. Nearly 90% of respondents indicated they are not considering using any other treatments other than those they currently employ. Of the few agencies considering alternate treatments, the majority do not have the funding necessary to pursue such options.

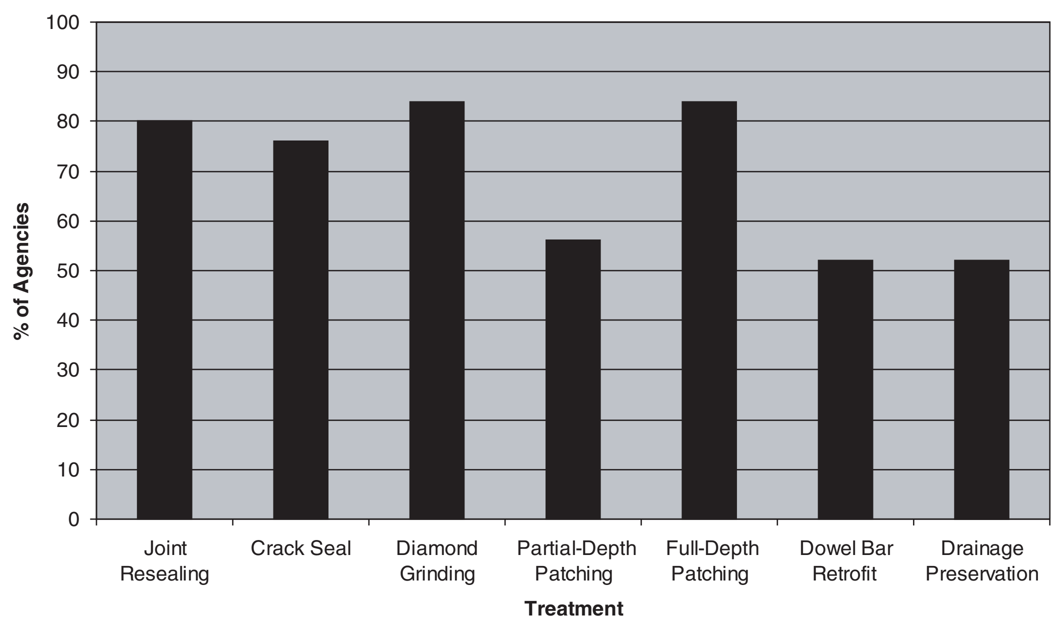


Figure 2.11. Treatment use on urban PCC-surfaced roadways, based on revised definition of urban high traffic volume (ADT ≥ 10,000 vpd).

Table 2.13. Summary of Preservation Treatments Considered Not Applicable for HMA Rural and Urban Roadways

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Not Applicable % Checked Rural/Urban
Fog seal	51/69
Scrub seal	54/72
Slurry seal	51/62
Single-course chip seal	83/91
Multiple-course chip seal	80/88
Chip seals with polymer-modified asphalt binder	71/84
Ultra-thin whitetopping	57/NA

Performance Issues Addressed by Preservation Treatments

The top three deficiencies addressed on rural HMA-surfaced pavements are light and moderate surface distress, raveling, and friction loss. On urban HMA-surfaced pavements, the top three deficiencies are light surface distress, raveling, and friction loss.

Considering the most-used treatments for HMA-surfaced pavements, the primary issues targeted are related to surface deterioration. As shown in Figures 2.12 through 2.14, thin HMA overlays are applied to target a wider range of performance issues, including raveling, bleeding, and friction concerns.

Table 2.14. Summary of Preservation Treatments Considered Not Applicable for PCC Rural and Urban Roadways

Treatments for Portland Cement Concrete (PCC) Pavements	Not Applicable % Checked Rural/Urban
Thin PCC overlays	62/55
Ultra-thin bonded wearing course	75/73
Thin HMA overlays (<1.5 in. [<38 mm])	62/55

For PCC pavements, the top three pavement performance issues addressed are related to smoothness/ride quality and surface distress, with some concern about noise issues. The most-used preservation treatments appear to address specific issues without as much overlap between treatments; that is, joint resealing targets light to moderate surface distresses (Figure 2.15), whereas full-depth patching targets moderate to high surface distresses (Figure 2.16), and diamond grinding targets smoothness, friction, and noise concerns (Figure 2.17).

Work-Zone Requirements

For most of the treatments listed, an overwhelming number of respondents reported using overnight or single-shift closures for application. Ultra-thin whitetopping on HMA-surfaced pavements and thin PCC overlays on PCC pavements are exceptions, requiring longer closure times. On urban PCC

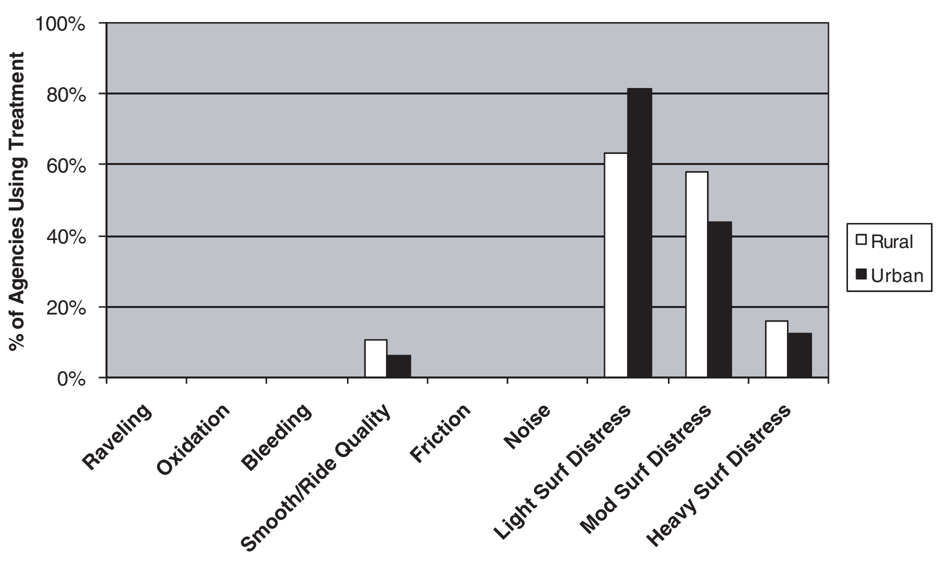


Figure 2.12. Percentage of agencies filling cracks on rural and urban high-traffic-volume HMA-surfaced roadways to address pavement distresses.

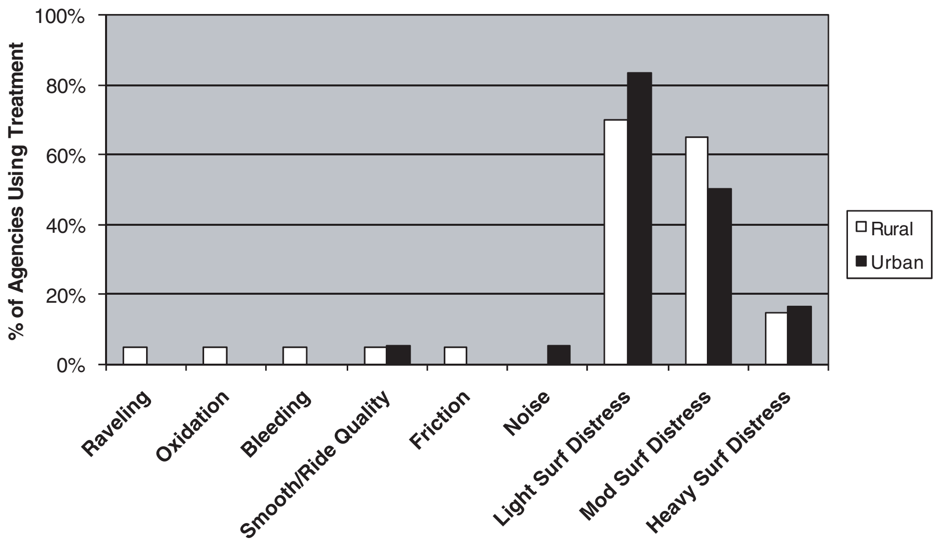


Figure 2.13. Percentage of agencies sealing cracks on rural and urban high-traffic-volume HMA-surfaced roadways to address pavement distresses.

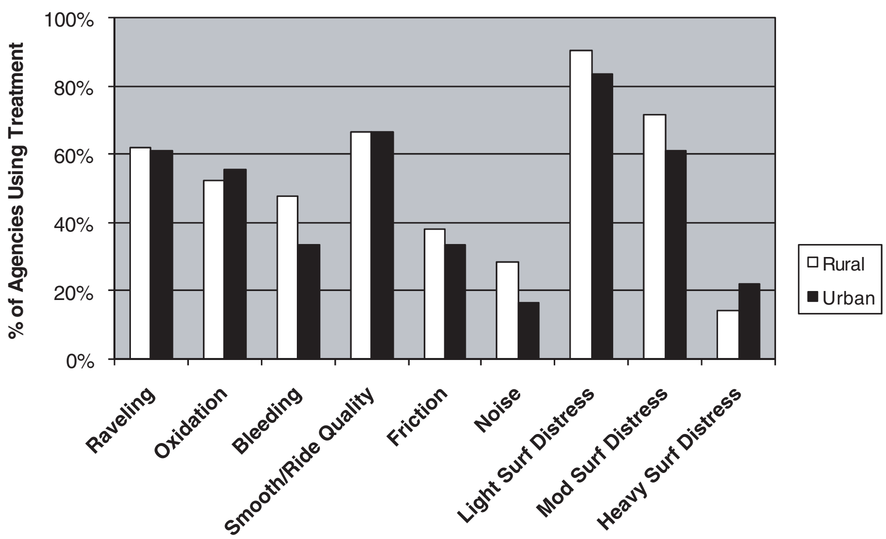


Figure 2.14. Percentage of agencies applying thin HMA overlay on rural and urban high-traffic-volume HMA-surfaced roadways to address pavement distresses.

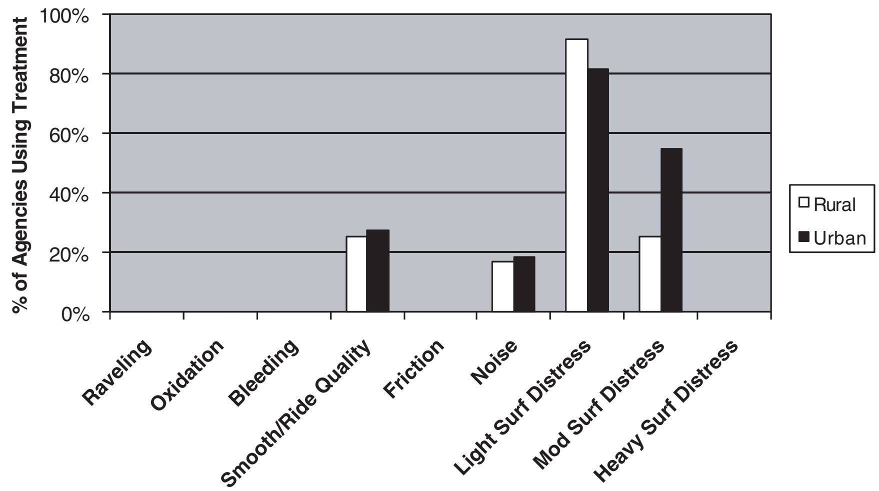


Figure 2.15. Percentage of agencies resealing joints on rural and urban high-traffic-volume PCC roadways to address pavement distresses.

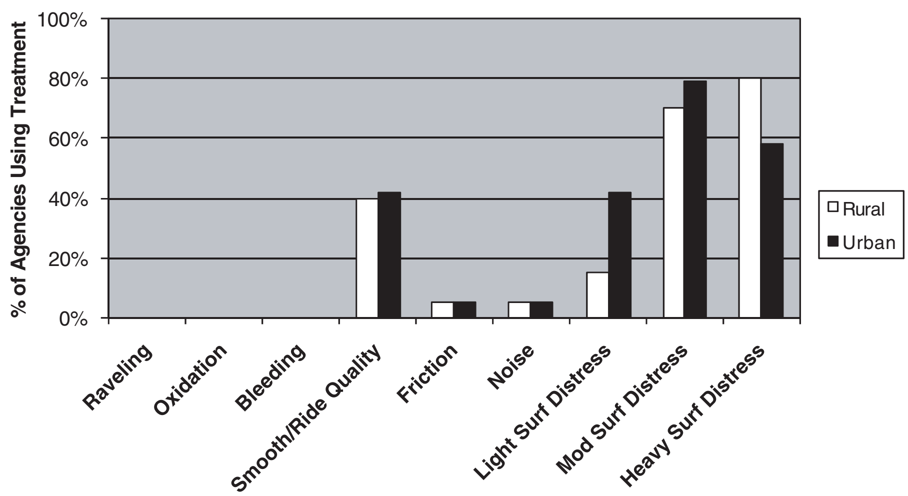


Figure 2.16. Percentage of agencies using full-depth patching on rural and urban high-traffic-volume PCC roadways to address pavement distresses.

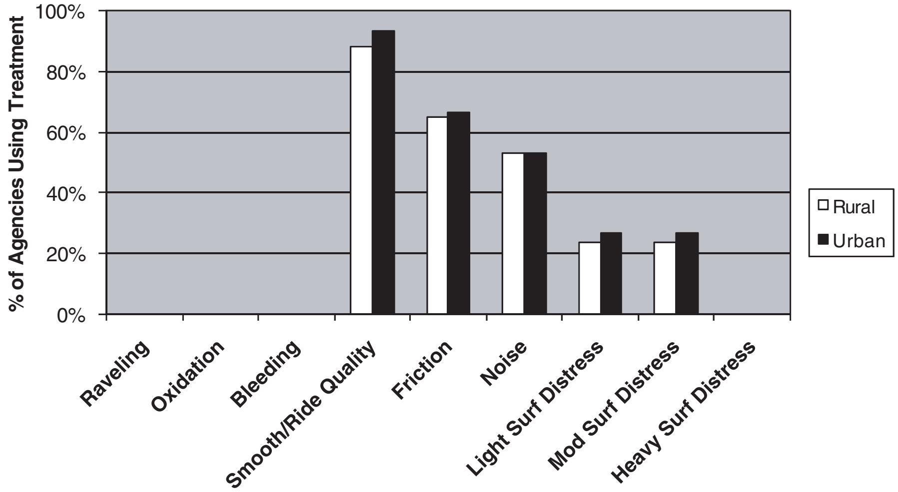


Figure 2.17. Percentage of agencies diamond grinding rural and urban high-traffic-volume PCC roadways to address pavement distresses.

roadways, there is a distinct hierarchy amongst the scenarios, but the majority tends to use overnight or single-shift closures; noticeably fewer note using longer closures, except for thin PCC overlays.

Contracting Mechanisms

Between 30% and 50% of the respondents reported using contract maintenance for constructing preservation treatments on high-traffic-volume HMA- and PCC-surfaced roadways. Fewer than 25% reported using warranties for treatments applied to HMA-surface pavements, whereas less than 5% reported using warranties for treatments applied to PCC-surfaced pavements.

Between 65% and 75% of the respondents indicated using method-based specifications (with some level of QC/QA) for ensuring the quality and performance of treatments applied to HMA-surfaced pavements, whereas between 50% and 75% used method-based specifications for treatments applied to PCC-surfaced pavements. Between 25% and 50% indicated using performance specifications to ensure the quality and performance of treatments applied to both surface types. The majority of those that do not currently practice QC/QA for pavement preservation indicated they do not plan to implement such practices or to require warranties.

Preservation Guidance Needs

In general, the respondents did not report that guidance is needed for determining typical traffic control requirements or for closure-time information. However, some guidance was requested concerning the following:

- Other agency experience;
- Typical noise associated with treatment;
- Treatment production rate;
- Treatment costs by region;
- Obtaining experienced contractors;
- Material availability; and
- Opening to traffic.

The areas where the most guidance is needed include the following:

- Durability and expected life of treatment;
- Applicable traffic volume; and
- Appropriate climatic conditions for treatment.

Closing

The survey of practice provided insight into agency practices regarding pavement preservation of high-traffic-volume roadways. Although most agencies use a variety of preservation treatments on their respective networks, a more selective approach is required when considering such treatments for use on high-traffic-volume roadways. By analyzing treatment preference across the United States and Canada through this survey, the more commonly used treatments were identified, allowing the evaluation of best practices for a limited number of treatments.

CHAPTER 3

Development of Preservation Guidelines for High-Traffic-Volume Roadways

The results of the literature review and the questionnaire survey are an excellent starting point for identifying the state of the practice for preservation of high-traffic-volume facilities. The information indicates the types of treatments that can be successfully used on pavements with high traffic volumes, and it also reveals much about other key factors that can influence the selection of treatments at the project level. Specific insights obtained relate to the following:

Performance Attributes

- Effect of existing pavement condition (distress) and serviceability (smoothness) on treatment performance.
- Effect of traffic volume on treatment performance.
- Effect of climate and environment on treatment performance:
  - Direct climatic and environmental stresses; and
  - Stresses associated with snowplowing and studded or chained tire use.
- Effect of treatment on pavement condition, serviceability, safety (friction, surface drainage [splash/spray, cross slope]), and noise.

Constructability Issues

- Costs (agency and user).
- Complexity of construction.
- Availability of skilled and experienced or qualified contractors.
- Need for specialized equipment or materials.
- Availability of quality materials.
- Environmental constraints.
- Traffic disruption.
- Traffic control constraints.
- Restrictions on available time for lane closures to complete the work.

This chapter draws upon the findings presented in Chapter 2 and incorporates additional information, concepts, and ideas that convey the state of the practice within the backdrop of the treatment selection process depicted in Figure 3.1. In this process, the current and historical conditions of the existing pavement are first established through condition surveys or the agency's pavement management system (PMS) records or both. A preliminary list of preservation treatments that best address the deficiencies of the existing pavement is then developed. The candidate treatments are evaluated according to their ability to satisfy the performance needs and construction constraints of the project. A final list of feasible treatments is then generated and these treatments are analyzed for cost-effectiveness and other considerations to arrive at the preferred treatment.

Preliminary Analysis of Treatment Feasibility: Consideration of Existing Pavement Conditions

Applying preservation treatments at the correct time is often cited as a key to cost-effectively extending pavement serviceability. If a treatment is applied too soon, funds are expended on roads that do not require treatment or do not exhibit sufficient benefit to justify the costs. If a treatment is applied too late, the road may have deteriorated to the point that the treatment is ineffective or does not add sufficient life to the pavement to justify the cost. Thus, the correct time represents a "window of opportunity" in terms of the condition or serviceability of the pavement.

Most practitioners agree that preservation treatments should be applied during the period when the pavement remains in fair to good condition. A recent NCHRP survey on pavement preservation revealed that more than two-thirds of the reporting agencies treat roads while they are still in fair to good condition, whereas less than 5% treat pavements in very poor condition (Peshkin and Hoerner 2005). This leads to the conclusion that most state agencies try to restrict treatment to pavements in fair to good condition. Findings from

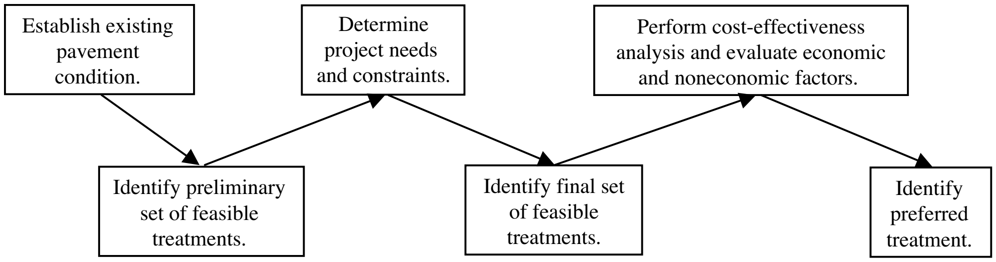


Figure 3.1. Process of selecting the preferred preservation treatment.

the SHRP SPS-3 and SPS-4 studies of PM on both HMA and PCC support this, concluding that "treatments applied to pavements in good condition had shown good results" (Morian et al. 1997).

Preservation treatments have often been applied according to a predetermined schedule based on a time (or a window of time) since original construction or the last major rehabilitation (e.g., crack seal at Year 5, apply a chip seal between Years 7 and 10). In some cases, recurring intervals were established (e.g., reseal joints every 7 years). This is also referred to by some agencies as cyclic maintenance. The schedule was usually established based on information obtained from maintenance surveys or on agency experience with the types and rates of deterioration incurred by certain pavement types. However, whereas a schedule-based approach has the advantage of ease of budgeting and programming, it often results in poor treatment choices for existing problems (Shober and Friedrichs 1998) because pavement condition is only indirectly considered through the proxy of time.

A variation of the schedule-based approach is remaining service life (RSL). In this approach, a minimum time period before an expected rehabilitation is assigned to each treatment, based either on the number of years remaining in the design life of the existing pavement structure or on the projected performance trend (overall condition or smoothness curves and corresponding terminal and threshold levels), as illustrated in Figure 3.2.

An example of RSL-based windows of opportunity is featured in a report covering the development of a pavement PM program in Colorado (Galehouse 2004). The recommended RSL criteria for various HMA- and PCC-surfaced treatments are listed in Table 3.1. These criteria are used in conjunction with distress index scores (discussed later in this chapter), which provide the direct tie-in needed with pavement condition.

With the advancements in PMSs in recent years, the identification of candidate treatments can be more closely tied to the existing pavement conditions. Using historical data on overall condition (pavement condition index/rating [PCI/PCR]), serviceability (present serviceability index/rating [PSI/PSR]), or roughness (international roughness index [IRI]), performance models can be developed for groups of

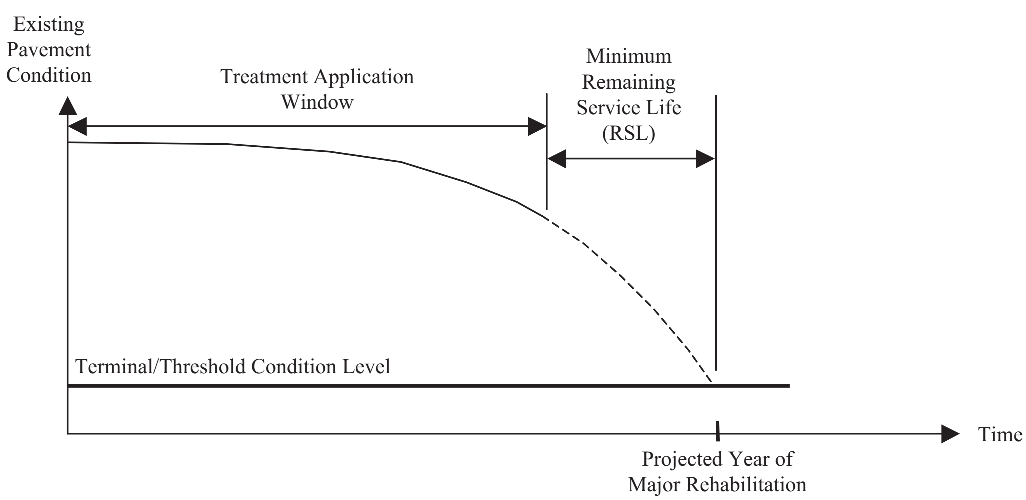


Figure 3.2. Remaining service life approach to establishing treatment application windows.

Table 3.1. Recommended RSL Criteria for PM Treatments in Colorado

Flexible Pavements		Rigid Pavements	
Treatment	**Minimum RSL (years)**	**Treatment**	**Minimum RSL (years)**
Crack filling	9	Crack sealing	10
Crack sealing	10	Joint resealing	10
Sand seals	9	Diamond grinding	8
Chip seals	8	Partial-depth spall repair	10
Microsurfacing (single course)	12	Dowel bar retrofit	10
Microsurfacing (multiple course)	8	Full-depth concrete repair	7
Ultra-thin bonded wearing course	8		
Thin HMA overlay	6		
Mill and thin HMA overlay	6		

Source: Galehouse 2004.

similar pavements (i.e., pavement families), which can then be used to set condition-based windows of opportunity for individual treatment types. As overall condition, serviceability, or roughness is tracked at the project level, feasible treatments can be identified according to the established windows of opportunity (see Figure 3.3).

Overall condition, serviceability, and roughness measures do not indicate specific pavement deficiencies or problems; they can only provide a general indication of when specific treatments should be considered for use. Hence, it is critical that they be augmented with application criteria pertaining to individual pavement distresses. The next section presents some examples in which overall pavement condition is evaluated in conjunction with detailed distress data in order to identify candidate preservation treatments. It also presents general guidelines for establishing condition-based windows of opportunity for preservation treatments on high-traffic-volume facilities.

Two important considerations in the identification of treatments based on windows of opportunity are the rate of deterioration and the gap between when a treatment is selected and when it formally gets constructed. Pavements showing abnormally high reductions in condition (say more than 4 to 5 PCI/PCR points per year or more than 7 to 8 in./mi (0.11 to 0.13 mm/m) of IRI per year) are likely being affected by structural or subsurface material issues that could greatly limit the effectiveness of a preservation treatment. If the gap between treatment selection and construction is expected to be 1 year or more, the conditions of the pavement will likely have changed enough to warrant the reevaluation of treatments.

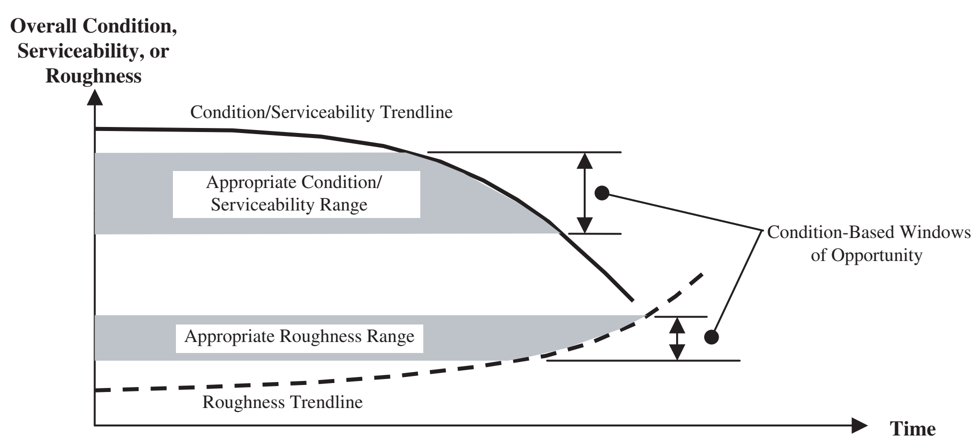


Figure 3.3. Windows of opportunity based on age and overall condition.

This is particularly true if the condition data upon which a treatment was selected did not fully reflect the conditions at the time of selection (i.e., the condition survey data were collected or processed several months before the evaluation or selection process).

Windows of Opportunity

Ohio, New York, and Alberta represent agencies that use overall pavement condition in conjunction with detailed distress data to identify candidate preservation treatments. As seen in Table 3.2, the Ohio DOT uses PCR ranges as criterion for identifying candidate PM treatments for HMA-surfaced pavements. The PCR ranges for five of the six treatments span the same condition range defined by ODOT as good (75 to 90), while the range for the sixth treatment, crack sealing, extends partly into the very good condition category (90 to 100). As discussed later, additional criteria, including detailed distress data and traffic levels, are also used by Ohio in identifying candidate treatments.

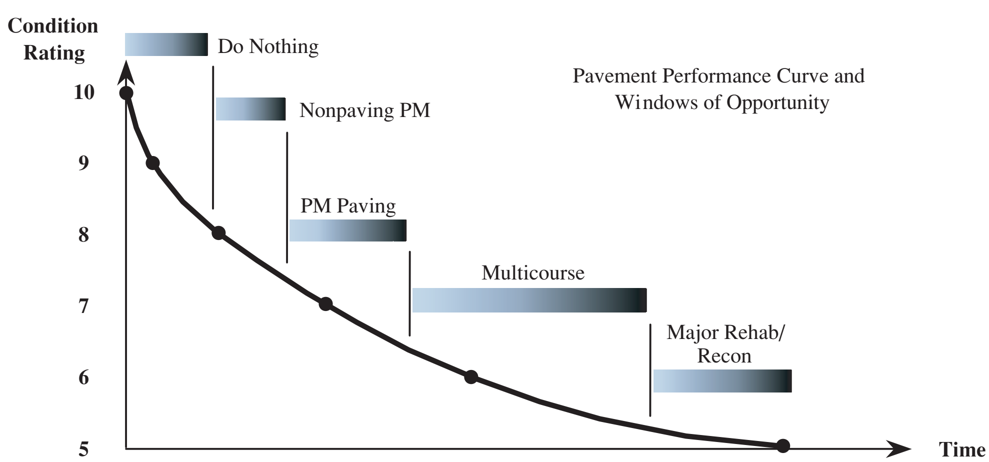
The New York State DOT uses a 1-to-10 surface condition rating along with pavement roughness (IRI) to identify candidate treatments (preventive and rehabilitation) for high-traffic-volume roads. The performance curve and windows of opportunity shown in Figure 3.4 provide a general basis for the treatment selection matrix, which is shown in Figure 3.5. Generally speaking, non-paving-type PM (i.e., crack sealing) is prescribed for pavements with surface ratings between 7.5 and 8.5 and any level of roughness. Paving-type PM, such as ultra-thin and thin HMA overlays, are candidates for pavements with condition ratings between 6.5 and 7.5 and with IRI ≤ 95 in./mi (≤ 1.5 mm/m). Multicourse treatments that entail light to moderate forms of rehabilitation are candidates for pavements with (a) condition ratings between 5.5 and 6.5 and IRI ≤ 95 in./mi (≤ 1.5 mm/m) or (b) condition ratings between 6.5 and 7.5 and 96 ≤ IRI ≤ 170 in./mi (1.51 ≤ IRI ≤ 2.7 mm/m).

The Alberta Ministry of Transportation (MOT) uses pavement smoothness as the first level in the hierarchy of assessing and selecting preservation treatments (Alberta MOT 2006). Rural highway pavements smoother than the following IRI levels are analyzed according to individual distress types,

Table 3.2. Ohio DOT Condition Criteria for PM Treatments

	Pavement Condition Rating (PCR) Range[a]	
PM Treatment	**Flexible Pavements**	**Composite Pavements**
Crack sealing	75 to 95	75 to 95
Chip seal	75 to 90	75 to 90
Microsurfacing (single course)	75 to 90	75 to 90
Microsurfacing (double course)	75 to 90	75 to 90
PMAC overlay	75 to 90	75 to 90
Thin HMA overlay	75 to 90	75 to 90

Source: ODOT 2001.
Note: PMAC = Polymer-modified asphalt concrete.
[a] Condition categories listed in ODOT Pavement Condition Rating Manual: 90–100, very good; 75–90, good; 65–75, fair; 55–65, fair to poor; 40–55, poor; 0–40, very poor.



Source: NYSDOT 2008.

Figure 3.4. Condition rating windows of opportunity for various forms of pavement preservation for New York highways.

Surf Rating	**9+**	D	D	D	D	D	D
	8	1	1	1	1	1	1
	7	5	5A	9	9	11	11
	6	9	9	9	11	12	12
	5	9	9	11	12	12	13
		≤60	**61–95**	**96–135**	**136–170**	**171–220**	**>220**
		Ride Quality (IRI, in./mi)					

Flexible Overlay			
1	Crack seal	8	CIPR (not used on high volume)
3	Thin overlay	9	Mill and fill
5	6.3 mm asphalt	11	Mill and fill w/underlying pvt repairs
5A	6.3 mm asphalt mill and fill	12	Major rehab: 2-course OL w/repairs
6	1.5 in. hot-mix overlay	13	Reconstruction: 3-course OL w/repairs
		D	Defer treatment

Pavement Surface Rating Based on Frequency and Severity Descriptions										
Frequency		**Severity**								
		None	**Slight**	**Minor**	**Moderate**	**Moderate to Severe**	**Severe**	**Very Severe**	**Travel Is Impaired**	**Impassable**
No distress is present. A single random defect per 0.10 mi is allowed.	None	10/9	-	-	-	-	-	-	-	-
Most of pavement is free of distress. One or two cracks or distresses are visible for the next 0.10 mi.	Infrequent	-	8	8	8	7	7	-	-	-
Much of pavement is free of cracking. Large blocks of distress-free pavement are present.	Infrequent to occasional	-	8	7	7	7	6	6	-	-
Much (<0.5) to most (>0.5) of the pavement is cracked. Uncracked or undistressed blocks of pavement range from 20 to 30 ft/lane to 12 ft/lane.	Occasional to frequent	-	7	7	6	6	5	5	-	-
Nearly all the pavement is cracked. Uncracked or undistressed blocks of pavement are 12 ft^2 or less.	Frequent	-	7	6	6	5	4	3	2	1
Mostly cracked. Cracks or distress are continuous and spaced only a few feet apart.	Very frequent	-	6	6	5	5	4	3	2	1

Slight: Cracks are tight, single, and only a few feet long. Tight, single longitudinal joint cracks, partial or continuous, are included.

Minor: Cracks are generally <0.125 in. wide, some with minor secondary cracks, no or very few connected cracks. May have a few small spalls (<1 ft^2).

Moderate: Cracks are generally >0.125 in. wide, secondary cracking is common, some cracks connected; may have some minor popouts or small (1 to 2 ft) to medium (3 to 4 ft) patching.

Moderate to Severe: Distresses vary from "moderate" to "severe."

Severe: Cracks are wide and/or have extensive interconnected secondary cracking; holes, loose material, and/or patching are common; patches may have patches.

Very Severe: Cracks are very wide; holes and/or patching is extensive; patches extend across the full lane or extend several feet along the lane; patches on patches are common.

Travel Is Impaired: Holes in pavement are large and/or pavement has so many layers of patches that the section can be traveled only at reduced speed.

Impassible: Travel by ordinary car would risk damage to the vehicle.

Source: NYSDOT 2008.

Figure 3.5. Treatment selection matrix used for high-traffic-volume (AADT > 20,000 vpd) HMA-surfaced Interstates and highways in New York.

severities, and extents to determine candidate preservation treatments:

AADT, vpd	IRI Trigger, in./mi (mm/m)
<400	190 (3.0)
400 to 1,500	165 (2.6)
1,501 to 6,000	145 (2.3)
6,001 to 8,000	132.5 (2.1)
>8,000	120 (1.9)

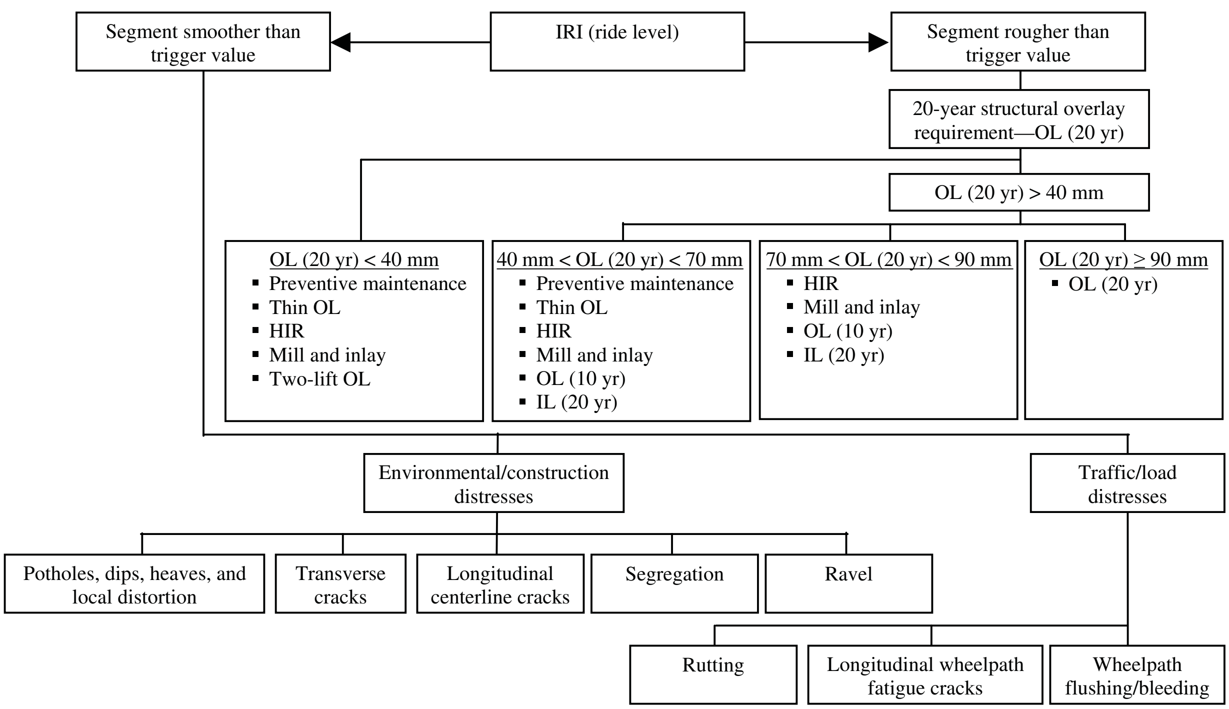
Pavements rougher than these levels are analyzed for structural capacity to determine treatment thickness requirements. Candidate treatments are then identified based on detailed assessments of individual distress types, severities, and extents. Depending on the structural needs and specific deficiencies to be addressed, the candidate treatments may range from low-cost preventive treatments to expensive major rehabilitation activities. Figure 3.6 illustrates the process used by Alberta.

Guidelines for Condition-Based Windows of Opportunity

Although overall condition, serviceability, and roughness indicators are not indicators of the specific forms of distress that are present, they can effectively serve as preliminary identifiers of candidate preservation treatments. This is because for an adequately designed and constructed pavement, there is a fairly consistent pattern to distress development and to the sequence of treatments intended to address the distresses at various points in the deterioration cycle. The pattern is as follows:

- Within the first few years of HMA construction, various environment-related distresses often begin to develop at the pavement surface, causing the overall condition to reduce slightly. Preventive treatments, like crack sealing and thin surface seals, are best applied at this time in order to slow or reduce the severity of these distresses.
- As environment-related distresses continue to develop and other non-load-related distresses emerge, a further reduction in overall condition occurs and some roughness becomes apparent. Consequently, more significant treatments, like chip seals and thin overlays, become more suitable for use.
- Further distress development (and possibly the initial onset of some load-related distresses) reduces the overall condition and increases roughness even more, making restorative treatments, such as mill-and-overlay and in-place recycling, the more appropriate preservation treatment options.
- As load-related distresses become more significant, moderate to major forms of pavement rehabilitation become appropriate.

Using the information just presented and the following categories of PCI (USACE et al. 2004) and IRI (FHWA 2002),



Source: Alberta MOT 2006.

Figure 3.6. Alberta guidelines for assessing pavement preservation treatments and strategies.

Table 3.3. Recommended PCI Windows of Opportunity for Pavement Preservation Treatments

HMA-Surfaced Pavements		PCC-Surfaced Pavements	
Treatment	**PCI Window**	**Treatment**	**PCI Window**
Crack fill	75 to 90	Concrete joint resealing	75 to 90
Crack seal	80 to 95	Concrete crack sealing	70 to 90
Slurry seal (Type III)	70 to 85	Diamond grinding	70 to 90
Microsurfacing, single	70 to 85	Diamond grooving	70 to 90
Microsurfacing, double	70 to 85	Partial-depth concrete patching	65 to 85
Chip seal, single			
Conventional	70 to 85	Full-depth concrete patching	65 to 85
Polymer modified	70 to 85		
Chip seal, double			
Conventional	70 to 85	Dowel bar retrofitting	65 to 85
Polymer modified	70 to 85		
Ultra-thin bonded wearing course	65 to 85	Ultra-thin bonded wearing course	70 to 90
Ultra-thin HMAOL	65 to 85	Thin HMA overlay	70 to 90
Thin HMAOL	60 to 80		
Cold milling and thin HMAOL	60 to 75		
Hot in-place recycling			
Surf recycle and HMAOL	70 to 85		
Remixing and HMAOL	60 to 75		
Repaving	60 to 75		
Cold in-place recycling and HMAOL	60 to 75		
Profile milling	80 to 90		
Ultra-thin whitetopping	60 to 80		

Note: HMAOL = Hot-mix asphalt overlay.

some basic guidelines for condition-based windows of opportunity have been developed and are presented in Table 3.3:

Condition Description	PCI
Good	86 to 100
Satisfactory	71 to 85
Fair	56 to 70

IRI, in./mi (mm/m)	Condition Description
<95 (<1.5)	Good ride quality and good condition
95 to 119 (1.5 to 1.88)	Acceptable ride quality, fair condition
120 to 170 (1.9)	Acceptable ride quality, mediocre condition

The windows of opportunity listed in Table 3.3 can be considered as starting points or reference values for agencies that have not developed formal criteria for preservation treatment selection. Agency practices and experiences will generally dictate any adjustments or refinements that need to be made.

Detailed Assessment of Treatments and Deficiencies

Because preservation treatments address pavement deficiencies to varying degrees and no one treatment is best suited to all conditions, a detailed assessment is needed that matches treatment capabilities with existing deficiencies. Ideally, this assessment should consider not only the specific distress types present and their causes but also the severity and extent of each observed distress. Moreover, it should consider important functional performance attributes, such as friction, splash-spray, and pavement-tire noise.

Two approaches for identifying feasible preservation treatments based on existing pavement deficiencies are decision support matrices and decision support trees. Both approaches rely

Table 3.4. Example Decision Support Matrix for Identifying Flexible Pavement PM Strategies

	Seal Coat	Slurry Seal	Microsurfacing
1. Traffic			
ADT < 2000	R	R	R
2000 > ADT < 5000	M[a]	M[a]	R
ADT > 5000	NR	NR	R
2. Bleeding	R	R	R
3. Rutting	NR	R	R
4. Raveling	R	R	R
5. Cracking			
Few tight cracks	R	R	R
Extensive cracking	R	NR	NR
6. Improving friction	Yes	Yes	Yes[b]
7. Snowplow damage	Most susceptible	Moderately susceptible	Least Susceptible

Rut Depth				
Treatment	**<0.25 in.**	**0.25 to 0.5 in.**	**0.5 to 1 in.**	**>1 in.**
Microsurfacing[c]	One course	Scratch course and final surface	Rut box and final surface	Multiple placement with rut box
Slurry seal[d]	One course	One course	Microsurfacing scratch course and final surface	See note *e*

Source: Jahren et al. 2000. Courtesy of Center for Transportation Research and Education, Iowa State University.
Note: R = Recommended; NR = Not recommended; M = Marginal.
[a] There is a greater likelihood of success when used in lower-speed traffic.
[b] Microsurfacing reportedly retains high friction for a longer period of time.
[c] As recommended by International Slurry Seal Association.
[d] Current practice in Iowa.
[e] Sometimes successful (anecdotal evidence).

on a set of rules and criteria to identify appropriate preservation treatments; the former uses a tabular structure like the one shown in Table 3.4 and the latter, a more systematic graphical approach like the one illustrated in Figure 3.7 (Peshkin and Hoerner 2005).

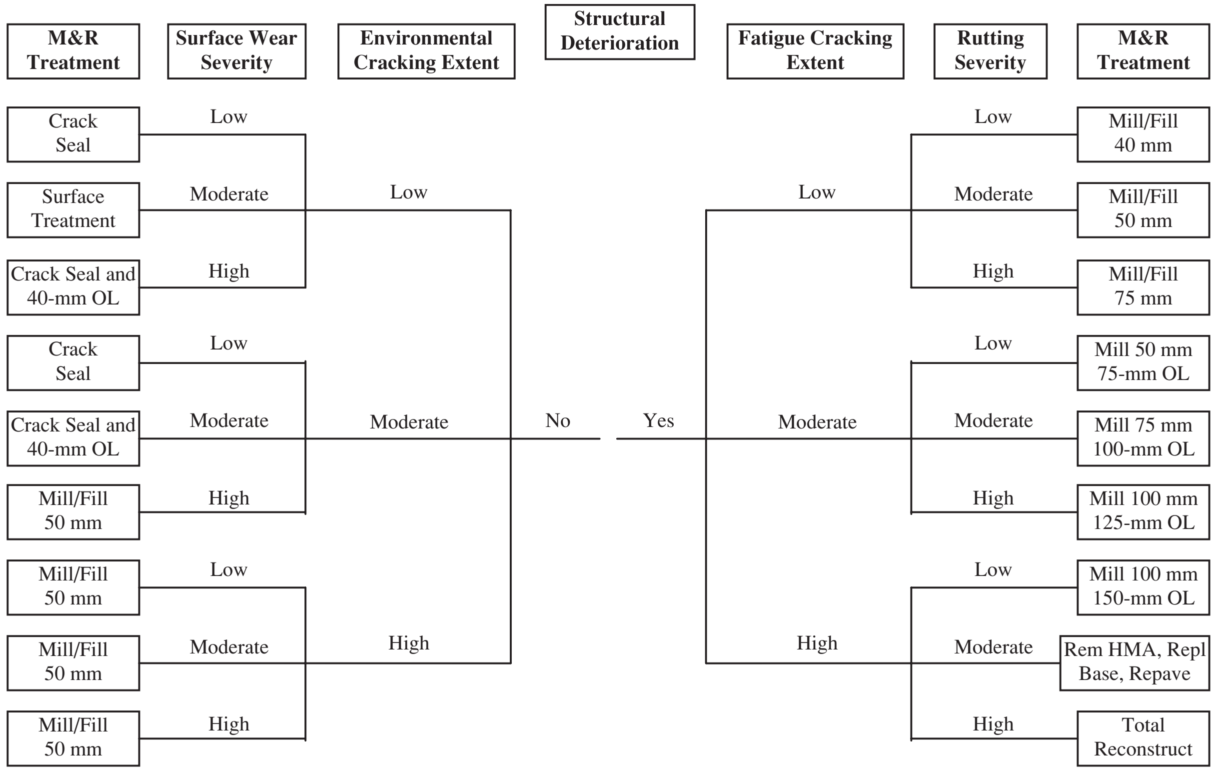
The benefits and limitations of these approaches were previously identified by Hicks et al. (2000) as follows:

Benefits
- Make use of existing experience;
- Work well for local conditions;
- Good as project-level tools;
- Reflect decision processes normally used by an agency;
- Flexible in modifying both the decision criteria and the associated treatments;
- Generate consistent treatment recommendations; and
- Explain and program selection process with relative ease.

Limitations
- Not always transferrable from agency to agency;
- May be more difficult to innovate or introduce new treatments;
- Hard to incorporate all important factors (e.g., competing projects, functional classification, remaining life);
- Difficult to develop matrix that can incorporate multiple pavement distress types (i.e., do not always address the actual distress conditions);
- Generally only designed to focus attention on one or two treatments that have worked well in the past and tend to ignore or overlook new or improved treatments that may be more effective;
- Do not include more comprehensive evaluation of various feasible alternatives and life-cycle cost analysis (LCCA) to determine the most cost-effective strategy; and
- Not good for network evaluation.

The last two limitations listed are not relevant in the present study because the treatment selection framework and methodology developed and presented in this report are intended for use at the project level and include a cost-effectiveness analysis component.

The rules and criteria behind decision support matrixes or trees are based on an understanding (from past experience or historical performance data) of the ability of individual treatments to fix or mitigate specific distresses. As illustrated in Figure 3.8, a key step in developing rules and criteria is to evaluate the primary purposes and functions of treatments in relation to the factors and causes of individual distresses, the



Source: Hicks et al. 1999.

Figure 3.7. Example decision support tree for identifying flexible pavement preservation and rehabilitation strategies.

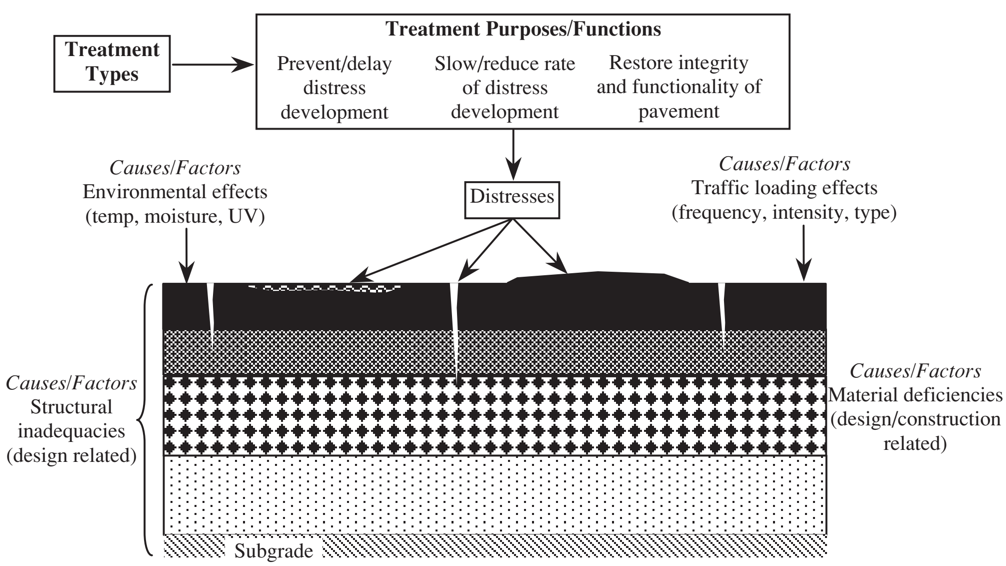


Figure 3.8. Matching of treatments with distress types through evaluation of treatment purposes/functions and distress causes/factors.

locations of the distresses within the pavement structure, and the operational impacts (functional or structural) of the distresses. For instance, a treatment whose primary purpose is to seal surface cracks and rejuvenate the HMA surface layer, would be a good candidate for a pavement that has become oxidized and has consequently developed considerable amounts of low- to medium-severity cracks.

A number of decision support matrices and trees were identified in the literature, ranging from simple routines involving a few treatments and several key distress types to complex algorithms featuring many treatments and an array of distress types, severity levels, and extents. As noted by Hicks et al. (2000), both tools can be used effectively in the selection and identification of suitable preservation and rehabilitation treatments.

For the guidelines produced in this study, it was determined that a decision support matrix should be used as the basis for identifying candidate preservation treatments based on pavement condition. A decision support matrix provides users with a more systematic and understandable approach; however, decision trees could also be easily constructed from the formulated decision matrix.

Decision Support Matrixes for HMA-Surfaced Pavements

Three of the more comprehensive decision support matrixes prepared for HMA-surfaced pavements are illustrated in Tables 3.5 through 3.7 (pp. 43–46). Each of these tables provides an indication of treatment suitability for different types of distress. In addition, Tables 3.5 and 3.6 give indications of treatment suitability corresponding to different distress severity levels. These and other similar matrixes and trees have served as a basis for the development of preservation guidelines in various states and provinces, including California, Illinois, Ohio, Montana, Nebraska, New York, Virginia, Alberta, and Ontario. Tables 3.8 through 3.10 (pp. 48–53) show the decision support matrixes developed by the California and Illinois DOTs. Tables 3.11 and 3.12 (pp. 54–55) illustrate the Ohio DOT's matrixes for flexible and composite pavements, respectively.

Decision Support Matrixes for PCC-Surfaced Pavements

The FHWA's *Concrete Pavement Preservation Workshop Reference Manual* (Smith et al. 2008) provides detailed guidance on the application of preservation and rehabilitation treatments for PCC-surfaced pavements. Table 3.13 (p. 56) presents examples of both general trigger and limit values for different distress and performance indicators and different traffic volume categories. The trigger values define the point when preservation may be appropriate, while the limit values define the point at which the pavement is in need of major structural improvements.

Table 3.14 (p. 58) shows the basic decision support matrix (treatment–distress matches) presented in the preservation workshop manual. It is supplemented with more specific information regarding the suitability of some treatments for different distress severity levels. It should be pointed out that the unshaded columns in this table depict the preservation treatments covered in the SHRP 2 Renewal Project R26 study, whereas the shaded columns represent rehabilitation treatments.

Survey Results on Treatments and Deficiencies

Tables 3.15 and 3.16 (pp. 60–61) reflect the state of the practice for treatment use by transportation agencies based on existing pavement surface conditions. In these tables, "extensive" use means that two-thirds or more of the highway agencies reported using a particular treatment to address a certain pavement deficiency. "Moderate" represents use by between one-third and two-thirds of the agencies, whereas "limited" represents use by less than one-third of the agencies.

Guideline Decision-Support Matrixes

The treatment application information presented above, representing both best and current practices, was used to formulate decision-support matrixes for identifying feasible treatments based on existing pavement condition. Tables 3.17 and 3.18 (pp. 62–65) show the guideline matrixes developed for HMA- and PCC-surfaced pavements, respectively. These matrixes are a key part of the treatment selection framework and process presented in *Guidelines for the Preservation of High-Traffic-Volume Roadways.*

Final Analysis of Treatment Feasibility: Consideration of Project Needs and Constraints

Once a preliminary list of feasible treatments has been developed based on existing pavement conditions, further evaluation is needed to determine which of the treatments largely satisfies the needs and constraints of the project. The needs center on the targeted or required performance of the preservation activity and the impacts that various project and site location factors can have on the performance of the identified feasible treatments. The constraints center on funding limitations for the preservation work and various other factors that can affect the constructability of the identified feasible treatments.

Detailed discussions of these two feasibility aspects are provided in the sections that follow. Included in these discussions

(text continues on page 46)

Table 3.5. Guidelines for Effective Maintenance Treatments (Based on SHRP Southern Region Review of SPS-3 Test Sites)

Pavement Conditions		Parameters	Treatments[a]								
			Thin Overlay	Slurry Seal	Crack Seal	Rout and Seal[b]	Rout and Fill[b]	Chip Seal: Fine[c]	Chip Seal: Coarse[c]	Microsurface	Fog
Traffic	ADT/lane[d]	<1000	E	E	E	E	E	E	E	E	E
		1000 < ADT < 4000	E	E	E	E	E	E-Q	E-Q	E	E-Q
		>4000	E	E	E	E	E	E-N-Q	E-N-Q	E	E-Q
	Ruts[e]	<⅜ in.	E	E	E	E	E	E	E	E	E
		⅜ in. < R < 1 in.	E	M-N	E	E	E	M-N-Q	M-N-Q	E	T
		>1 in.	E	T	E	E	E	T	T	M-C	T
Cracking	Fatigue	Low	E	E	E	E	E	E	E	E	M
		Moderate	E	M	M	M	M	E	E	M	T
		High	M	T	T	T	T	E	E	T	T
	Longitudinal	Low	E	E	E	E	E	E	E	E	M
		Moderate	E	M	E	E	E	E	E	M	T
		High	M	T	M	E	E	M	M	T	T
	Transverse	Low	E	E	E	E	E	E	E	E	M
		Moderate	E	M	E	E	E	E	E	M	T
		High	M	T	M	E	E	M	M	T	T
Asphalt surface condition	Surface appearance	Dry	E	E	T	T	T	E	E	E	E
		Flushing	E	E	T	T	T	M-Q	E-Q	E	T
		Bleeding	E	E	T	T	T	N-Q	N-Q	E	T
		Variable	E	E	T	T	T	M-Q	E-Q	E	M[f]
	Raveling	Low	E	E	T	T	T	E	E	E	E
		Moderate	E	E	T	T	T	E	E	E	M
		High	E	M	T	T	T	E-Q	E-Q	E	M
	Potholes	Low	E	E	T	T	T	E	E	E	T
		Moderate	E	M	M	T	T	E	E	M	T
		High	M	M	M	T	T	M	M	M	T
Existing pavement texture is rough			E	E	T	T	T	M-Q	M-Q	E	T
Poor ride			E	E	T	T	T	T	T	M	T
Rural (minimum turning movements)			E	T	T	T	T	E	E	E	E
Urban (maximum turning movements)			E	E	E	E	E	E-Q	E-Q	E	E
Subsurface moisture											
High snowplow usage			E	E	E	E	E	E-Q	E-Q	E	E
Low frictional resistance			E	E	T	T	T	E	E	E	T

Source: Hicks et al. 2000.

Note: E = Effective; M = Marginally effective; N = Not recommended; Q = Requires a higher degree of expertise and quality control; T = Not effective.

[a] The chart provides general guidance only. Engineering judgment and experience should be used to select the proper treatment.

[b] Typically requires routine retreatment at 2-year intervals.

[c] For ADT in excess of 50,000 (total) and/or truck volumes in excess of 20%, this treatment can be effective but is not recommended.

[d] Higher percentages of trucks have a significant effect on performance.

[e] Rutting has occurred over an extended period of time.

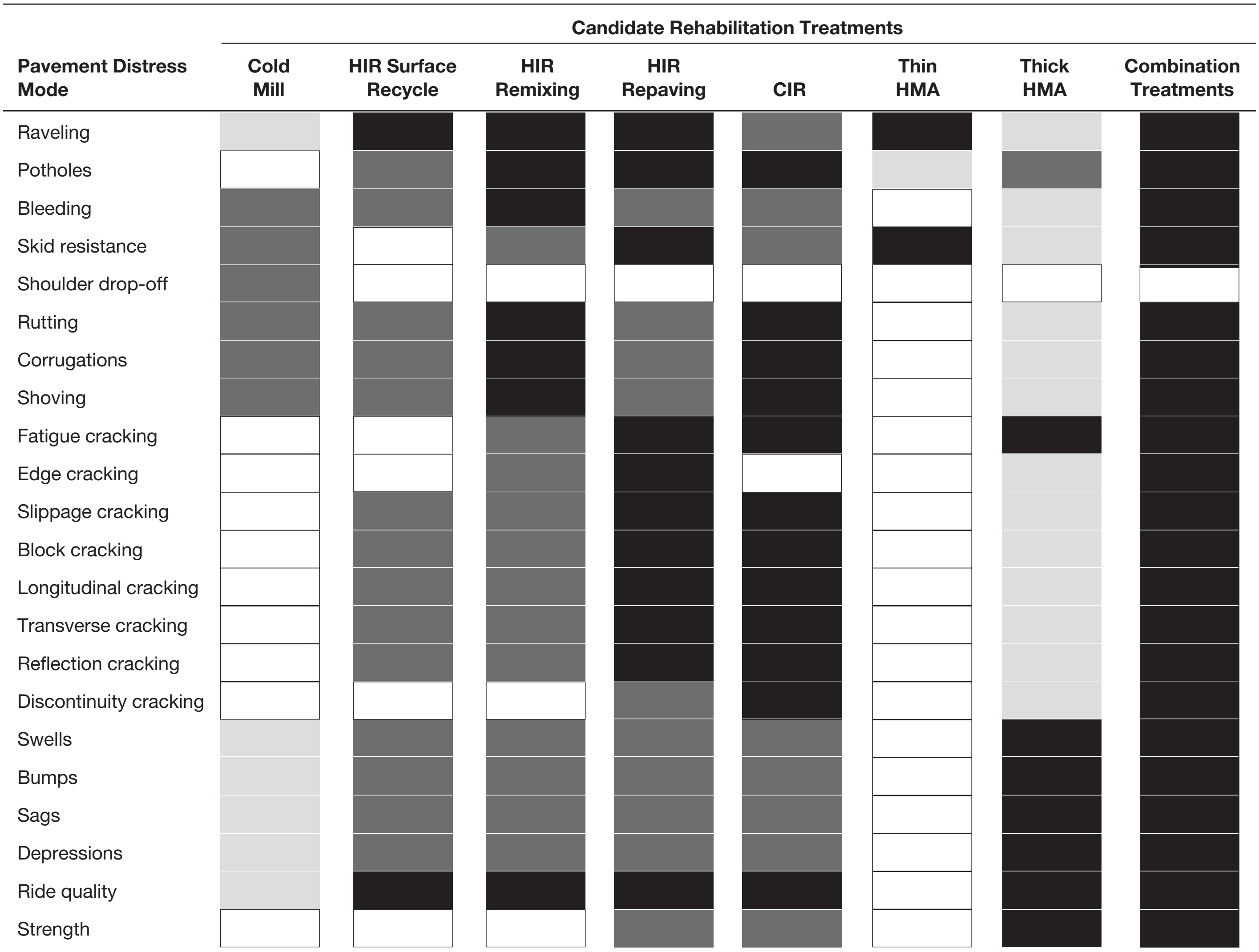
[f] Spot treatments on dry conditions only.

Table 3.6. FHWA/FP² Guidelines for Pavement Treatment Selection

Pavement Conditions	Parameters	Fog Seal	Crack Seal	Sand Seal	Std. Chip Seal	Mod. Chip Seal	High-Performance Chip Seal	Slurry Seal	Microsurfacing	Ultra-Thin Bonded Wearing Course	Recycled Asphalt Pavement	Cold In-Place Recycling	Hot In-Place Recycling	Thin Overlay	Full-Depth Reclamation Granular Base Stabilization	Reflective Crack Relief Interlayer
Traffic (ADT)	<1000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
(% trucks should	1000–4000	*	*	*	*	*	*	*	*	*	?	*	*	*	*	*
also be considered)	>4000	?	*	X	*	*	*	*	*	*	?	*	?	*	*	*
Ruts	<⅜ in.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	⅜–1 in.	X	?	?	?	?	?	?	*	X	*	?	?	?	*	?
	>1 in.	X	X	X	X	X	X	X	?	X	?	?	X	X	*	?
Cracking fatigue	Low	?	*	*	*	*	*	X	*	*	*	*	*	*	*	*
	Moderate	X	?	?	*	?	*	X	?	?	?	*	*	*	*	*
	High	X	X	X	X	X	X	X	X	X	?	*	?	?	?	*
Cracking longitudinal	Low	?	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Moderate	X	*	?	*	*	*	?	?	?	?	*	*	*	*	*
	High	X	?	X	X	X	X	X	X	X	X	*	?	?	*	*
Cracking transverse	Low	?	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Moderate	X	*	?	*	?	*	?	?	?	?	*	*	*	*	*
	High	X	?	X	X	X	X	X	X	X	X	*	?	?	*	*
Surface condition	Dry	*	X	*	*	*	*	?	*	*	*	*	*	*	*	*
	Flushing	X	X	?	*	*	*	X	*	*	*	*	*	*	*	?
	Bleeding	X	X	X	?	*	*	*	*	*	*	*	*	*	*	?
	Variable	?	X	?	*	*	*	*	*	*	*	*	*	*	*	?
	PCC	X	?	*	*	*	*	*	*	*	?	X	X	*	X	*
Raveling	Low	*	X	*	*	*	*	*	*	*	*	*	*	*	*	*
	Moderate	?	X	*	*	*	*	*	*	*	*	*	*	*	*	*
	High	?	X	*	*	*	*	?	*	*	*	*	*	*	*	*
Potholes	Low	X	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Moderate	X	?	?	?	?	?	?	?	X	*	*	*	*	*	*
	High	X	?	X	X	X	X	?	?	X	?	*	?	*	*	*
Stripping	Moist. Damage	X	X	X	X	X	X	X	X	X	X	?	X	X	?	X
Texture	Rough	X	X	?	?	?	?	*	*	*	*	*	*	*	*	*
Ride	Poor	X	X	X	X	X	X	*	?	*	*	*	*	*	*	*
Rural	Min. turning	*	*	*	*	*	*	X	*	*	*	*	*	*	*	*
Urban	Max. turning	*	*	?	*	*	*	*	*	*	*	*	*	*	*	*
Drainage	Poor	X	X	X	X	X	X	X	X	X	X	?	X	X	X	?
Snowplow use	High	*	*	*	?	*	*	*	*	*	*	*	*	*	*	*
Skid resistance	Low	X	X	*	*	*	*	*	*	*	*	*	*	*	?	*
Noise	Low	?	?	X	X	X	*	?	?	*	?	?	?	?	?	?
Initial cost concern	Low	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	High	*	?	*	*	?	*	?	X	X	*	?	*	?	?	?
Life cost concern	Low	*	*	*	*	?	*	*	*	?	*	*	*	?	*	?
	High	?	*	?	?	*	*	?	*	*	*	*	*	?	*	*
Local const. quality	Low	X	?	X	X	?	*	X	*	*	?	X	*	?	X	?
	High	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
User-delay $	High	?	?	?	?	?	*	?	*	*	?	?	*	?	?	*

Source: FHWA and FP² 2005.
Notes: These are broad assumptions. Assessment of a given road should take precedence, with special attention to distress course(s) and needed repairs before treatment.
Recommendations in top chart assume good-quality design and construction. Multipliers from the bottom chart should be used. This information is meant to be fed into a decision matrix.
X = Not recommended; ? = May be recommended; * = Recommended.

Table 3.7. Guidelines for Preliminary Selection of Candidate Rehabilitation Techniques for HMA-Surfaced Pavements



Source: Modified from Dunn and Cross 2001. Courtesy of Asphalt Recycling and Reclaiming Association.

(continued from page 42)

is information on the best and current practices that are used in developing the guidelines featured in *Guidelines for the Preservation of High-Traffic-Volume Roadways.*

Performance Needs

Performance Definition

The term "performance" takes on many connotations when used in reference to pavements. It normally refers to the deterioration of pavement condition over time, as gauged by an overall condition indicator (PCI/PCR), a serviceability indicator (PSI/PSR), a roughness parameter (IRI), or a variety of individual distress indicators (rutting, fatigue cracking, and so on). It is also used to refer to the service life of a pavement, as defined by the time until the pavement needs a major or structural rehabilitation (which can be determined in a variety of ways using time-series condition data or historical pavement construction and rehabilitation event data).

The meaning of "performance" is further complicated when applied to a preservation treatment. This is because both the performance of the treatment itself and the influence of the treatment on the performance of the existing pavement are of interest. In addition, the term "effectiveness" is often used when referring to the immediate, short-term, or long-term effects of the treatment application (Kuennen 2006c).

For the purposes of this study, performance has been defined as the length of time that a treatment serves the purpose for which it was placed (i.e., provides a benefit). It is the extension in service life imparted to the existing pavement by the preservation treatment. This designation of performance is most compatible with the procedures needed to evaluate the cost-effectiveness of preservation treatments as part of a project-level treatment selection process.

Performance Targets and Requirements

In addressing treatment feasibility, the user should identify targeted or required levels of performance for the planned preservation activity. This performance goal may be based on a nominal assessment of (a) the expected performance capabilities of the alternative treatments for the conditions at hand, (b) the long-term planning and programming impacts for the subject project, and (c) the importance of minimizing delays associated with future maintenance and rehabilitation (M&R) activities.

Expected Treatment Performance

As a starting point for establishing expected treatment performance, the project literature was reexamined for information on general treatment performance (and not specifically on high-traffic-volume roadways). Although the type of performance data sought was pavement life extension, the availability of such data was limited. Hence, treatment life data were also sought and compiled.

A collective summary of the performance information for treatments applied to HMA- and PCC-surfaced pavements is presented in Tables 3.19 and 3.20 (p. 66), respectively. These ranges are based on information reported by various sources, representing a variety of conditions and using different performance measures. As such, these reported ranges may be based as much (or more) on perception instead of on well-designed, quantitative experimental analyses.

The literature review discussion in Chapter 2 demonstrated that preservation treatment performance is affected by the conditions in which the treatment is installed and must function. Specifically, treatment effectiveness is influenced by the condition of the pavement upon which it is placed, and treatment durability is influenced by the level of traffic and the type of climate to which it is exposed.

An investigation of how these factors—pavement condition, traffic, and climate—affect the general performance ranges listed in the previous tables was made by reexamining the project literature. The results are summarized in the following sections.

Impact of Pavement Condition on Treatment Performance

Pavement survival analysis of the performance of SPS-3 PM treatments in the southern long-term pavement performance (LTPP) region revealed quantifiable effects of existing pavement condition on treatment performance (Eltahan et al. 1999). Using a failure criterion defined by severities and quantities of cracking, patching, and bleeding, the median survival time (time until 50% of sections reach failure) of thin HMA overlay, slurry seal, chip seal, and crack seal treatments at 28 SPS-3 sites were computed. The results are summarized in Table 3.21 (p. 67).

A recent study of Ohio DOT PM treatments examined the effect of existing pavement condition on treatment performance (Rao et al. 2008). Using historical data on hundreds of pavement sections on different facility types throughout the state, the study showed that there is generally an increase in the extension in life of 1 to 2 years corresponding to treatments placed on pavements in good condition (PCR between 80 and 90) versus those placed on pavements in fair condition (PCR between 70 and 80). This effect is illustrated in Table 3.22 (p. 67).

The evaluation of preservation treatment performance data by Caltrans indicated significant reductions in performance corresponding to lower overall pavement conditions at the time of treatment application. Table 3.23 (p. 67) shows the estimated lives of five different treatments when applied at three different pavement condition levels. As can be seen, there are significant increases in treatment performance (4 to 5 years) for chip seals, slurry seals, microsurfacing, and thin HMA overlays when they are placed on pavements in good condition rather than on those in fair condition.

Impact of Traffic on Treatment Performance

Satisfactory treatment performance in part depends upon the ability of the treatment to withstand the stresses placed upon it by traffic. These stresses include not only the vertical shear stresses and abrasive forces of repeated traffic applications but also the horizontal shear stresses of turning or braking vehicles and, in certain environments, the abrasive forces of studded tires and snowplows.

There is little published information on a quantitative assessment of the impact of traffic level on preservation treatment performance. Although the LTPP SPS-3 and SPS-4 studies included sections of varying traffic levels, the various published reports covering treatment performance provided no indication of the effect of traffic level on performance. A 1998 national study of the longevity and performance of diamond-ground PCC pavements (Rao et al. 1999) illustrated the general effect of traffic on surface texture wear following grinding, but age and climate were established as the key variables in a texture deterioration model (traffic and snowplow

(text continues on page 57)

Table 3.8. Caltrans Flexible Pavement Maintenance Treatment Matrix

Preventive Treatments	Raveling	Oxidation	Bleeding	Rutting: <½ in.	Rutting: >½ in.	Climate: Desert	Climate: Valley	Climate: Coastal	Climate: Mountains	Traffic Volume: ADT < 5,000	Traffic Volume: ADT > 5,000 < 30,000	Traffic Volume: ADT > 30,000	Night	Cold	Stop Points	Urban	Rural	High Snowplow Use	Treatment Costs: Cost per Lane-Mile (total project cost includes traffic control)	Cost: $/sq yd (Treatment Only): Large Projects	Cost: $/sq yd (Treatment Only): Medium Projects	Cost: $/sq yd (Treatment Only): Small Projects	Cost: $/sq yd (Treatment Only): Additional Premium for Night Work, $/sq yd	Cost: $/sq yd (Treatment Only): Additional Premium for Short Work Periods or Work Zones, $/sq yd.
Crack/joint seal																								
Emulsion	N	N	N	N	N	G	G	G	G	G	G	G	N	N	G	G	G	G	8,000	0.50–0.65	0.60–0.75	0.70–0.85	+0.15–0.20	+0.60–1.00
Modified (rubber)	N	N	N	N	N	G	G	G	G	G	G	G	G	G	G	G	G	G	8,000	0.55–0.70	0.65–0.80	0.75–0.90	+0.15–0.20	+0.60–1.00
Seal coats																								
Fog seal (see note *a*)	F	G	N	N	N	G	G	G	G	F	F	N	N	P	F	G	G	F	13,000	0.15–0.30	0.15–0.30	0.15–0.30	+0.05	+0.10
Rejuvenator (see note *a*)	G	G	N	N	N	G	G	G	G	G	F	N	N	N	N	G	G	F	15,000	0.20–0.50	0.20–0.50	0.20–0.50	+0.10	+0.20
Scrub seal (see note *d*)	G	G	N	N	N	G	G	G	G	G	F	N	N	G	N	F	G	P	17,000	2.15	2.15	2.15	NA	NA
Slurry seals																								
Type II (See note *a*)	F	G	N	N	N	G	G	G	F	G	G	G	N	N	G	G	G	P	23,000	1.60–2.20	1.75–2.40	1.90–2.60	NA	+0.30
Type III	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P	24,000	1.60–2.20	1.75–2.40	1.90–2.60	NA	+0.30
REAS	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P		1.20–1.80	1.20–1.80	1.20–1.80	NA	+0.30
Microsurfacing																								
Type II	G	G	N	G	F	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00–2.80	2.10–2.90	2.25–3.00	+0.10–0.20	NA
Type III	G	G	N	G	G	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00–2.80	2.10–2.90	2.25–3.00	+0.10–0.20	NA
Chip seals																								
PME: Med. fine (see note *d*)	G	G	N	F	N	G	G	F	F	G	G	N	N	N	P	P	G	P	27,000	1.80–2.00	2.25–2.75	3.00–3.50	NA	+0.50–1.00
PME: Medium (see note *d*)	G	G	N	F	N	G	G	F	F	G	N	N	N	N	P	P	G	F	27,000	1.80–2.00	2.25–2.75	3.00–3.50	NA	+0.50–1.00
PMA: Medium (see note *c*)	G	G	N	F	N	G	G	G	G	G	G	N	N	G	P	P	G	F	24,000				NA	
PMA: Coarse (see note *c*)	G	G	N	F	N	G	G	G	G	G	N	N	N	G	P	P	G	G	24,000				NA	
AR: Medium	G	G	N	F	N	G	G	G	G	G	G	N	G	G	P	P	G	F	65,000	3.75–4.55	4.00–4.75	4.25–5.00	NA	+0.50–1.00
AR: Coarse	G	G	N	F	N	G	G	G	G	G	N	N	G	G	P	P	G	G	65,000	3.75–4.55	4.00–4.75	4.25–5.00	NA	+0.50–1.00
Cape seals																								
Slurry	G	G	N	F	N	G	G	G	G	G	G	G	N	N	G	G	G	P						
Micro	G	G	N	G	F	G	G	G	G	G	G	G	N	N	G	G	G	P						
PM alternative to a seal coat >30,000 ADT																								
PBA-O	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	P	65,000	8–12	8–14	10–16		+1.20–4.00
RAC-O	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	60,000	10–14	10–14			+1.50–3.50
RAC-O high binder (HB)	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	65,000	10–14	10–14			+1.50–3.50
RAC-G	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10–14	10–14			+1.50–3.50
PBA-G	G	G	P	P	N	G	G	G	G	G	G	G	F	F	G	G	G	G	60,000	8–12	8–14	10–16		+1.20–4.00
Thin bonded wearing course (BWC)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10–14	10–14			+1.50–3.50
Thin bonded wearing course rubber (BWC-RAC-O/G)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10–14	10–14			+1.50–3.50
Maintenance treatments																								
Thin lift overlays																								
Conventional	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	45,000	8–12	8–14	10–16		+1.20–4.00
PBA	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	60,000	8–12	8–14	10–16		+1.20–4.00
RAC	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10–14	10–14			+1.50–3.50
Digouts	P	P	G	N	G	G	G	G	G	G	G	G	G	G	G	G	G	G	125,000					

Source: Caltrans 2008a.

Note: G = Good performance; F = Fair performance; P = Poor performance; N = Not recommended.

[a] Usually limited to shoulders, low-volume roads, and parking areas.

[b] Generally used on shoulders, parking areas, and locations where less-aggressive surface is desired.

[c] Under evaluation. Please consider other strategy at this time.

[d] Use of pass rejuvenating seal under evaluation. Please consider other PME strategy at this time.

Table 3.9. Caltrans Treatment Guidelines for Effective Maintenance of Cracking in Bituminous Pavements

	Type of Cracking														
	Alligator A			Alligator B			Alligator C			Longitudinal/Transverse			Edge		
Criteria	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Width	<1/4″	>1/4″, <1/2″	>1/2″	<1/4″	>1/4″, <1/2″	>1/2″	<1/4″	>1/4″, <1/2″	>1/2″	<1/4″	>1/4″, <1/2″	>1/2″	No Material Loss	>0%, <10% Material Loss	>10% Material Loss
	or	or	or	or	or	or	or	or	or						
Area	<10%	>10%, <20%	>20%, <30%	<10%	>10%, <20%	>20%, <30%	<10%	>10%, <20%	>20%, <30%						
Preventive treatments															
Crack/joint seal (see note *e*)															
Emulsion	N	F	N	N	P	N	N	N	N	G	F	N	G	P	P
Modified (rubber)	N	G	P	N	P	N	N	P	N	P	G	F	P	P	P
Seal coats															
Fog seal (see note *a*)	G	P	N	G	N	N	F	N	N	F	N	N	F	P	P
Rejuvenator (see note *a*)	G	N	N	G	N	N	F	N	N	F	N	N	F	P	P
Scrub seals	G	F	N	G	F (see note *d*)	N	G	F (see note *d*)	N	P	N	N	F	P	P
Slurry seals															
Type II (see note *a*)	F	N	N	F	N	N	F	N	N	F	N	N	F	P	P
Type III	F	P	N	F	P	N	F	P	N	F	P	N	F	P	P
Microsurfacing															
Type II (see note *b*)	G	N	N	F	P	N	F	P	N	F	N	N	P	P	P
Type III	G	P	N	F	P	N	F	P	N	F	N	N	P	P	P
Chip seal															
PME: Med. fine	G	P	N	G	F (see note *d*)	N	G	P (see note *d*)	N	P	P	N	P	P	P
PME: Medium	G	P	N	G	F (see note *d*)	N	G	P (see note *d*)	N	P	P	N	P	P	P
PMA: Medium (see note *c*)	G	P	P	G	F (see note *d*)	P	G	P (see note *d*)	P	P	P	N	P	P	P
PMA: Coarse (see note *c*)	G	P	P	G	F (see note *d*)	P	G	P (see note *d*)	P	P	P	N	P	P	P
AR: Medium	G	G	F	G	G	F	G	F (see note *d*)	F	P	F	F	P	P	P
AR: Coarse	G	G	F	G	G	F	G	F (see note *d*)	F	P	F	F	P	P	P
PM alternative >30,000 ADT															
Conventional															
PBA OGAC	G	F	N	G	F (see note *d*)	N	G	F (see note *d*)	N	G	F	P	P	P	P
RAC-O	G	G	F	G	G	F (see note *d*)	G	G	F	G	F	P	P	P	P
RAC-O high binder (HB)	G	G	F	G	G	F (see note *d*)	G	G	F	G	F	P	F	F	F
RAC-G	G	G	G	G	G	F (see note *d*)	G	G	G	G	F	P	G	G	G
Thin bonded wearing course rubber (BWCR)	G	G	G	G	F (see note *d*)	F (see note *d*)	G	F (see note *d*)	F	F	F	P	P	P	P
Maintenance treatments															
Conventional	G	G	F	G	G (see note *d*)	P (see note *d*)	G	G	F	P	F	F	N	F	F
PBA	G	G	G	G	G (see note *d*)	P (see note *d*)	G	G	G	P	F	F	N	F	F
RAC	G	G	P	G	P (see note *d*)	P	G	F	P	P	P	F	N	F	F
BWC	G	G	G	G	F (see note *d*)	F (see note *d*)	G	F (see note *d*)	F	F	F	P	P	P	P
Digouts	N	N	F	N	N	G	N	N	G	N	F	F	N	F	G

Source: Caltrans 2008a.

Note: G = Good performance; F = Fair performance; P = Poor performance; N = Not recommended.

[a] Usually limited to shoulders, low-volume roads, and parking areas.

[b] Generally used on shoulders, parking areas, and locations where less-aggressive surface is desired.

[c] Under evaluation. Please consider other strategy at this time.

[d] Effective when proper prep work has been performed.

[e] Per maintenance manual: For cracks <¼ in., crack seal not recommended.

Table 3.10. Illinois DOT Flexible Pavement PM Treatment Matrix

Pavement Conditions	Severity Levels	Crack Filling	Crack Sealing	Fog Seal	Sand Seal	Scrub Seal	Rejuvenator	Slurry Seal	Microsurfacing
Alligator/fatigue cracking[a]	L1	F	F	NR	NR	NR	NR	F	F
	L2, L3, L4	NR	NR	NR	NR	NR	NR	NR	NR
Block cracking	M1	R	R	F	R	R	F	R	R
	M2	R	R	NR	NR	F	NR	F	NR
	M3, M4	F	F	NR	NR	NR	NR	NR	NR
"Stable" rutting[b]	N1, N2	NR	NR	NR	NR	NR	NR	F	R
	N3	NR	NR	NR	NR	NR	NR	NR	F
Joint reflection and transverse cracking[c]	O1	NR	NR	F	R	R	NR	F	R
	O2, O3	R	R	NR	NR	NR	NR	NR	F
	O4, O5	F	F	NR	NR	NR	NR	NR	NR
Overlayed patch reflective cracking	P1, P2, P3, P4, P5	F*	F*	F*	F*	F*	F*	F*	F*
Longitudinal/center of lane cracking	Q1	R	R	F	F	F	NR	F	F
	Q2, Q3	R	F	NR	NR	F	NR	NR	F
	Q4, Q5	NR	NR	NR	NR	NR	NR	NR	NR
Reflective widening crack	R1	R	R	F	F	F	NR	F	F
	R2, R3	F	F	NR	NR	NR	NR	F	F
	R4, R5	NR	NR	NR	NR	NR	NR	NR	NR
Centerline deterioration	S1, S2, S3, S4	F*	F*	F*	F*	F*	F*	F*	F*
Edge cracking	T1	F	F	F	R	R	NR	F	F
	T2	F	F	NR	NR	NR	NR	NR	F
	T3, T4	NR	NR	NR	NR	NR	NR	NR	NR
Permanent patch deterioration	U1, U2, U3, U4	F*	F*	F*	F*	F*	F*	F*	F*
Shoving, bumps, sags, and corrugation	V1	NR	NR	NR	NR	NR	NR	NR	F
	V2, V3	NR	NR	NR	NR	NR	NR	NR	NR
Weathering/raveling	W1, W2	NR	NR	F	F	F	F	R	R
	W3, W4	NR	NR	NR	NR	NR	NR	F	F
Reflective D-cracking	X1, X2, X3	NR	NR	NR	NR	NR	NR	NR	NR
Friction	Poor	NR	NR	NR	R	R	NR	R	R
ADT	<5,000	R	R	R	R	R	R	R	R
	5,000–10,000	R	R	F	F	F	R	F	R
	>10,000	R	R	NR	NR	NR	NR	NR	F
Relative cost	($ to $$$$)	$	$	$	$$	$$	$$	$$	$$

Source: IDOT 2009.
Notes:
ADT = Average daily traffic.
CIR = Cold in-place recycling.
HIR = Hot in-place recycling.
HMA = Hot-mix asphalt.
UTW = Ultra-thin whitetopping.
R: Recommended treatment for the specified pavement condition. Care must be taken in making sure that all critical distress types are addressed by the selected treatment.
R*: Recommended treatment when used with milling prior to treatment.
R**: Used in combination with crack sealing.
F: Feasible treatment, but depends on other project constraints, including other existing distresses.
F*: This is a localized distress and should be treated locally, while other distress types present should dictate choice of global treatment.
NR: Treatment is not recommended to correct the specified pavement condition.
[a] Preservation treatments do not correct alligator cracking. Of the treatments, chip seals are most appropriate at addressing alligator cracking.
[b] If stable rutting is present without other distresses, microsurfacing or mill and overlay is the recommended treatment.
[c] If cracking is joint reflection related, the preservation treatments will not correct the distress.

(continued on next page)

Table 3.10 (continued)

Pavement Conditions	Chip Seal	Cape Seal	CIR	HIR	Thin HMA Overlay	Ultra-Thin Bonded Wearing Course	UTW	Cold Mill	Drainage Preservation
Alligator/fatigue cracking[a]	F NR	F NR	F NR	F NR	F NR	F NR	F NR	NR NR	R F
Block cracking	R F NR	R F NR	R F F	R F F	F NR NR	F NR NR	R NR NR	F NR NR	NR NR NR
"Stable" rutting[b]	F NR	F NR	R R	R R	R* R*	F NR	R* R*	F F	R F
Joint reflection and transverse cracking[c]	R F NR	R F NR	F F NR	F F NR	R** F NR	F NR NR	NR NR NR	F NR NR	NR NR NR
Overlayed patch reflective cracking	F*	F*	F*	F*	F*	F*	F*	F*	F*
Longitudinal/center of lane cracking	F F NR	F F NR	F F F	F F F	F F NR	F F NR	F F NR	F F NR	NR NR NR
Reflective widening crack	F F NR	F F NR	F F NR	F F NR	F F NR	F NR NR	F F NR	F NR NR	NR NR NR
Centerline deterioration	F*	F*	F*	F*	F*	F*	F*	F*	F*
Edge cracking	R F NR	F F NR	R F NR	R F NR	R** F NR	F NR NR	F F NR	F NR NR	R R F
Permanent patch deterioration	F*	F*	F*	F*	F*	F*	F*	F*	F*
Shoving, bumps, sags, and corrugation	F NR	F NR	R R	R R	R R	F NR	F F	R R	F F
Weathering/raveling	R F	R F	F R	F R	F R*	F NR	F NR	F NR	NR NR
Reflective D-cracking	NR	NR	F	F	NR	F	NR	F	NR
Friction	R	R	F	F	R	R	F	F	NR
ADT	R R F	R R F	R F NR	R R R	R R R	R R R	R R R	R R R	R R R
Relative cost	$$	$$	$$$	$$$	$$$	$$$	$$$$	$	Varies

Table 3.11. Ohio DOT's GQL Logic Summary for Selecting Candidate PM Projects on Flexible Pavements

	Crack Sealing	Chip Seal	Single Microsurfacing	Double Microsurfacing	PMAC Overlay	Thin HMAC Overlay
Raveling	L: OFE M: O H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: NA M: NA H: NA
Bleeding	L: – M: – H: –	L: – M: – H: –	L: – M: O H: –	L: – M: OFE H: –	L: – M: O H: –	L: NA M: NA H: NA
Patching	L: O M: O H: O	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: O M: O H: O	L: O M: O H: O
Debonding	L: O M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: O M: O H: O	L: O M: O H: O
Crack seal deficiency	L: E M: E H: E	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA
Rutting	L: OFE M: O H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: O H:	L: OFE M: – H: –	L: OFE M: O H: –
Settlement	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA
Potholes	L: NA M: NA H: NA	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: O M: O H: O	L: O M: O H: O
Wheel track cracking	L: OFE M: O H: –	L: OFE M: – H: –	L: OF M: O H: –	L: OF M: O H: –	L: OF M: O H: –	L: OF M: O H: –
Block and transverse cracking	L: OFE M: O H: –	L: OF M: O H: –	L: OFE M: O H: –	L: OFE M: OF H: –	L: OFE M: OF H: –	L: OFE M: OF H: –
Longitudinal cracking	L: OFE M: O H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –
Edge cracking	L: OFE M: O H: –	L: OF M: O H: O	L: OF M: O H: O	L: OFE M: O H: O	L: OF M: O H: O	L: OF M: O H: O
Thermal cracking	L: OFE M: O H: –	L: OFE M: O H: –	L: OFE M: O H: –	L: OFE M: O H: –	L: OFE M: OF H: –	L: OFE M: OF H: –

Sources: Rao et al. 2008; ODOT 2001.

Notes:

PMAC = Polymer-modified asphalt concrete.

L, M, H: Low, medium, and high severity, respectively.

O, F, E: Occasional, frequent, and extensive, respectively.

– = Not suitable for distress severity level.

NA = Particular distress is not considered in the logical decision.

Table 3.12. Ohio DOT's GQL Logic Summary for Selecting Candidate PM Projects on Composite Pavements

	Crack Sealing	Chip Seal	Single Microsurfacing	Double Microsurfacing	PMAC Overlay	Thin HMAC Overlay
Raveling	L: OFE M: O H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: NA M: NA H: NA
Bleeding	L: – M: – H: –	L: – M: – H: –	L: – M: O H: –	L: – M: OFE H: –	L: – M: O H: –	L: NA M: NA H: NA
Patching	L: O M: O H: O	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: O M: O H: O	L: O M: O H: O
Disintegration/debonding	L: O M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: O M: O H: O	L: O M: O H: O
Rutting	L: OFE M: O H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: O H: –	L: OFE M: – H: –	L: OFE M: O H: –
Pumping	L: O M: O H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –
Shattered slab	L: NA M: NA H: NA	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –
Settlement	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA
Transverse cracks	L: OFE M: OFE H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: O H: –	L: OFE M: OF H: –	L: OFE M: OF H: –
Joint reflection cracking	L: OFE M: OFE H: –	L: OFE M: – H: –	L: OFE M: – H: –	L: OFE M: O H: –	L: OFE M: OF H: –	L: OFE M: OF H: –
Intermediate transverse cracking	L: OFE M: OFE H: –	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –	L: O M: O H: –	L: O M: O H: –
Longitudinal cracking	L: OFE M: O H: –	L: OFE M: O H: –	L: OFE M: O H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –	L: OFE M: OFE H: –
Pressure damage/upheaval	L: NA M: NA H: NA	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –
Crack seal deficiency	L: FE M: FE H: FE	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA	L: NA M: NA H: NA
Corner breaks	L: NA M: NA H: NA	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –	L: O M: – H: –
Punchouts	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –	L: – M: – H: –

Sources: Rao et al. 2008; ODOT 2001.
Notes:
PMAC = Polymer-modified asphalt concrete.
L, M, H: Low, medium, and high severity, respectively.
O, F, E: Occasional, frequent, and extensive, respectively.
– = Not suitable for distress severity level.
NA = Particular distress is not considered in the logical decision.

Table 3.13. Example Critical Trigger and Limit Values for PCC Pavement Distress and Performance Indicators

Pavement Type and Performance Measure	First Value = Trigger Value/Second Value = Limit Value[a]		
	High (ADT > 10,000)	Medium (3,000 < ADT < 10,000)	Low (ADT < 3,000)
Jointed Plain Concrete Pavement (Joint Space < 20 ft)[b]			
Structural Measurements			
Low-high severity fatigue cracking (% of slabs)	1.5/5.0	2.0/10.0	2.5/15.0
Deteriorated joints (% of joints)	1.5/15.0	2.0/17.5	2.5/20.0
Corner breaks (% of joints)	1.0/8.0	1.5/10.0	2.0/12.0
Average transverse joint faulting (in.)	0.10/0.50	0.10/0.60	0.10/0.70
Durability distress (severity)	Medium-high		
Joint seal damage (% of joints)	>25/—		
Load transfer (%)	<50/—		
Skid resistance	Minimum local acceptable level/—		
Functional Measurement			
IRI (in./mi)	63/158	76/190	89/222
PSR	3.8/3.0	3.6/2.5	3.4/2.0
California profilograph (in./mi)	12/60	15/80	18/100
Jointed Reinforced Concrete Pavement (Joint Space < 20 ft)[c]			
Structural Measurements			
Medium-high severity trans. cracking (% of slabs)	2.0/30.0	3.0/40.0	4.0/50.0
Deteriorated joints (% of joints)	2.0/10.0	3.0/20.0	4.0/30.0
Corner breaks (% of joints)	1.0/10.0	2.0/20.0	3.0/30.0
Average transverse joint faulting (in.)	0.16/0.50	0.16/0.60	0.16/0.70
Durability distress (severity)	Medium-high		
Joint seal damage (% of joints)	>25/—		
Load transfer (%)	<50/—		
Skid resistance	Minimum local acceptable level/—		
Functional Measurement			
IRI (in./mi)	63/158	76/190	89/222
PSR	3.8/3.0	3.6/2.5	3.4/2.0
California profilograph (in./mi)	12/60	15/80	18/100
Continuously Reinforced Concrete Pavement			
Structural Measurements			
Failures (punchouts, full-depth repairs) (no./mi)	3/10	5/24	6/39
Durability distress (severity)	Medium-high		
Skid resistance	Minimum local acceptable level/—		
Functional Measurement			
IRI (in./mi)	63/158	76/190	89/222
PSR	3.8/3.0	3.6/2.5	3.4/2.0
California profilograph (in./mi)	12/60	15/80	18/100

Source: Smith et al. 2008.

Note: 1 mi = 1.609 km; 1 m = 3.281 ft; 1 in. = 25.4 mm.

[a] Values should be adjusted for local conditions. Actual percentage repaired may be much higher if the pavement is restored several times.

[b] Assumed slab length = 15 ft.

[c] Assumed slab length = 33 ft.

(continued from page 47)
wear were acknowledged as key components of the age and climate variables).

An evaluation of thin HMA overlays in Ohio indicated differences in both treatment life and extensions in pavement service life, when placed on facilities with different traffic levels (Chou et al. 2008). Based on an analysis of 820 sections placed on the state's priority system (Interstates and other higher-volume, four-lane divided highways) and 2,870 sections placed on the general system (two-lane undivided highways), average treatment service lives of 6.6 and 9.1 years, respectively, were observed, based on actual section terminations (i.e., rehabilitation of the overlaid pavement). Additional analysis revealed service lives of 8.0 and 6.0 years for overlays placed on priority-system flexible and composite pavements, respectively, and 8.5 and 8.4 years for overlays placed on general-system flexible and composite pavements, respectively.

Chou et al. (2008) also analyzed thin overlay service life, based on the time until a threshold condition level (PCR = 65 for priority system, PCR = 60 for general system) is achieved. As, illustrated in Figure 3.9 (p. 68), average service lives of 9.0 and 13.0 years for applications on the priority and general systems, respectively, were observed. Had the same threshold PCR level been used for both systems, overlay life on the priority system would still have been at least 2 years shorter than the life on the general system. Additional analysis of the data was performed to determine the life extension of thin overlays. These results indicated an average extension of 7.5 years on the priority system and 10.7 years on the general system, a 3.2-year difference between the two systems. Based on this study, although no traffic levels were reported for the two highway systems, it appears that higher traffic levels decrease the performance of HMA overlays by 2 or more years.

In a recent evaluation of Colorado's PM program, guidelines for the application of various preservation treatments were drafted based on subjective discussions of performance with DOT staff (Galehouse 2004). The guidelines included expected pavement service life extensions corresponding to different truck traffic levels. A summary of these expected life extensions is provided in Table 3.24 (p. 68). Although the values listed are subjective, they show that the durability of treatments is perceived to be affected by increasingly heavier traffic loads, the impact being between 1 and 3 years when moving from the moderate to heavy truck traffic category.

In considering the impact of traffic, there is a tendency to want to also introduce equivalent single-axle loads (ESALs) or some other measure of loading. This was seen even in the survey responses, where one agency categorized high versus low traffic by ESALs and another used a traffic index rather than ADT or AADT. The assumption in focusing on traffic rather than on loads is that the pavement is adequately designed and constructed for the loads it is carrying. If it is not, then it is probably not a good candidate for preservation anyway.

Impact of Climate on Treatment Performance

Satisfactory treatment performance is also a function of the treatment's ability to withstand stresses associated with climate and environment (temperature, moisture, and the interaction of the two). In some snow and icy climates, the treatment must also withstand the effects of snowplows and deicing salts (and in some states, studded tire use).

Little published information was available that involved a quantitative assessment of the impact of climate on preservation treatment performance. The main bodies of work involved the 1998 national study on diamond grinding of PCC pavements (Rao et al. 1999) and the same-year evaluation of LTPP SPS-3 PM test sites (Morian et al. 1998). As mentioned previously, in the case of the former study, age and climate were established as the key variables in a surface texture deterioration model. Plotted trends for freeze and nonfreeze climates suggested an average difference of nearly 0.005 in. (0.125 mm) of reduced texture depth after a 10-year period, with the freeze climate experiencing greater reduction.

Evaluation by Morian et al. (1998) of pavement rating score (PRS) data collected on PM test sections at 58 SPS-3 sites throughout the United States and Canada resulted in estimates of treatment performance across four climatic zones. Using a threshold PRS of 50, performance lives were computed, indicating (for the most part) a few years reduction in life associated with use in freeze environments (Table 3.25, p. 69).

Adjustments to General Expectations of Treatment Performance

The evaluations described above indicate that small to moderate reductions in treatment performance can be expected to occur as a result of any of the following circumstances:

- Existing pavement condition is rated in the fair category instead of the satisfactory/good category.
- Traffic level is more characteristic of a high-volume roadway facility than a low-volume facility.
- Climate is more characteristic of a freezing climate than a nonfreezing one, with significant snow and ice removal operations necessary for winter precipitation events.

Whereas it was beyond the ability and scope of this study to develop estimates of treatment performance that account for various combinations of pavement condition, traffic level, and climatic conditions, it was deemed appropriate to adjust the general expected performance ranges so that they account for the high-traffic-volume levels defined in the study (rural ADT > 5,000 vpd, urban ADT > 10,000 vpd). A conservative approach was taken in making the adjustments, using the findings of the Ohio thin HMA overlay study. A performance reduction value of 2.6 years (the average of the two values [2.0 and 3.2 years] reported) was divided by the midpoint

(text continues on page 61)

Table 3.14. Concrete Pavement Preservation and Rehabilitation Treatments Best Suited for Distresses in PCC-Surfaced Pavements

	Concrete Pavement Preservation and Rehabilitation Treatments							
Distress	**Partial-Depth Repair**	**Full-Depth Repair**	**Dowel Bar Retrofitting**	**Diamond Grinding**	**Diamond Grooving**	**Joint Resealing**	**Crack Sealing**	**Asphalt Overlay**
Corner breaks		LS MS HS					LS[e] MS[e]	
Linear cracking (transverse, longitudinal, diagonal)		MS HS					LS[e] MS[e]	
Punchouts		LS MS HS						
D-cracking (at joints/cracks)		MS HS						√
Map cracking/scaling (non-AAR)	LS[a] MS[a] HS[a]							√
Map cracking/scaling (AAR)		MS HS						√
Joint seal damage						√[d]		
Joint spalling	LS[a] MS[a] HS[a]	MS HS						
Blowups		LS MS HS						
Pumping			√[b]					
Joint faulting			√[b]	√[c]				√
Bumps, settlements, heaves		MS HS		√				√
Polishing				√	√			√

Source: Modified from Smith et al. 2008.
Notes:
AAR = Alkali-aggregate reaction.
LS = Low severity; MS = Medium severity; HS = High severity.
[a] Deterioration confined to top one-third of slab.
[b] Joint/crack deflection load transfer ≤ 60%, faulting greater than 0.10 in. but less than 0.25 in., and differential deflection of 0.01 in.
[c] Faulting > 0.125 in.
[d] Existing joint sealant no longer performing intended function of preventing intrusion of incompressibles and infiltration of water into the joints.
[e] Crack widths ≤ 0.5 in.

(continued on next page)

Table 3.14 (continued)

Distress	Concrete Pavement Preservation and Rehabilitation Treatments						
	Slab Stabilization	Retrofitted Edge Drains	Pressure Relief Joints	Asphalt Overlay of Fractured Slab	Bonded Concrete Overlay	Unbonded Concrete Overlay	Reconstruction
Corner breaks				√		√	√
Linear cracking (transverse, longitudinal, diagonal)				√		√	√
Punchouts				√		√	√
D-cracking (at joints/cracks)				√		√	√
Map cracking/scaling (non-AAR)							
Map cracking/scaling (AAR)			√	√		√	√
Joint seal damage							
Joint spalling				√		√	√
Blowups				√		√	√
Pumping	√	√					
Joint faulting				√	√	√	
Bumps, settlements, heaves				√	√	√	√
Polishing					√		

Table 3.15. Highway Agency Treatment Usage on HMA-Surfaced Roadways According to Pavement Condition

	Pavement Distress								
							Surface Distress[a]		
Treatment	**Raveling**	**Oxidation**	**Bleeding**	**Smoothness**	**Friction**	**Noise**	**Light**	**Moderate**	**Heavy**
Crack filling	NA	NA	NA	Limited	NA	Limited	**Extensive**	Moderate	Limited
Crack sealing	NA	NA	NA	Limited	NA	Limited	**Extensive**	Moderate	Limited
Slurry seal	**Extensive**	**Extensive**	Limited	Limited	Limited	None	Moderate	Limited	None
Microsurfacing	Moderate	Moderate	Limited	Moderate	Moderate	Limited	**Extensive**	Moderate	Limited
Chip seals	Moderate	**Extensive**	Limited	Limited	Moderate	None	**Extensive**	**Extensive**	Limited
Ultra-thin bonded wearing course	Moderate	Moderate	Limited	Moderate	**Extensive**	Limited	**Extensive**	Moderate	Limited
Thin HMA overlay	**Extensive**	Moderate	Moderate	**Extensive**	Moderate	Limited	**Extensive**	**Extensive**	Limited
Cold milling and overlay	**Extensive**	Moderate	Moderate	**Extensive**	Moderate	Limited	**Extensive**	**Extensive**	Moderate
Ultra-thin HMA overlay	Moderate	Moderate	Moderate	Moderate	Moderate	Limited	**Extensive**	Moderate	Limited
Hot in-place HMA recycling	Moderate	Moderate	Limited	Moderate	Moderate	Limited	**Extensive**	Moderate	Moderate
Cold in-place recycling	Limited	Limited	Limited	Moderate	Limited	Limited	Moderate	**Extensive**	**Extensive**
Profile milling	None	None	Limited	**Extensive**	Moderate	Limited	Moderate	Limited	None
Ultra-thin whitetopping	Limited	Limited	Limited	Moderate	Limited	Limited	Moderate	Moderate	Limited

Note: Extensive = Used by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.
[a] Various forms of cracking.

Table 3.16. Highway Agency Treatment Usage on PCC-Surfaced Roadways According to Pavement Condition

	Pavement Distress					
				Surface Distress[a]		
Treatment	**Smoothness**	**Friction**	**Noise**	**Light**	**Moderate**	**Heavy**
Concrete joint resealing	Limited	None	Limited	**Extensive**	Moderate	Limited
Concrete crack sealing	Limited	None	Limited	**Extensive**	Moderate	Limited
Diamond grinding	**Extensive**	Moderate	Moderate	Limited	Limited	Limited
Diamond grooving	Moderate	**Extensive**	Limited	Limited	Limited	Limited
Partial-depth concrete patching	Moderate	None	Limited	Moderate	**Extensive**	Moderate
Full-depth concrete patching	Moderate	Limited	Limited	Limited	**Extensive**	**Extensive**
Dowel bar retrofit	Moderate	Limited	Limited	Limited	Moderate	Moderate
Ultra-thin bonded wearing course	**Extensive**	Moderate	Limited	Moderate	Moderate	Limited
Thin HMA overlay	Moderate	Moderate	Limited	Moderate	Moderate	Limited

Note: Extensive = Used by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.
[a] Spalling, various forms of cracking.

(continued from page 57)
(8.5 years) of the expected performance range (5 to 12 years) of the thin overlay treatment. This resulted in a reduction of 30%. The lower and upper limits of each treatment's general expected performance range were then reduced by this percentage. The adjusted ranges are listed in Tables 3.26 (p. 69) and 3.27 (p. 70) and were incorporated into the preservation guidelines document.

To ensure that the effects of existing pavement condition and climate are properly accounted for, the preservation guidelines suggest using values near the lower limit of the performance range for treatments to be applied on pavements in fair condition and located in severe-freeze environments. On the other hand, it is suggested that values near the upper limit of the range be used for treatments applied to pavements in good condition and located in nonfreeze environments.

For the purposes of this study, three climatic regions were identified based on the LTPP test site classifications established by Jackson and Puccinelli (2006). These regions consist of the following:

- Deep freeze (northern-tier states, freezing index [FI] > 400);
- Moderate freeze (middle-tier states, 50 < FI ≤ 400); and
- Nonfreeze (southern-tier states and portions of coastline, FI ≤ 50).

An approximate delineation of the climate zone boundaries is presented in Figure 3.10 (p. 70).

One final consideration in assessing treatment performance is the potential for substandard construction and performance due to agency or contractor inexperience or limitations in the quality of locally available materials. One approach to account for construction quality risk is to apply a confidence factor to the expected performance range, with a factor of 1.0 representing 100% confidence, 0.75 representing 75% confidence, and so on. Thus, if the expected performance of a treatment ranged from 4.0 to 6.0 years and the level of confidence was 75% (reflecting some shortcomings in agency or contractor experience or materials quality), then the range would be reduced to between 3.0 and 4.5 years.

Construction Constraints

There are several construction factors that affect the feasibility of a preservation treatment, including the following:

- *The anticipated or targeted time frame (i.e., time of year) for construction.* Each candidate treatment must be examined in terms of the weather patterns (temperature, precipitation) for which they are most suitable for application and of the various weather-related effects (e.g., moisture left in pavement structure, salt or sand from winter maintenance operations remaining in cracks and joints). Table 3.28 (p. 71) provides an illustration of one agency's recommendations for treatment timing restrictions.
- *Work zone duration restrictions.* Depending on agency policies and practices and a variety of other factors (traffic volume and speed, driving difficulty, facility setting, and so on), there may be a need to restrict the duration of work zone setups so as to minimize congestion and maximize

(text continues on page 69)

Table 3.17. Guideline Decision-Support Matrix for Preliminary Identification of Candidate Treatments for HMA-Surfaced Pavements

Preservation Treatment	Window of Opportunity		Distress Types and Severity Levels (L = Low, M = Medium, H = High)									
			Surface Distress					Cracking Distress				
	PCI/ PCR	Age (yr)	Ravel/ Weather	Bleed/ Flush	Polish	Segre- gation	Water Bleed/ Pump[a]	Fatigue/ Long WP/ Slippage	Block	Trans Therm	Joint Reflect	Long/ Edge
			L/M/H	—	—	L/M/H	—	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H
Crack fill	75–90	3–6[d]						×××	⊙○×	○××	○××	●⊙○
Crack seal	80–95	2–5[d]						×××	⊙○×	●⊙○	●⊙○	○××
Slurry seal (Type III)	70–85	5–8	⊙●⊙	×	⊙	⊙○×	⊙	⊙○×	●⊙○	⊙○×	⊙○×	⊙○×
Microsurfacing: Single	70–85	5–8	⊙●⊙	×	⊙	●⊙○	⊙	⊙○×	●⊙○	⊙○×	⊙○×	⊙○×
Microsurfacing: Double	70–85	5–8	⊙●⊙	×	⊙	●⊙○	○	⊙○×	●⊙○	●⊙○	●⊙○	●⊙○
Chip seal: Single												
Conventional	70–85	5–8	⊙●⊙	○	●	●⊙○	⊙	⊙××	●⊙○	●⊙○	●⊙○	⊙⊙○
Polymer modified	70–85	5–8	○⊙⊙	×	●	⊙⊙○	○	⊙○×	●⊙⊙	●⊙⊙	●⊙⊙	⊙○×
Chip seal: Double												
Conventional	70–85	5–8	○⊙⊙	×	⊙	⊙⊙○	×	⊙○×	●⊙⊙	●⊙⊙	●⊙⊙	●⊙⊙
Polymer modified	70–85	5–8	○○⊙	×	⊙	○⊙○	×	●⊙○	●●⊙	●●⊙	●●⊙	●⊙⊙
Ultra-thin bonded wearing course	65–85	5–10	⊙●⊙	×	●	⊙⊙○	○	⊙○×	⊙⊙○	⊙⊙○	⊙⊙○	⊙⊙○
Ultra-thin HMAOL	65–85	5–10	⊙●⊙	×	●	⊙⊙○	○	⊙○×	⊙⊙○	⊙⊙×	⊙⊙×	⊙⊙×
Thin HMAOL	60–80	6–12	⊙●⊙	○	●	⊙⊙○	○	●⊙○	●●⊙	⊙●⊙	⊙●⊙	⊙⊙●
Cold milling and thin HMAOL	60–75	7–12	○⊙●	○	○	⊙●⊙	×	⊙⊙○	○⊙⊙	⊙⊙●	⊙⊙●	○⊙●
Hot in-place recycling												
Surf recycle/HMAOL	70–85	5–8	○⊙●	○	○	⊙●⊙	○	⊙⊙○	●⊙○	○⊙●	○⊙●	⊙⊙○
Remixing/HMAOL	60–75	7–12	×○○	○	⊙	×○⊙	×	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙
Repaving	60–75	7–12	×○○	○	⊙	×○⊙	×	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙
Cold in-place recycling and HMAOL	60–75	7–12	××○	○	○	×○⊙	×	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙	⊙●⊙
Profile milling	80–90	3–6	○⊙⊙	⊙	○	×○○	×	×××	×××	×××	×××	×××
Ultra-thin whitetopping	60–80	6–12	××○	○	⊙	×○⊙	×	○⊙⊙	○⊙⊙	○⊙⊙	○⊙⊙	○⊙●

Note: ● = Highly Recommended; ⊙ = Generally Recommended; ○ = Provisionally Recommended; × = Not Recommended.

[a] Porous surface mix problem.

[b] Rutting primarily confined to HMA surface layer and largely continuous in extent.

[c] Corrugation/shoving primarily HMA surface layer mix problem and frequent in extent.

[d] For composite AC/PCC pavements, a more probable window of opportunity is 2–4 years for crack filling and 1–3 years for crack sealing.

[e] Localized application in the case of bumps.

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Table 3.17 (continued)

Preservation Treatment	Distress Types and Severity Levels				Surface Characteristics Issues		
	Deformation Distress						
	Wear/ Stable Rutting[b]	Corrug/ Shove[c]	Bumps/ Sags	Patches	Ride Quality	Friction	Noise
	L/M/H	L/M/H	L/M/H	L/M/H	–	–	–
Crack fill							
Crack seal							
Slurry seal (Type III)	○××	×××	×××	⊙○×	×	⊙	⊙
Microsurfacing: Single	⊙○×	○××	○××	⊙○×	○	●	⊙
Microsurfacing: Double	●⊙○	○○×	○○×	●⊙○	⊙	●	⊙
Chip seal: Single							
Conventional	⊙○×	○○×	○○×	⊙⊙○	○	●	×
Polymer modified	⊙○×	○○×	○○×	⊙⊙○	○	●	×
Chip seal: Double							
Conventional	●⊙○	⊙○×	⊙○×	●⊙⊙	⊙	⊙	○
Polymer modified	●⊙○	⊙○×	⊙○×	●⊙⊙	⊙	⊙	○
Ultra-thin bonded wearing course	⊙○×	⊙○×	⊙○×	⊙⊙○	⊙	●	⊙
Ultra-thin HMAOL	⊙○×	⊙○×	⊙○×	⊙⊙○	⊙	●	●
Thin HMAOL	⊙●⊙	●⊙○	●⊙○	●●⊙	●	●	●
Cold milling and thin HMAOL	⊙●⊙	●⊙⊙	●⊙○	●●⊙	●	⊙	○
Hot in-place recycling							
Surf recycle/HMAOL	⊙●⊙	⊙⊙○	⊙⊙○	⊙⊙○	⊙	⊙	○
Remixing/HMAOL	⊙●●	⊙●●	○⊙●	○⊙⊙	●	⊙	○
Repaving	⊙●●	⊙●●	○⊙●	○⊙⊙	●	⊙	○
Cold in-place recycling and HMAOL	⊙●●	⊙●●	○⊙●	○⊙⊙	●	⊙	○
Profile milling	●⊙○	○××	⊙⊙○[e]	⊙⊙○[e]	⊙	○	×
Ultra-thin whitetopping	○⊙⊙	○⊙⊙	×○○	○⊙⊙	⊙	○	×

Table 3.18. Guideline Decision-Support Matrix for Preliminary Identification of Candidate Treatments for PCC-Surfaced Pavements

	Window of Opportunity		Distress Types and Severity Levels (L = Low, M = Medium, H = High) — Surface Distress				
			Polish	Map Crack/Scale (Non-ASR)	D-Crack	Popouts	Water Bleed/Pump
Preservation Treatment	**PCI/ PCR**	**Age (yr)**	**—**	**—**	**L/M/H**	**—**	**—**
Concrete joint resealing	75–90	5–10					
Concrete crack sealing	70–90	5–12					
Diamond grinding	70–90	5–12	●	⊙	×××	×	×
Diamond grooving	70–90	5–12	○	×	×××	×	×
Partial-depth concrete patching	65–85	6–15	×	○	×××	⊙	×
Full-depth concrete patching	65–85	6–15	×	○	○⊙●[b]	×	⊙
Dowel bar retrofitting	65–85	6–15	×	×	×××	×	⊙
Ultra-thin bonded wearing course	70–90	5–12	⊙	●	⊙○×	○	×
Thin HMA overlay	70–90	5–12	⊙	●	⊙○×	○	×

Note: ● = Highly Recommended; ⊙ = Generally Recommended; ○ = Provisionally Recommended; × = Not Recommended.

[a] May be appropriate in conjunction with partial- and/or full-depth repairs to ensure smooth profile.

[b] Isolated incidences of D-cracking only.

[c] Isolated incidences of faulting only.

[d] Likely needed in conjunction with diamond grinding.

(continued on next page)

Table 3.18 (continued)

	Distress Types and Severity Levels						Surface Characteristics Issues		
	Joint Distress		Cracking Distress		Deformation Distress				
	Joint Seal Damage	Joint Spall	Corner	Long/ Trans	Faulting	Patches	Ride Quality	Friction	Noise
Preservation Treatment	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**—**	**—**	**—**
Concrete joint resealing	○⊙●	○××							
Concrete crack sealing			●⊙○	●⊙○					
Diamond grinding	×××	×××	×××	××○[a]	⊙●⊙	⊙●⊙	●	⊙	●
Diamond grooving	×××	×××	×××	×××	×××	×××	×	⊙	●
Partial-depth concrete patching	×××	⊙●●	×××	×○⊙	×××	○⊙○	×	×	×
Full-depth concrete patching	×××	×○⊙	⊙●●	××○	×○⊙[c]	○⊙●	⊙	×	×
Dowel bar retrofitting	×××	×××	×○○	×××	○⊙●[d]	×××	×	×	×
Ultra-thin bonded wearing course	×××	×××	○××	○⊙○	⊙○×	⊙●⊙	●	●	⊙
Thin HMA overlay	×××	×××	○××	○⊙○	⊙○×	⊙●⊙	●	●	●

Table 3.19. General Expected Performance of Preservation Treatments Applied to HMA-Surfaced Pavements

Treatment	Expected Performance (Treatment Life) (yr)	Expected Performance (Pavement Life Extension) (yr)
Crack filling	2 to 4	NA
Crack sealing	3 to 8	2 to 5
Slurry seal	3 to 5	4 to 5
Microsurfacing		
Single course	3 to 6	3 to 5
Double course	4 to 7	4 to 6
Chip seal		
Single course	3 to 7	5 to 6
Double course	5 to 10	8 to 10
Ultra-thin bonded wearing course	7 to 12	NA
Thin HMA overlay		
Dense graded	5 to 12	NA
Open graded (OGFC)	6 to 12	NA
Gap graded (SMA)	NA[a]	NA
Cold milling and thin HMA overlay	5 to 12	NA
Ultra-thin HMA overlay	4 to 8	NA
Hot in-place recycling		
Surface recycle and thin HMA overlay	6 to 10[b]	NA
Remixing and thin HMA overlay	7 to 15[c]	NA
Repaving	6 to 15	NA
Cold in-place recycling and thin HMA overlay	Between 6 to 8 and 7 to 15[d]	NA
Profile milling	2 to 5	NA
Ultra-thin whitetopping	NA	NA

Sources: Peshkin et al. 1999; Lamptey et al. 2005; Peshkin and Hoerner 2005; Dunn and Cross 2001; Newcomb 2009; Cuelho et al. 2006; Okpala et al. 1999; Caltrans 2008a; NDOR 2002.

Note: NA = Not available.

[a] Current indications are that SMA overlays perform the same or slightly better than dense-graded overlays.

[b] Range based on reported performance of surface recycle and subsequent surface treatment.

[c] Range based on reported performance of remixing and subsequent HMA overlay of unspecified thickness.

[d] Range based on reported performance of CIR and subsequent surface treatment (6 to 8 years) and CIR and subsequent HMA overlay of unspecified thickness (7 to 15 years).

Table 3.20. General Expected Performance of Preservation Treatments Applied to PCC-Surfaced Pavements

Treatment	Expected Performance (Treatment Life) (yr)	Expected Performance (Pavement Life Extension) (yr)
Concrete joint resealing	2 to 8	5 to 6
Concrete crack sealing	4 to 7	NA
Diamond grinding	8 to 15	NA
Diamond grooving	10 to 15	NA
Partial-depth concrete patching	5 to 15	NA
Full-depth concrete patching	5 to 15	NA
Dowel bar retrofit	10 to 15	NA
Ultra-thin bonded wearing course	6 to 10	NA
Thin HMA overlay	6 to 10	NA

Sources: Peshkin et al. 1999; Smith et al. 2008; Peshkin et al. 2007; Caltrans 2008a; Caltrans 2008b; NDOR 2002.

Table 3.21. Median Survival Time of PM Treatments

Pretreatment Pavement Condition	Thin HMA Overlay	Chip Seal	Slurry Seal	Crack Seal
Good	7.5 yr	NA	6.5 yr	6.5 yr
Fair	7.3 yr	NA	5.0 yr	7.2 yr
Poor	2.2 yr	NA	2.5 yr	0.75 yr

Source: Eltahan et al. 1999.

Table 3.23. Projected Performance of Preservation Treatments in California

Treatment	Good Condition (PCI = 80) (yr)	Fair Condition (PCI = 60) (yr)	Poor Condition (PCI = 40) (yr)
Fog seal	3 to 5	1 to 3	1 to 2
Chip seal	7 to 10	3 to 5	1 to 3
Slurry seal	7 to 10	3 to 5	1 to 3
Microsurfacing	8 to 12	5 to 7	2 to 4
Thin HMA overlay	10 to 12	5 to 7	2 to 4

Source: Hicks and Marsh 2005.

Table 3.22. Performance of PM Treatments in Ohio

PM Treatment	PCR Range at Time of Treatment	Existing Pavement Type	Primary Applications with Respect to Highway Class[a]	Pavement Life Extension, Based on Projected Treatment Age (yr) at Terminal PCR of:			
				80	75	70	65
Chip seals	70 to 80	Flexible	General	6.0	9.0		12.0
	80 to 90	Flexible	General	6.5	9.0		12.0
	All	**All**	**All**	**6.25**	**9.0**		**12.0**
Single-course microsurfacing	70 to 80	Flexible	General and urban	3.75	5.75	7.5	9.5
	80 to 90	Flexible	General and urban	5.0	7.0	8.5	10.5
	70 to 80	Composite	Urban and priority	2.25	4.0	6.25	8.5
	80 to 90	Composite	Urban and priority				
	All	**All**	**All**	**3.75**	**5.5**	**7.25**	**9.25**
Double-course microsurfacing	70 to 80	Flexible	Priority and urban	3.75	5.25	7.0	9.0
	80 to 90	Flexible	Priority and urban				
	70 to 80	Composite	Priority and urban				
	80 to 90	Composite	Priority and urban	6.5	8.5	10.5	12.0
	All	**All**	**All**	**5.0**	**6.5**	**8.25**	**10.0**
Ultra-thin bonded wearing course[b]	70 to 80	All	Priority	6.0	8.0	10.0	11.5
	80 to 90	All	Priority	6.0	8.0	10.25	12.0
	All	**All**	**All**	**6.0**	**8.0**	**10.0**	**11.5**
PMAC overlays[c]	70 to 80	Flexible	Priority and urban	6.5	8.25	10.25	12.0
	80 to 90	Flexible	Priority and urban	7.0	8.25	10.25	12.0
	70 to 80	Composite	Priority and urban	6.0	8.25	10.75	12.0
	80 to 90	Composite	Priority and urban				
	All	**All**	**All**	**6.5**	**8.25**	**10.25**	**12.0**
Thin HMA overlays (without repairs)	70 to 80	Flexible	General, urban, and priority	8.5	11.0		14.0
	80 to 90	Flexible	General, urban, and priority	10.25	12.0		15.0
	70 to 80	Composite	Priority and urban	7.0	9.25		12.0
	80 to 90	Composite	Priority and urban	10.0	12.0		15.0
	All	**All**	**All**	**8.5**	**11.0**		**14.0**
Thin HMA overlays (with repairs)	70 to 80	Flexible	Urban and general	11.0	12.0		15.0
	80 to 90	Flexible	Urban and general				
	70 to 80	Composite	General, urban, and priority	11.0	12.0		15.0
	80 to 90	Composite	General, urban, and priority				
	All	**All**	**All**	**11.0**	**12.0**		**15.0**

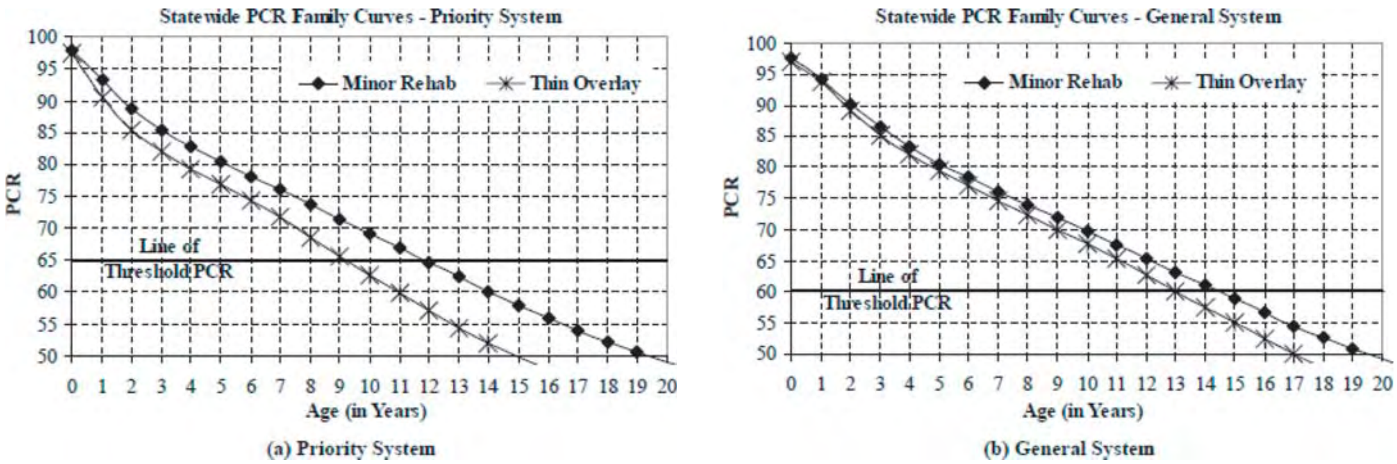
Source: Rao et al. 2008.

Note: PMAC = Polymer-modified asphalt concrete.

[a] ODOT Highway Classification: Priority = Interstates and four-lane NHS highways outside urban area; Urban = Nonpriority state routes in urban areas; General = All remaining state routes (mostly two-lane highways).

[b] Proprietary product NovaChip.

[c] Proprietary product SmoothSeal.



Source: Chou et al. 2008.

Figure 3.9. Average performance trends of thin HMA overlay on Ohio priority-system and general-system pavements.

Table 3.24. Expected Pavement Service Life Extensions Affected by Pavement Preservation Treatments in Colorado, Corresponding to Truck Traffic Levels

Treatment	Pavement Type	Expected Pavement Life Extension (yr) for: AADTT < 400 tpd	400 ≤ AADTT ≤ 6,000 tpd	AADTT > 6,000 tpd
Crack filling	Flexible	≤4	≤2	≤2
Crack sealing	Flexible	≤4	≤3	≤2
Sand seals	Flexible	≤3	Not advised	Not advised
Chip seals	Flexible	6 to 9	3 to 6	2 to 3
Microsurfacing (single course)	Flexible	6 to 9	3 to 5	2 to 3
Microsurfacing (multiple course)	Flexible	8 to 9	4 to 6	2 to 4
Ultra-thin bonded wearing course	Flexible	≤9	≤7	≤5
Thin HMA overlay	Flexible	10 to 11	5 to 9	3 to 5
Mill and thin HMA overlay	Flexible	10 to 11	5 to 10	3 to 5
Crack sealing	Rigid	≤6	≤3	≤2
Joint resealing	Rigid	4 to 6	3 to 5	2 to 3
Diamond grinding	Rigid	6	3	2 to 3
Partial-depth spall repair	Rigid	4 to 6	2 to 3	≤3
Dowel bar retrofitting	Rigid	4 to 6	2 to 3	≤3
Full-depth concrete repair	Rigid	6 to 11	3 to 10	≤5

Source: Galehouse 2004.
Note: AADTT = average annual daily truck traffic; tpd = trucks per day.

Table 3.25. Estimates of Treatment Performance in Four Climatic Zones

Climate Zone	Thin HMA Overlay	Chip Seal	Slurry Seal	Crack Seal
Dry nonfreeze	>12 yr	7 yr	>12 yr	9–10 yr
Dry freeze	6–7 yr	11 yr	5 yr	6 yr
Wet nonfreeze	>12 yr	>12 yr	>12 yr	7 yr
Wet freeze	7 yr	6–7 yr	5 yr	3–4 yr

Source: Morian et al. 1998.

(continued from page 61)

safety. Such restrictions could be tight, entailing that work be performed in a single daytime or overnight shift, or more moderate, allowing work to take place over a weekend, for example.

The impact of work zone duration restrictions must be evaluated against the time-to-opening requirements of each candidate treatment. The preservation survey results indicated that most treatments can satisfy the tightest restriction of a single daytime or overnight shift. For treatments applied to HMA-surfaced pavements, only ultra-thin whitetopping was reported as not being able to meet this restriction; longer closure time is needed in order for the PCC to cure and reach an acceptable strength level. For PCC-surfaced pavements, longer closure times are generally required for partial-depth and full-depth repairs and for dowel bar retrofitting. Although the use of high early strength PCC mixes and fast-track proprietary repair materials (and precast full-depth repair panels) do enable these treatments to be used in single-shift or overnight closures, the costs are often significantly greater than the conventional cementitious materials used and their durability is more variable.

- *Roadway geometrics.* Every project consists of a unique set of geometric conditions or circumstances. The presence of features such as significant horizontal or vertical curves, intersections or interchanges, overhead bridges or sign structures, paved shoulders, and curb-and-gutter could be problematic to the construction of certain preservation

Table 3.26. Expected Performance of Preservation Treatments Applied to HMA-Surfaced Pavements on High-Traffic-Volume Roads

Treatment	Expected Performance (Treatment Life) (yr)	Expected Performance (Pavement Life Extension) (yr)
Crack filling	1.5 to 3	NA
Crack sealing	2.0 to 5.5	2 to 5
Slurry seal	2.0 to 3.5	4 to 5
Microsurfacing		
Single course	2.0 to 4.0	3 to 5
Double course	3.0 to 5.0	4 to 6
Chip seal		
Single course	2.0 to 5.0	5 to 6
Double course	3.5 to 7.0	8 to 10
Ultra-thin bonded wearing course	5.0 to 8.5	NA
Thin HMA overlay		
Dense graded	3.5 to 8.5	NA
Open graded (OGFC)	4.5 to 8.5	NA
Gap graded (SMA)	NA	NA
Cold milling and thin HMA overlay	3.5 to 8.5	NA
Ultra-thin HMA overlay	2.5 to 5.5	NA
Hot in-place recycling		
Surface recycle and thin HMA overlay	4.0 to 7.0	NA
Remixing and thin HMA overlay	5.0 to 10.5	NA
Repaving	4.0 to 10.5	NA
Cold in-place recycling and thin HMA overlay	5.0 to 7.5	NA
Profile milling	1.5 to 3.5	NA
Ultra-thin whitetopping	NA	NA

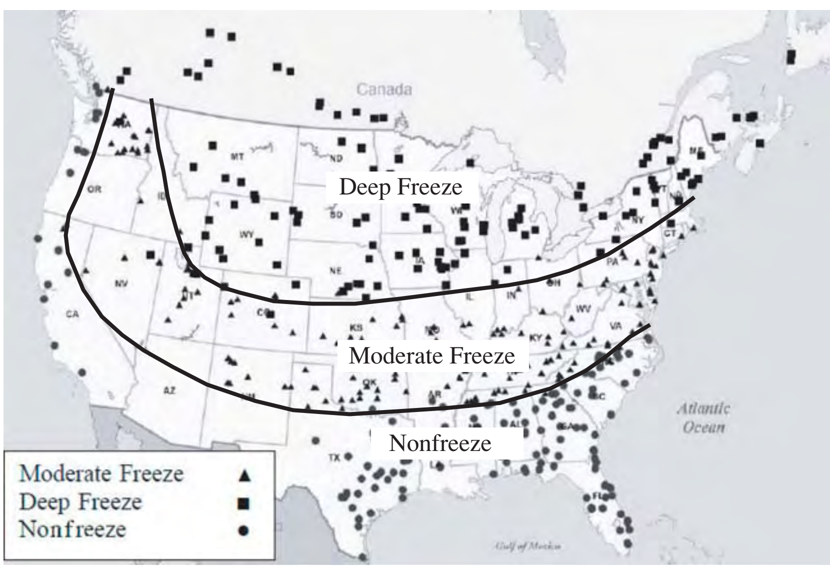
Note: NA = Not available.

Table 3.27. Expected Performance of Preservation Treatments Applied to PCC-Surfaced Pavements on High-Traffic-Volume Roadways

Treatment	Expected Performance (Treatment Life) (yr)	Expected Performance (Pavement Life Extension) (yr)
Concrete joint resealing	1.5 to 5.5	5 to 6
Concrete crack sealing	3.5 to 4.0	NA
Diamond grinding	5.5 to 7.0	NA
Diamond grooving	7.0+	NA
Partial-depth concrete patching	3.5 to 10.5	NA
Full-depth concrete patching	3.5 to 10.5	NA
Dowel bar retrofitting	7.0 to 10.5	NA
Ultra-thin bonded wearing course	4.0 to 6.5	NA
Thin HMA overlay	4.0 to 6.5	NA

treatments. Likewise, how each candidate treatment would deal with existing pavement markers and striping must be determined.

- *Availability of experienced contractors and quality materials.* Certain treatments, like microsurfacing, in-place recycling, and diamond grinding, require specialized equipment and materials that may not be locally available. Others may require a level of expertise or high-quality materials that may also not be locally available. Each candidate treatment must be evaluated for shortcomings in these regards.
- *Traffic accommodation and safety issues.* Some projects may include geometrics or other features that could be problematic from the standpoint of accommodating or controlling traffic during treatment construction. Each candidate treatment must be evaluated for shortcomings in these regards.
- *Environmental considerations.* In some agencies and for certain locations (generally urban areas), a special emphasis is placed on using construction activities that are sensitive to the environment. Techniques that involve reduced carbon emissions and recycling of materials or that fit well with pavement sustainability concepts are viewed as desirable.



Source: Adapted from Jackson and Puccinelli 2006.

Figure 3.10. Deep freeze, moderate freeze, and nonfreeze climatic regions.

Table 3.28. Recommended Time Periods for Constructing Pavement Preservation Treatments in Colorado

Asphalt Pavement Treatments	Application Timing[a]	Concrete Pavement Treatments	Application Timing[a]
Crack filling Crack sealing	Early fall	Crack sealing	Early fall
Sand seals Chip seals Microsurfacing	Elev ≥ 10,000 ft: 7/4 to 8/1 8,000 ≤ Elev < 10,000 ft: 6/15 to 8/15 6,000 ≤ Elev < 8,000 ft: 6/1 to 9/1 4,000 ≤ Elev < 6,000 ft: 5/15 to 9/1 Elev < 4,000 ft: 5/1 to 9/1	Joint resealing Diamond grinding Partial-depth repair Dowel bar retrofitting Full-depth repair	—
Ultra-thin bonded wearing course Thin HMAOL Mill and thin HMAOL	—		

Source: Galehouse 2004.
Notes: HMAOL = Hot-mix asphalt overlay; 1 ft = 0.305 m.
[a] Exclusive of weather limitations placed on treatments.

Selection of the Preferred Preservation Treatment

Cost is an important consideration in treatment selection. While the cost of a treatment does not have a direct bearing on the effectiveness of a treatment, costs are an obvious consideration in what an agency can afford. However, agencies are strongly encouraged to look beyond the first costs or treatment initial construction costs and instead consider both the life-cycle costs and the benefit of the treatment. Approaches for doing this are described in greater detail here.

Treatment Cost-Effectiveness Analysis

Cost-effectiveness analysis is an economic evaluation technique for comparing that which is sacrificed (cost) to that which is gained (performance benefit) for the purpose of evaluating alternatives (Lamptey et al. 2005). Cost-effectiveness can be measured in the short term (i.e., for one or more treatments administered at a given time) or in the long term (i.e., for several treatments carried out over an extended period of time) using analysis procedures that range from detailed and complex to less detailed and simple. In simple terms, the alternative that provides the greatest benefits for the least costs is the "best."

This section presents two approaches that can be used to evaluate the cost-effectiveness of preservation treatments. These approaches are the equivalent annual cost (EAC) and the benefit-cost ratio (BCR). EAC is simpler to conduct and requires only basic information regarding cost and performance. It measures cost-effectiveness in the short term for alternatives that are assumed to provide similar benefit (for example, a chip seal and a slurry that are both applied to improve surface texture). The second approach, BCR, requires much more data and computational effort and measures cost-effectiveness in the long term. It is appropriate for evaluating treatments that do not necessarily provide the same benefit, such as crack sealing and a chip seal.

Each approach requires reliable, up-to-date estimates of the cost and performance of the treatments to be analyzed. Historical bid prices are an excellent source for developing treatment cost estimates, but these data must be adjusted to current-day values to account for the effects of inflation. To the extent possible, care should be exercised in developing estimated costs so that they account for project-specific factors, such as size (quantity of treatment needed), site-specific surface preparation requirements (such as material removal, patching, and cleaning), special traffic control requirements, and various contingencies (e.g., striping and pavement marker removal and replacement and associated shoulder work), that may have affected the documented treatment costs. Also, to ensure a fair cost comparison of all treatment options, the final estimated costs should be based on a common unit of measure, such as $/yd^2 ($/m^2) or $/lane-mi ($/lane-km).

Obtaining meaningful estimates of treatment performance is more complicated. Ideally, these are developed using data from the PMS database and the pavement history database (if separate from the PMS database) and, more recently, from maintenance management systems. However, very few PMS databases include information on preservation treatment performance or are able to discern the issue of greatest interest: when the treatment stopped being effective. In any analysis of available data, care should be taken to ensure that the data analyzed are from projects with characteristics (e.g., existing pavement type and conditions, traffic loadings, and climatic conditions) that are similar to those of the proposed project. This is sometimes referred to as the "pavement family" concept. Although pavement survival analysis techniques (i.e., time until treatment failure or until a specific threshold condition is reached) can be used, estimates of treatment performance are more easily achieved using pavement performance modeling techniques (i.e., time-series trends of overall condition, serviceability, and individual distress development). And, since pretreatment pavement condition can have a significant impact on treatment life, the analysis should be limited to projects with pretreatment condition levels that are similar to the proposed project.

If historical performance data are not available or are insufficient for analysis, then performance information should be sought from other sources. These may include agencies that have utilized the candidate treatments in similar conditions or from practitioners knowledgeable of the performance of the candidate treatments.

Equivalent Annual Cost

The EAC method of cost-effectiveness is an inverse measure of the "bang for the buck" concept. It involves a simple calculation of the treatment unit cost (inclusive of supplemental preparation work and maintenance of traffic) divided by the expected treatment performance, as shown in Equation 1.

$$\text{EAC} = \frac{\text{Treatment Unit Cost}}{\text{Expected Performance, years}} \tag{1}$$

In this analysis method, the expected treatment performance is the extension in service life of the pavement generated by the preservation treatment. Although this extension may be easily identified as (a) the time taken for the pavement condition or serviceability/smoothness to return to the level it was at immediately prior to the treatment, a more discerning appraisal uses (b) the *difference* between the time taken for the treated pavement to deteriorate to a certain threshold level and the time taken for the untreated pavement to deteriorate to the same threshold level. Both approaches are illustrated in Figure 3.11.

Benefit-Cost Ratio

The BCR method of cost-effectiveness combines the results of individual evaluations of treatment benefits and treatment costs to generate a benefit-to-cost (B/C) ratio. The B/C ratios of alternative preservation treatments (and, if desired, a "no treatment" option) are then compared and the treatment with the highest ratio is deemed the most cost-effective. Since the analysis is performed over a long period covering the life cycle of a pavement, the costs and performance characteristics of the existing pavement (whether the original structure or the last significant rehabilitation treatment) and all future projected preservation and rehabilitation treatments associated with a given preservation strategy must be estimated.

In the BCR method, the benefits associated with a particular preservation strategy are evaluated from the standpoint of benefits accrued to the highway user over a selected analysis period (usually 25 to 40 years, beginning from the original construction). They are quantified by computing the area under the pavement performance curve, which is defined by

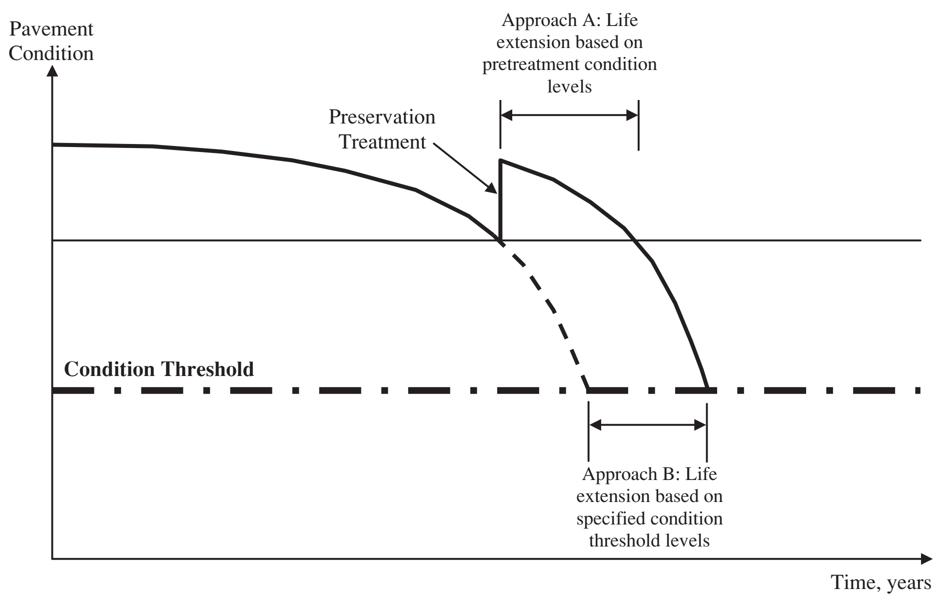


Figure 3.11. Estimation of preservation treatment life.

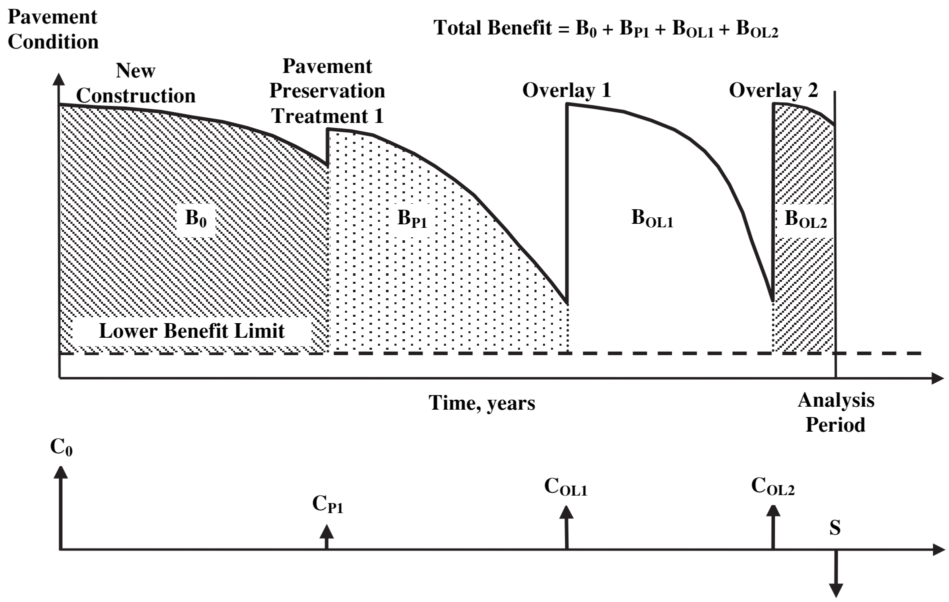


Figure 3.12. Illustration of benefits and costs associated with a pavement preservation treatment strategy.

the expected timings of future preservation and rehabilitation treatments and the corresponding jumps and subsequent deterioration in condition or serviceability/smoothness. The expected timings are determined from service life analyses of the existing pavement and the specific rehabilitation treatments, and from the service life extensions estimated for the preservation treatment.

The top portion of Figure 3.12 illustrates the assessment of benefits using the area-under-the-performance-curve approach. A treatment alternative with more area under the curve yields greater benefit through higher levels of condition or serviceability/smoothness provided to the highway users.

The costs associated with a particular preservation strategy are evaluated using life-cycle cost analysis (LCCA) techniques. The LCCA must use the same analysis period and the same timings of preservation and rehabilitation treatments as those used previously in computing benefits. A specified discount rate (typically 3% to 5%) is used to convert the costs of the future projected preservation and rehabilitation treatments (and any salvage value at the end of the analysis period) to present-day costs. These costs are then summed together with the cost of the existing pavement (again, either the original structure or the last significant rehabilitation) to generate the total life-cycle cost (expressed as net present value [NPV]) associated with the preservation strategy. The computational formula used in this process is shown in Equation 2.

$$NPV = IC + \sum_{j=1}^{k} M\&R_j \times \left[\frac{1}{1+i_{dis}}\right]^{n_j} - SV \times \left[\frac{1}{1+i_{dis}}\right]^{AP} \qquad (2)$$

where

NPV = Net present value, \$;
IC = Present cost of initial construction activity, \$;
k = Number of future preservation/rehabilitation activities;
$M\&R_j$ = Cost of jth future preservation/rehabilitation activity in terms of present costs (i.e., constant/real dollars), \$;
i_{dis} = Discount rate;
n_j = Number of years from the present of the jth future M&R activity;
SV = Salvage value, \$; and
AP = Analysis period length, years.

The bottom portion of Figure 3.12 illustrates the stream of costs included in the LCCA. These costs occur in accordance with the preservation and rehabilitation treatment timings established and used in the analysis of benefits. They represent the costs paid by the agency to construct the existing pavement and apply the subsequent preservation and rehabilitation treatments.

Although most state highway agencies have a standardized procedure for conducting LCCA, state-of-the-practice guidance has been developed and made available by the FHWA through the *Interim Technical Bulletin on LCCA in Pavement Design* (Walls and Smith 1998). A companion LCCA spreadsheet program, *RealCost,* has also been developed and is available for public use at www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm.

In the final step of the BCR method, the B/C ratio for each preservation strategy is computed by dividing the “benefit” obtained from the area-under-the-performance-curve analysis by the “cost” obtained from the LCCA:

$$B/C = \text{Benefit}/\text{NPV} \tag{3}$$

As stated previously, the treatment with the highest B/C ratio is deemed the most cost-effective.

Treatment Costs

Although treatment costs do not affect treatment performance, certain cost considerations are inevitably a crucial part of the treatment selection process. The costs of interest are (a) the direct costs incurred by the highway agency as a result of constructing the treatment and (b) the indirect costs borne by the highway users as a result of the disruptions created by treatment construction work zones.

Direct Agency Costs

The direct agency costs primarily consist of the in-place cost of the treatment (typically, the product of the awarded contractor’s unit cost for the treatment and the estimated treatment quantity, supplemented by surface preparation costs and maintenance of traffic costs). In some instances, a percentage of this cost (5% to 10%) may be added to reflect the engineering (design and construction), administrative, and traffic control costs anticipated with the treatment’s construction.

Treatment unit costs depend on several factors, the most notable of which include the size and location of the project, severity and quantity of distresses, and the quality of a treatment’s constituent materials. In this study, unit cost information was gleaned from the literature to serve as a general resource in the absence of agency estimates derived from historical bid tabulations. Tables 3.29 and 3.30 show the unit costs obtained for treatments applied to HMA- and PCC-surfaced roadways, respectively, along with a relative cost indicator. The costs represent the in-place costs of the treatments, exclusive of traffic control costs and any associated surface preparation costs.

The use of these relative or comparative costs is introduced because the recent volatility of materials prices, as well as variations in prices by region, project location, contractor availability, project size, and so on highlight the perils of reporting costs that will most certainly change. What is less likely to change is the comparative relationship between these costs, although even that is not an absolute.

Indirect User Costs

User costs are defined as nonagency costs that are borne by the users of a pavement facility (Peshkin et al. 2004). User

Table 3.29. Estimated and Relative Treatment Costs for Preservation Treatments on HMA-Surfaced Pavements

Treatment	Relative Cost ($ to $$$$)	Estimated Unit Cost
Crack filling	$	$0.10 to $1.20/ft
Crack sealing	$	$0.75 to $1.50/ft
Slurry seal	$$	$0.75 to $1.00/yd²
Microsurfacing (single course)	$$	$1.50 to $3.00/yd²
Chip seal (single course)	$$ (conventional) $$$ (polymer modified)	$1.50 to $2.00/yd² (conventional) $2.00 to $4.00/yd² (polymer modified)
Ultra-thin bonded wearing course	$$$	$4.00 to $6.00/yd²
Thin HMA overlay (dense graded)	$$$	$3.00 to $6.00/yd²
Cold milling and thin HMA overlay	$$$	$5.00 to $10.00/yd²
Ultra-thin HMA overlay	$$	$2.00 to $3.00/yd²
Hot in-place recycling (excluding thin HMA overlay for surface recycle and remixing types)	$$/$$$	$2.00 to $7.00/yd²
Cold in-place recycling (excluding thin HMA overlay)	$$	$1.25 to $3.00/yd²
Profile milling	$	$0.35 to $0.75/yd²
Ultra-thin whitetopping	$$$$	$15.00 to $25.00/yd²

Note: $ = low cost; $$ = moderate cost; $$$ = high cost; $$$$ = very high cost.

Table 3.30. Estimated and Relative Treatment Costs for Preservation Treatments on PCC-Surfaced Pavements

Treatment	Relative Cost ($ to $$$$)	Estimated Unit Cost
Joint resealing	$	$1.00 to $2.50/ft
Crack sealing	$	$0.75 to $2.00/ft
Diamond grinding	$$	$1.75 to $5.50/yd^2
Diamond grooving	$$	$1.25 to $3.00/yd^2
Partial-depth patching	$$/$$$	$75 to $150/yd^2 (patched area) (equivalent $2.25 to $4.50/yd^2, based on 3% surface area patched)
Full-depth patching	$$/$$$	$75 to $150/yd^2 (patched area) (equivalent $2.25 to $4.50/yd^2, based on 3% surface area patched)
Dowel bar retrofit	$$$	$25 to $35/bar (equivalent $3.75 to $5.25/yd^2, based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft)
Ultra-thin bonded wearing course	$$$	$4.00 to $6.00/yd^2
Thin HMA overlay	$$$	$3.00 to $6.00/yd^2

Note: $ = low cost; $$ = moderate cost; $$$ = high cost; $$$$ = very high cost.

costs are incurred through various mechanisms and at any time over the life of a project. Overall, there are five primary mechanisms of user costs:

- *Time-delay costs.* Opportunity costs incurred as a result of additional time spent completing a journey because of work zones (i.e., lane restrictions, road closures) associated with construction, maintenance, or rehabilitation activities. The opportunity cost represents the value associated with other activities that cannot be completed because of the extra time that is normally spent completing a journey.
- *Vehicle operating costs (VOCs).* Costs associated with fuel and oil consumption, tire wear, emissions, maintenance and repair, and depreciation due to work zone traffic flow disruptions or significantly rough roads. VOCs typically involve the out-of-pocket expenses associated with owning, operating, and maintaining a vehicle.
- *Crash costs.* Costs associated with additional crashes brought about by work zones or by rough or slippery roads. Crash costs are primarily composed of the costs of human fatalities, nonfatal injuries, and accompanying property damage.
- *Discomfort costs.* Costs associated with driving in congested traffic or on rough roads.
- *Environmental costs.* Costs associated with traffic noise and with the operation of work zone construction equipment.

Additionally, user costs can be incurred during the establishment of a work zone or during normal (nonrestricted) highway operating conditions:

- *Work zone costs.* This category of user costs deals with costs brought about by the establishment of a work zone. A work zone is defined as an area of a highway where maintenance, rehabilitation, or construction operations are taking place that impinge on the number of lanes available to moving traffic or affect the operational characteristics of traffic flowing through the area (Walls and Smith 1998). A work zone disrupts normal traffic flow, drastically reduces the capacity of the roadway, and leads to specific changes in roadway use patterns that affect the nature of user costs.
- *Normal operating condition costs.* In between work zone periods, user costs are still incurred during normal operating conditions. These include highway user costs associated with using a facility during periods free of construction, repair, rehabilitation, or any work zone activity that restricts the capacity of the facility.

The inclusion of user costs as part of any economic analysis of pavements is a controversial issue. Less than a quarter of the survey respondents reported that they account for user costs when evaluating preservation treatments. However, on high-traffic-volume roadways, user costs can represent a significant portion of the total cost.

Current FHWA-recommended practice is to consider including in the economic analysis only the time-delay and VOC components associated with work zones. These components can be estimated reasonably well and make up a large portion of the total user costs. Other work zone user cost components are either too difficult to collect and reasonably quantify or do not factor to an appreciable amount. Further, for most pavement facilities in fair or good condition (e.g., pavements with a PSR of 2.5 or greater), user costs during normal operating conditions are minimal (Peshkin et al. 2004).

For projects in which time-delay and VOC user costs are likely to occur as a result of performing preservation or rehabilitation activities, consideration should be given to evaluating these costs as part of the selected cost-effectiveness analysis method. Detailed procedures for computing them are provided in the FHWA's *Interim Technical Bulletin on LCCA in Pavement Design* (Walls and Smith 1998), and the *RealCost* spreadsheet program can be used to perform the computations. A somewhat simplified approach for computing work zone time-delay costs is presented in *NCHRP Report 523* (Peshkin et al. 2004). The *OPTime* spreadsheet program developed as part of that study on optimal timing of PM can be used to perform the computations. The following are brief descriptions of how user costs can be incorporated into the EAC and BCR methods of cost-effectiveness analysis:

- In the EAC method, two aspects of user costs can be considered. The first aspect is the work zone user costs associated with each alternative preservation treatment. Since the work zone characteristics of each alternative will vary based on application rates, material setting and curing times, and other construction factors, the delays experienced as a result of the different work zone requirements will also vary.
- The second aspect is the work zone user costs associated with the timing of an assumed future rehabilitation at the end of the preservation treatment's expected life. A preservation treatment with a longer forecasted life results in a delay in the timing of the assumed rehabilitation. When discounted to present-day costs, the work zone user costs associated with the rehabilitation will be lower than the same rehabilitation work zone user costs associated with a shorter-life preservation treatment. This is illustrated in Figure 3.13.
- In the BCR method, the user costs of all future preservation and rehabilitation treatments associated with each preservation strategy can be computed as part of the LCCA. Although the user cost NPV results may be combined with the agency cost NPV results, it is generally recommended that they be examined separately because of the possibility that they will overwhelm the agency costs.

Evaluation of Economic and Noneconomic Factors

Although treatment cost-effectiveness is a major consideration in the selection of the preferred treatment, it is not the final answer in the process. The reality of the decision process is

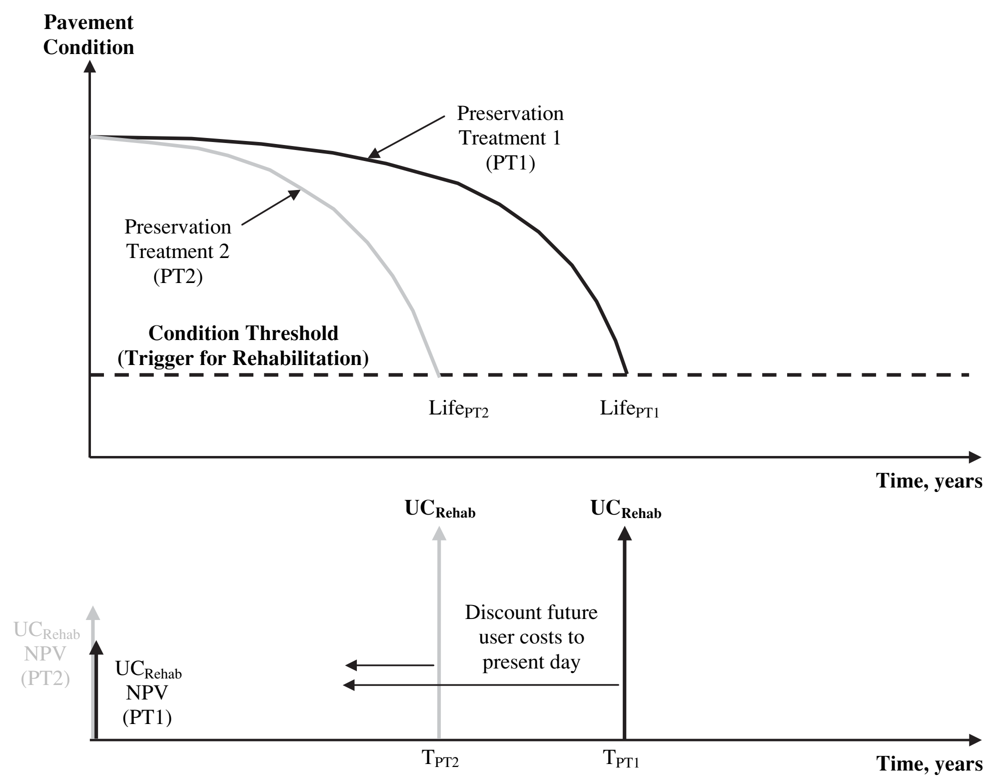


Figure 3.13. Effect of preservation treatment life on discounted rehabilitation user costs.

that many other factors (economic and noneconomic) must be considered along with cost-effectiveness. Some of these factors may have been previously considered as part of the steps to identify feasible treatments, yet may also be desired for consideration in the final selection. Examples include the availability of qualified (and properly equipped) contractors and quality materials, the anticipated level of traffic disruption, and surface characteristics issues.

Upon completion of the cost-effectiveness analysis, it may be desirable to eliminate certain treatment alternatives on the basis of not being able to meet key financial goals. Such elimination criteria might include the following:

- Substantially lower cost-effectiveness compared with other treatment alternatives (e.g., EAC greater than 10% higher than the EACs of the alternatives, B/C ratios greater than 10% less than the ratios of the alternatives);
- Initial cost greater than available funding, resulting in negative impact on network-level budgeting; and
- Excessive user costs that would have serious negative impact on roadway users.

Alternatively, these economic factors can be combined with several noneconomic factors, as described below.

A useful mechanism to systematically and rationally evaluate the different factors and identify the preferred treatment is a treatment decision matrix. In a treatment decision matrix, various selection factors are identified for consideration and each factor is assigned a weight. The weights are then multiplied by rating scores given to each treatment alternative, based on how well the treatment satisfies each of the selection factors. The weighted scores of each treatment alternative are then summed and compared with the weighted scores of the other treatments. The treatment with the highest score is then recognized as the preferred treatment.

A fairly complete list of factors that are appropriate for inclusion in the final selection process follows. The factors are grouped according to different attributes, which can also be assigned weights as part of a decision matrix:

- Economic attributes:
  - Initial cost;
  - Cost-effectiveness (EAC or BCR);
  - Agency cost; and
  - User cost.
- Construction/materials attributes:
  - Availability of qualified (and properly equipped) contractors;
  - Availability of quality materials;
  - Conservation of materials/energy; and
  - Weather limitations.
- Customer satisfaction attributes:
  - Traffic disruption;
  - Safety issues (friction, splash/spray, reflectivity/visibility); and
  - Ride quality and noise issues.
- Agency policy/preference attributes:
  - Continuity of adjacent pavements;
  - Continuity of adjacent lanes; and
  - Local preference.

A decision matrix that incorporates these factors and illustrates the assignment of weights and the basis for rating scores is provided in Table 3.31.

Table 3.31. Example of Preservation Treatment Decision Matrix

Attribute and Selection Factor	Attribute Weight	Factor Weight	Combined Weight	Treatment 1 Rating Score	Treatment 1 Weighted Score	Treatment 2 Rating Score	Treatment 2 Weighted Score
Economic	40						
Initial cost		30	12.0				
Cost-effectiveness		30	12.0				
Agency cost		10	4.0				
User cost		30	12.0				
Total		100					
Construction/materials	25						
Availability of qualified contractors		20	5.0				
Availability of quality materials		20	5.0				
Conservation of materials/energy		30	7.5				
Weather limitations		30	7.5				
Total		100					
Customer satisfaction	25						
Traffic disruption		40	10.0				
Safety issues		40	10.0				
Ride quality and noise issues		20	5.0				
Total		100					
Agency policy/preference	10						
Continuity of adjacent pavements		20	2.0				
Continuity of adjacent lanes		20	2.0				
Local preference		60	6.0				
Total		100					
			Cumulative Weighted Score				

Note: Basis for treatment rating scores (1-to-5 scale); initial cost: 1 = highest, 5=lowest; cost-effectiveness: 1 = least cost effective, 5 = most cost-effective; agency cost: 1 = highest, 5 = lowest; user cost: 1 = highest, 5 = lowest; availability of qualified contractors: 1 = low/none, 5 = high; availability of quality materials: 1 = low/none, 5 = high; conservation of materials/energy: 1 = low, 5 = high; weather limitations: 1 = major, 5 = low/none; traffic disruption: 1 = major, 5 = low/none; safety issues: 1 = serious, 5 = none; ride quality and noise issues: 1 = serious, 5 = none; continuity of adjacent pavements: 1 = does not match at either end, 5 = matches at both ends; continuity of adjacent lanes: 1 = does not match, 5 = matches; local preference: 1 = inconsistent with preference, 5 = consistent with preference.

CHAPTER 4

Implementation of Preservation Guidelines

This chapter discusses how the pavement preservation guidelines developed in this study and presented in *Guidelines for the Preservation of High-Traffic-Volume Roadways* can be successfully implemented within a highway agency's existing program for managing and maintaining pavements. It also describes several potentially significant barriers to putting the guidelines into practice and offers suggestions for overcoming these barriers.

Barriers to Implementation

Like so many other paradigm shifts that have taken place over the years in highways agencies, there are sure to be a variety of institutional and external issues that will hinder implementation of the preservation guidelines developed in this study. These issues are to be expected when a new process or a new way of thinking leads to substantive changes in an agency's policies and practices.

One of the most significant barriers that can be expected is the resistance to allowing the use of preservation treatments traditionally linked to lower-volume roadways, such as microsurfacing and chip seals, on higher-volume roads. There will certainly be skepticism that certain preservation treatments are not durable enough for use on high-volume roads, particularly those in severe climates. Furthermore, for those agencies still in the early stages of developing a general preservation program, in order to minimize risk they may choose to focus on lower-volume road applications. Although a few agencies might be inclined to immediately expand the scope of their program to higher-volume applications, the preference of most would be to first develop rational, proven practices at the lower traffic volumes and then gradually adapt those practices to higher-traffic-volume facilities. Hence, use of the preservation guidelines developed in this study may be perceived as premature.

Another major barrier is the ability of the highway agency to persuade elected government officials—and ultimately the traveling public—of the net positive benefits of applying preservation treatments on high-traffic-volume roadways. Justifying the importance of performing preservation work on lower-volume roadways in good condition has been difficult enough over the past several years. Convincing government officials and the traveling public of the need to perform work on good roads that are used by much higher percentages of the population can be expected to be even more difficult.

A third major barrier involves marketplace pressures that are bound to be applied by affected industry groups. On one side of the highway construction aisle (i.e., suppliers of traditional rehabilitation materials), there will be significant resistance to a shift from worst-first to best-first because of the potential loss of market share. On the other side of the aisle (suppliers of various preservation treatment materials), there will be pressure to move more aggressively to preservation because of the potential gain in market share.

Several other specific institutional barriers are likely to be encountered. These include the following:

- *Inadequate database for assessing preservation treatment best practices and cost-effectiveness.* Many of today's pavement preservation programs have been challenged by the lack of good quality data upon which to base its precepts. As a result, engineering judgment and experience are the primary basis for decision making, making the program more subjective and oriented toward traditional practices. While it is generally the case that pavement data are more complete and accurate for higher-traffic-volume roads than for lower-volume roads, every database has issues and these issues will likely have to be dealt with to some degree during the implementation process.
- *Greater perception of risk.* Over the years, many highway agencies have developed and continually refined their pavement preservation activities and procedures. They have experienced both successes and failures along the

way. In most cases, the initial proving grounds for preservation activities have been on lower-volume roadways where, if a premature failure occurred, the consequences beyond the monetary aspects were not tremendously serious. Application of preservation treatments on higher-volume roads yields the same kinds of uncertainties to inexperienced agencies as it did to those agencies that long ago started using preservation techniques on lower-volume roads. However, because the activities will now be performed on higher-type facilities, the consequences of premature failure will be much more serious. Not only will a failure be visible to a much higher percentage of the traveling public (who will then complain about the waste of taxpayer funds), but the traveling public will be affected by the delays and congestion associated with fixing the failure. Thus, agencies will perceive a much greater risk of implementing preservation activities on high-traffic-volume roads.

- *Heightened battles for dedicated funding of preservation activities.* Although several states have made significant progress over the years in establishing dedicated funding for preservation activities, the overwhelming amount of transportation infrastructure money is earmarked for capital improvement projects. The main difficulty lies in the agency's reluctance to treat good pavements while a backlog of significantly deteriorated pavements exists (Zimmerman and Peshkin 2006). If the preservation program is expanded to include more high-traffic-volume applications, an even greater reluctance may be expected because the projects will be on roads with higher risk and greater scrutiny.
- *Lack of experienced individuals to champion and direct the development of a high-traffic-volume roadway preservation program.* As has been the case with the development of several current preservation programs, the lack of experienced pavement management, maintenance, design, materials, and construction personnel can be a significant barrier to implementation.
- *Complexity in assessing treatment performance and cost-effectiveness.* Evaluating and determining treatment performance is not an easy task, considering that there are different ways in which performance can be evaluated (many performance indicators, various performance analysis techniques) and there are a number of factors that affect performance (existing pavement type and condition, traffic level, climatic conditions, construction/materials quality, and so on).

  Cost-effectiveness analysis can also be complex. Both the EAC and BCR approaches require the development of reliable unit cost data to go along with the treatment performance data. Although EAC is a simplified approach, the added importance of evaluating user costs for high-traffic-volume facilities can complicate or prolong the analysis. Furthermore, the inclusion of user costs in either analysis approach requires special judgment in weighing them against the computed agency costs.

Keys to Implementation

Although there are several potential barriers to implementation of the preservation guidelines, there are also actions that can be taken to either eliminate the barrier altogether or lessen its impact on implementation. Depending on the issue, these actions or measures may either need to take place at specific times in the implementation process or throughout the entire process.

Issue 1: Resistance to Allowing the Use of Lower-Volume Preservation Treatments on Higher-Volume Roads

Overcoming skepticism and doubt about the benefits and importance of pavement preservation is an ongoing and long-term issue that must rely on documented evidence and verified proof. Overcoming skepticism about the durability and performance of preservation treatments applied to high-volume roads requires the same tactic, and it begins with (a) showing the successes of treatments applied in the past within the state or in a neighboring state having similar conditions and (b) pressing for research studies that will provide opportunities for demonstrating preservation treatment effectiveness and cost-effectiveness.

Issue 2: Ability to Convince the Traveling Public of the Benefits and Importance of Preserving High-Traffic-Volume Roads

As noted by Galehouse et al. (2003), most of the public understands the importance of maintaining a car or a house to prevent major repairs. Pavement preservation engineers should be able to explain the value of preservation treatments now, compared with the cost of major repairs later. Also, since preservation activities do entail work zones that disrupt traffic and present safety hazards, preservation engineers must also be able to document and communicate the trade-offs between shorter work zone durations now versus much longer ones in the future.

Issue 3: Marketplace Pressures

Like the persistent debates between highway agencies and the two major pavement industry groups regarding pavement type selection, it is important to have documented performance and cost information that can help justify or support a change in pavement treatment policy. A thorough understanding of all the issues surrounding the performance and cost data is often just as crucial. In cases where performance and cost data are limited, a more incremental implementation approach, such as construction and monitoring of research test sections, may be warranted.

Issue 4: Database Inadequacies

A key tool in establishing sound preservation practices is a reliable database containing complete and accurate pavement history, construction/materials, performance, and cost information. Information from a reliable database can be used to quantify the benefits of preservation on high-traffic-volume facilities, which can help overcome skepticism and gain buy-in to the process. It can also be used to analyze the adequacy of treatment designs and the quality of treatment construction, so that improvements to the processes can be made that enhance performance. Further, it can be used to evaluate treatment performance and cost-effectiveness, so that the treatment-selection process is benefited. If the agency's practices associated with monitoring treatment placement and performance are not adequate for achieving these purposes, then the deficiencies and shortcomings should be identified early on so that steps can be taken to improve the database or alternative sources of data can be sought.

Issue 5: Greater Perception of Risk

Besides a gradual approach to implementing preservation activities on roadways with higher and higher traffic levels, the highway agency can do at least two things to minimize risk. First, it should be selective in the types of projects chosen for preservation and the type of treatment to be used. In trying to get "the right treatment on the right pavement at the right time," special attention must be placed on selecting the right pavement (and time). Second, the highway agency should commit all additional available resources toward conducting a proper design of the treatment, performing the necessary quality tests, and overseeing the construction workmanship. These activities will give the treatment the best possible chance of performing successfully and reducing the likelihood of premature failure.

Issue 6: Heightened Battles for Dedicated Funding

As is often the case with the development of pavement preservation programs, gaining the commitment of top-level management is vital to the successful implementation of preservation guidelines for high-traffic-volume roads. This commitment should include not only dedicated funding of preservation projects but also the resources needed to collect information on the effectiveness of preservation treatments (Galehouse et al. 2003).

Issue 7: Lack of Experienced Individual(s) to Champion Preservation

Like any new effort or program within an agency, the implementation of preservation guidelines for high-traffic-volume roads requires a champion or group of champions. This individual or group not only is instrumental in addressing the many technical issues surrounding the use of different preservation treatments but can also be a powerful voice for creating opportunities for preservation techniques at various management levels, including the districts. Ideally, the champion or champions will consist of the individual(s) responsible for championing the general preservation program. If this individual(s) is not interested or available, then alternatives must be explored, focusing on someone with a passion for, and substantial experience in, pavement preservation and preservation-related issues.

Issue 8: Complexity in Assessing Treatment Performance and Cost-Effectiveness

To the individual(s) directly involved in implementing the preservation guidelines, the task of assessing treatment performance and cost-effectiveness can seem daunting. However, by identifying champions in other areas of the agency, such as the pavement management group or the construction/materials group, the burden of performing these tasks can be lessened. This is because the champions can identify and delegate the right people to do the job (i.e., personnel who analyze performance or cost-effectiveness on a daily basis).

CHAPTER 5

Conclusions and Recommendations

The research described in this report was part of the SHRP 2 Renewal focus area, which addresses the need to complete long-lasting highway projects in a quick fashion with minimal disruption to the traveling public. The research focused on developing guidelines for the selection of preservation treatments for HMA- and PCC-surfaced pavements located on high-traffic-volume roadways. Key work activities included the following:

- An extensive search and review of literature relevant to preservation practices in the United States and abroad;
- A detailed questionnaire survey of highway agency preservation practices;
- Detailed analysis of the project literature information and questionnaire survey results;
- Identification of the current state of the practice for preserving high-traffic-volume roadways;
- Development of criteria for identifying successful or potentially successful preservation techniques; and
- Development of detailed guidelines for preservation strategies for high-traffic-volume roadways, including procedures for identifying feasible treatment options at the project level, evaluating their cost-effectiveness, and selecting the preferred treatment based on various economic and noneconomic factors.

Conclusions

The following are the major conclusions of the study:

- *High-traffic-volume definition.* Based on the results of the preservation survey, it was found that highway agencies use different ADT criteria for classifying roadways as high volume. Moreover, in some agencies, the same classification criteria are applied to roads in rural and urban settings, whereas in other agencies, different criteria are used for roads in the two settings. To more accurately determine the types of treatments used on rural and urban high-traffic-volume roads, an analysis of the ADT classification criteria was performed, which resulted in the following definitions of high traffic volume: ADT ≥ 5,000 vpd for rural roadways and ADT ≥ 10,000 vpd for urban roadways. Although it is recognized that there will be agencies that find these limits to be too high or too low, the limits represent median values and can serve as a benchmark for future evaluations of preservation performance.
- *Preservation treatment options.* A variety of treatments exist for preserving HMA- and PCC-surfaced pavements. Many of these treatments are already being used successfully on high-traffic-volume routes. Some treatments, such as fog seals and sand seals, are considered inappropriate for use on high-traffic-volume facilities. Others, such as slurry seals and chip seals, are deemed appropriate by some and inappropriate by others. Still other treatments, such as crack sealing and joint resealing, are widely considered to be appropriate for use on high-traffic-volume roads. Highway agency practices, as determined through the preservation survey, indicate considerable use (≥20% of respondents) of 12 basic treatment types for high-volume, HMA-surfaced pavements and seven basic treatment types for high-volume, PCC-surfaced pavements. Some of these treatments can be further subdivided on the basis of variations in material components and construction processes. In any case, there is a variety of available treatments that are successfully being used in the preservation of high-traffic-volume roadways, and the list is constantly being expanded by the development and application of new products.
- *Preservation treatment functions.* Pavement preservation treatments may be applied for two general purposes or functions: (1) prevention (or delay) of pavement distress development or slowing the development of existing distress and (2) restoration of functionality and serviceability of the pavement or improvement of its surface characteristics. To be effective, treatments must be matched with pavement

distress types through an evaluation of treatment functions and distress causes and factors. This is especially important for higher-traffic-volume roadways, which many agencies have historically managed with structural enhancements rather than preservation.

- *Preservation treatment selection process.* At the project level, the selection of treatments for high-traffic-volume roadways requires consideration and evaluation of many factors. A logical process for considering these factors begins with an assessment of the condition of the existing pavement and then progresses to an assessment of project needs and constraints. Following an evaluation of cost-effectiveness, it concludes with an assessment of both economic and noneconomic factors. On high-traffic-volume roadways, constraints, such as limited access times, and noneconomic costs, such as user delays, play a more significant role in the treatment selection process.
- *Consideration of pavement condition in treatment selection.* To identify an initial list of feasible preservation treatments, begin by evaluating the current and historical condition of the existing pavement. The goal is to determine the types, severities, and extents of distresses and their rates of development as well as their probable causes. In this manner, treatments can be matched with pavement distress types through an evaluation of treatment functions and distress causes and factors. With their higher traffic volumes and loadings, deterioration rates and failure modes are not the same as for lower-traffic-volume roadways, and it should also be expected that treatment windows may be different. Decision support matrixes are a useful tool for identifying feasible treatments based on detailed pavement condition. Two decision support matrixes—one for HMA-surfaced pavements and one for PCC-surfaced pavements—were developed in this study and are featured in *Guidelines for the Preservation of High-Traffic-Volume Roadways.* As a supplemental evaluation tool, the current and historical overall condition, serviceability, or roughness of a pavement can be tracked and compared with condition-based windows of opportunity previously established for each preservation treatment.
- *Consideration of project performance needs.* When selecting a preservation treatment at the project level, the performance capabilities of the candidate treatments must be examined with respect to an established performance target or requirement. Treatment performance is best measured in terms of the extension in service life imparted to the existing pavement by the preservation treatment. Investigation into the expected performance of several preservation treatments resulted in the identification of various performance ranges corresponding to a general application covering all traffic levels. Adjustments to these ranges were made to reflect the adverse impact of high traffic volumes on treatment durability and performance. The effects of existing pavement condition and climatic condition must also be taken into account when estimating treatment performance, as various studies have shown that small to moderate reductions in performance can be expected when
  - Existing pavement condition is rated in the "fair" category rather than the "satisfactory/good" category; and
  - Climate is more characteristic of a freezing climate than a nonfreezing one, with significant snow and ice removal operations necessary for winter precipitation events.

  It is also recognized that the acceptance of relatively frequent applications of short-lived preservation treatments can be problematic on higher-traffic-volume roadways.
- *Consideration of project construction constraints.* Candidate preservation treatments must also be evaluated for their ability to satisfy any specific construction constraints. Potential constraints include available project funds, the anticipated or targeted time frame (time of year) for construction, work zone duration restrictions, roadway geometrics, the availability of experienced contractors and quality materials, and traffic accommodation and safety issues. Of these, from an agency's viewpoint, work zone duration and traffic accommodation and safety issues are more critical factors on the higher-traffic-volume roadways. However, the contractor can also contribute to a successful project by making sure that he is using a skilled crew and that QC practices are followed.
- *Evaluation of treatment cost-effectiveness.* Cost-effectiveness analysis is an economic evaluation technique for comparing that which is sacrificed (cost) to that which is gained (performance benefit) for the purpose of evaluating alternatives. Two approaches for evaluating the cost-effectiveness of preservation treatments are identified in this study: equivalent annual cost (EAC) and benefit-cost ratio (BCR). EAC is a simpler approach that involves dividing the treatment unit cost by the expected treatment performance. BCR is a more detailed approach that involves calculating the long-term benefit of a treatment (using area under the pavement performance curve) and the life-cycle cost of the treatment, and dividing the former by the latter. Good unit cost and performance information for the alternative treatments are critical to each analysis technique. Moreover, because the analysis is focused on preservation of high-traffic-volume facilities, greater consideration should be given to evaluating user costs.
- *Evaluation of economic and noneconomic factors.* Although treatment cost-effectiveness is a major consideration in the selection of the preferred treatment, the reality is that several other factors are important to the decision-making process. A treatment decision matrix is an excellent way of rationally and systematically evaluating the different economic and noneconomic factors. It allows an analyst to weight the importance of the different factors, score the alternative treatments on each factor, and then generate overall scores using the individual factor weights and scores.

- *Implementation of preservation guidelines.* The preservation guidelines developed in this study are a useful tool for highway agencies to identify candidate high-volume roadways suitable for pavement preservation and to select appropriate pavement preservation treatments. A wealth of information is included in the guidelines regarding the applicability and limitations of the various pavement preservation treatments and the process by which preservation treatments should be evaluated for selection at the project level. Agencies interested in implementing the guidelines can expect to encounter a variety of issues that may hinder the implementation process. The most significant barriers entail institutional resistance to the use of certain treatments on high-volume roads, the ability to convince elected government officials and the traveling public of the importance of preserving good roads while some bad roads go untouched, and the external tug-of-war between competing pavement industry groups. Furthermore, because of their nature, a single failure on a higher-traffic-volume roadway can offset one hundred successes. At the roadway level, implementation is advanced by monitoring and documenting the benefits of preservation. At the organizational level, experienced individuals within the agency championing the preservation program also play an important role in implementation.

One of the objectives of this project was to identify promising strategies or strategies that are not widely used that have the potential to be effective preservation treatments. These did not readily emerge from the literature review, outreach to industry and overseas contacts, or the surveys of agency practice. However, the collected information clearly identifies some treatments that are used on high-traffic-volume roadways by some agencies that others would not consider using. Agencies interested in extending their practice in many cases need look no further than the accepted practice of others.

Recommendations

Although an enormous amount of information on pavement preservation and preservation-related topics was gathered and analyzed in this study, there are still technical gaps in the treatment selection process that need to be addressed. Provided below is a list of the most pressing issues and recommendations for addressing them in the future.

- *Develop a more comprehensive treatment-condition matching matrix.* Such a matrix might use applicability ratings (1-to-5 scale, with 1 being nonapplicable, 3 being generally applicable, and 5 being very applicable) that define how well a treatment addresses specific distress measures (i.e., a given distress type, severity level, and extent) and other condition parameters (i.e., overall condition, smoothness, friction, noise, and splash-spray). It would also use a weighting process to aggregate the individual applicability ratings for each treatment into an overall score. The overall scores of the treatments could be examined to identify feasible treatments—those with scores greater than or equal to a weighted 3.
- *Develop improved estimates of treatment performance on high-traffic-volume roadways.* The expected performance ranges developed in this study are derived from estimates provided in the literature. Some estimates represent treatment life, while others represent extensions in pavement service life. As mentioned throughout this report, the appropriate representation of treatment performance is the extension in pavement service life. While it will be incumbent upon an implementing agency to establish its own estimates of treatment performance, the performance ranges presented in this report need to be improved by incorporating pavement life extension data as it becomes available.
- *Investigate more fully the impact of pavement condition, traffic level, and climatic condition on treatment performance.* Although implementing agencies will be tasked with evaluating and developing quantified estimates of treatment performance for different pavement conditions, traffic levels, and climate conditions, further research is needed at the national level, along the lines of the LTPP SPS-3 and SPS-4 studies. Such research should include more treatment types (including little-used but promising treatments and new or innovative treatments), cover the various climatic zones, and stratify according to specific pavement type (e.g., composite vs. flexible, jointed vs. continuous), different ranges of high traffic volume (e.g., 5,000 to 25,000 vpd, 25,000 to 50,000 vpd, $\geq$ 50,000 vpd), highway setting (urban vs. rural), and overall pavement condition (e.g., $65 \leq PCR < 75$, $75 \leq PCR < 85$, $PCR \geq 85$) or serviceability/roughness.
- *Develop improved estimates of treatment unit costs.* The treatment unit cost ranges provided are based on cost information contained in the literature. The cost ranges have been adjusted upward slightly, because the source data are a few years old. Although costs vary significantly from agency to agency and from project to project, a detailed evaluation of current costs would provide a better sense of the relative costs among treatments and would better capture the effects of increased oil prices in recent years.

It is noted that the conclusions and recommendations presented herein in many ways mirror the pavement preservation research needs priorities identified in the FHWA's system preservation road map (FHWA 2008). While the problem statements in that document are not specifically aimed at preservation for high-traffic-volume roadways, the mix of topics identified as the highest priority are similar to needs identified in this research. It is reasonable to conclude that as the research needs identified in the road map are addressed, and if attention is paid in particular to high-traffic-volume roadways as considered in this research, then the practice of preservation on high-traffic-volume roadways will continue to advance.

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Glossary

AADT. The average annual daily traffic, expressed as the 24-hour traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location. AADT can also be approximated by adjusting the ADT count for daily (weekday versus weekend) and seasonal (summer versus winter) variations.

AADTT. The average annual daily truck traffic, expressed as the 24-hour truck traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location. ADTT may be expressed as a percentage of ADT.

ADT. The average daily traffic, expressed as the 24-hour traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location.

alligator cracking. Cracking of a hot-mix asphalt (HMA) roadway surface caused by fatigue failure of the HMA surface under repeated traffic loading. The cracks form many-sided, sharp-angled pieces that develop a pattern similar to the skin of an alligator.

alternatives. Available choices or courses of action (e.g., alternative pavement types or rehabilitation or preservation treatment types) that can be considered at each stage of resource allocation or utilization.

asphalt cement. A bituminous material often used as a binder with aggregate to form a cold- or hot-applied paving material.

asphalt concrete. See *hot-mix asphalt.*

asphalt emulsion. A mixture of asphalt cement, water, and an emulsifying agent used in pavement construction and maintenance.

base. The layer of material immediately beneath the pavement surface or binder course.

benefit-cost. A comparison analysis of the economic benefit of an investment to its cost. The benefit-cost analysis should include all costs and benefits to both the agency and the users of the facility over an appropriate life-cycle period. In asset management, benefit-cost can be applied for prioritizing projects, evaluation of the benefits and costs for all projects in a program, and determination of program trade-offs.

binder. An adhesive composition of asphalt cement, modified asphalt cement, or other bituminous materials, which is primarily responsible for binding aggregate particles together. Also used to refer to the layer of HMA directly below the surface course (i.e., binder course).

block cracking. Cracking of a roadway surface caused by shrinkage of the asphalt concrete and daily temperature cycling, usually developing in a block-shaped pattern.

cape seal. A surface treatment that involves the application of a slurry seal to a newly constructed chip seal. Cape seals are used to provide a dense, waterproof surface with improved skid resistance.

chip seal. A surface treatment in which a pavement surface is sprayed with asphalt (generally emulsified) and then immediately covered with aggregate and rolled. Chip seals are used primarily to seal the surface of a pavement with non-load-associated cracks and to improve surface friction (skid resistance). Also referred to as *seal coat.*

cold in-place recycling (CIR). A process in which a portion of an existing bituminous pavement is pulverized or milled, the reclaimed material is mixed with new binder and new materials, and the resultant blend is placed as a base for a subsequent overlay.

cold milling. A process of removing pavement material from the surface of the pavement either to prepare the surface to receive overlays (by removing rutting and surface irregularities), to restore pavement cross slopes and profile, or to reestablish the pavement's surface friction characteristics.

condition. Measure of the physical state of an asset as affected by deterioration and past maintenance and repair.

condition index. A numeric score determined from pavement condition data and used to represent the performance of the pavement.

corrective maintenance. Maintenance activities performed in response to the development of a deficiency or deficiencies that negatively affect the safe, efficient operations of a facility and future integrity of pavement sections. Corrective maintenance (sometimes referred to as reactionary maintenance) is usually performed to fix a localized defect or defects that arise from unforeseen conditions and restore a pavement to an acceptable level of service.

crack filling. A maintenance procedure that involves placement of materials into nonworking cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement. Nonworking cracks are defined as those that experience horizontal movements less than about 2 mm (0.1 in.).

crack sealing. A maintenance procedure that involves placement of specialized materials, either above or into working cracks, using unique configurations to reduce the intrusion of incompressibles into the crack and to prevent intrusion of water into the underlying pavement layers. Working cracks are defined as those that experience horizontal movements greater than about 2 mm (0.1 in.).

diamond grinding. A maintenance procedure for PCC pavements that involves the removal of a thin layer of PCC (generally no more than 6.4 mm [0.25 in.]) from the surface of a pavement to remove surface irregularities (most commonly joint faulting), to restore a smooth riding surface, and to increase pavement surface friction.

diamond grooving. The establishment of discrete grooves in the concrete pavement surface using diamond saw blades to provide a drainage channel for water and thereby reduce the potential for hydroplaning and wet weather accidents.

dowel bar retrofit (DBR). See *load transfer restoration (LTR).*

equivalent single-axle load (ESAL). A concept that equates the damage to a pavement structure caused by the passage of a nonstandard axle load to a standard 80-kN (18-kip) axle load, in terms of calculated or measured stress, strain, or deflection at some point in the pavement structure, or in terms of equal conditions of distress or loss of serviceability.

fatigue cracking. Cracking of a roadway surface caused by repetitive loading. Fatigue cracking often begins as a single crack in the wheelpath, develops into parallel cracks, and then continues as interconnected cracks. Also referred to as *alligator cracking.*

faulting. Differential vertical displacement of abutting PCC pavement slabs at joints or cracks, creating a steplike deformation in the pavement.

flexible pavement. A pavement structure composed of an asphalt concrete (AC) surface (usually HMA) and an aggregate or stabilized base/subbase.

fog seal. A light application of slow-setting asphalt emulsion diluted with water that is used on HMA pavements or chip seals.

full-depth repair. Cast-in-place concrete repairs that extend the full depth of the existing slab. The technique involves the full-depth removal and replacement of full- or half-lane-width areas of an existing deteriorated PCC pavement.

functional distress. Deterioration that affects the ability of the pavement to provide a safe, smooth, and quiet surface for driving. Most functional problems can be corrected with preservation treatments if there is no serious underlying structural problem.

high-traffic-volume roadway. As defined in this study, a rural roadway with ADT greater than 5,000 vpd, or an urban roadway with ADT greater than 10,000 vpd.

hot in-place recycling (HIR). A process that involves softening an existing bituminous surface with heat, mechanically removing the surface material, mixing the material with a recycling agent, adding new asphalt or aggregate to the material (if required), and then replacing the material back on the roadway. There are three types of HIR: surface recycling, remixing, and repaving.

hot-mix asphalt (HMA). A plant-produced, high-quality hot mixture of asphalt cement and well-graded, high-quality aggregate thoroughly compacted into a uniform dense mass.

international roughness index (IRI). A measurement of the roughness of a pavement, expressed as the ratio of the accumulated suspension motion to the distance traveled. It is obtained from a mathematical model of a standard quarter car traversing a measured profile at a speed of 80 km/h (50 mph).

joint resealing. The resealing of transverse joints in PCC pavements to minimize the infiltration of surface water into the underlying pavement structure and to prevent the intrusion of incompressibles into the joint.

life cycle. A length of time that spans the stages of asset construction, operation, maintenance, rehabilitation, and reconstruction or disposal or abandonment; when associated with analyses, refers to a length of time sufficient to span these several stages and to capture the costs, benefits, and long-term performance impacts of different investment options.

life-cycle cost analysis (LCCA). A method of reducing all of the significant costs of an asset over its lifetime to either a present worth (today's cost) or an equivalent uniform annual cost (annual cost). As such, LCCA accounts for initial (or in-place) costs, subsequent maintenance and rehabilitation costs, and salvage value. In addition to all of these costs, inputs to an LCCA include the analysis period and the discount rate (reflecting the time value of money).

load transfer restoration (LTR). The placement of load transfer devices, such as dowel bars, across joints or cracks in an existing jointed PCC pavement.

longitudinal cracking. Cracking in a pavement surface that is oriented parallel to the direction of travel.

major rehabilitation. Structural enhancements that extend the service life of an existing pavement or improve its load-carrying capability.

microsurfacing. A mixture of polymer-modified asphalt emulsion, mineral aggregate, mineral filler, water, and other additives, properly proportioned, mixed, and spread on a pavement (usually bituminous) surface.

minor rehabilitation. Nonstructural enhancements (e.g., thin HMA overlay, mill and thin HMA overlay) made to an existing pavement section to either eliminate age-related, top-down surface cracking that develops in flexible pavements due to environmental exposure, or to restore functionality of concrete pavements. Because of the nonstructural nature of minor rehabilitation techniques, they are placed in the category of pavement preservation.

open-graded friction course (OGFC). A bituminous paving layer consisting of a mix of asphalt cement and open-graded (also called uniformly graded) aggregate. An open-graded aggregate consists of particles of predominantly a single-size aggregate.

oxidation. Chemical reaction between the asphalt in an HMA pavement and air, causing the bituminous surface to become discolored and stiffer.

partial-depth repairs. Removal of small, shallow areas of deteriorated PCC and replacement with a suitable repair material. It cannot accommodate the movements of working joints and cracks, load transfer devices, or reinforcing steel without experiencing high stresses and material damage.

pavement condition index (PCI). A condition index with a scale of 0 to 100, where 0 represents a failed pavement and 100 represents a pavement that is in excellent condition. See American Society for Testing and Material Standard D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.*

pavement friction. The retarding force developed at the tire–pavement interface that resists sliding when braking forces are applied to the vehicle tires.

pavement maintenance. Work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service.

pavement management. All the activities involved in the planning, programming, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program. A system that involves the identification of optimum strategies at various management levels and maintains pavements at an adequate level of serviceability. These include, but are not limited to, systematic procedures for scheduling maintenance and rehabilitation activities based on optimization of benefits and minimization of costs.

pavement management system (PMS). A set of tools or methods that assists decision makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time.

pavement performance. The condition or serviceability of a pavement, either over time or at a given point in time.

pavement preservation. A network-level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices to extend pavement life, improve safety, and meet motorist expectations. Pavement preservation programs normally include a combination of preventive maintenance, minor rehabilitation, and routine maintenance work. However, the majority of work under typical pavement preservation programs is focused on preventive maintenance.

pavement preventive maintenance. A planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, maintains or improves the functional condition of the system, and extends the life of the existing pavement (without increasing the structural capacity).

pavement reconstruction. The replacement of an entire pavement structure with an equivalent or better pavement structure. Reconstruction usually requires the complete removal and replacement of the existing pavement structure. Reconstruction may incorporate either new or recycled materials into the materials used for the reconstruction of the complete pavement section. Reconstruction is required when a pavement has either failed or has become functionally obsolete.

pavement rehabilitation. Structural enhancements that extend the service life of an existing pavement or improve its load-carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays.

pavement texture. The characteristics of the pavement surface that contribute to both surface fiction and noise. Surface texture consists of microtexture and macrotexture.

performance measure. An indicator, preferably quantitative, of service provided by the transportation system to users; the service may be gauged in several ways (e.g., quality of ride, efficiency and safety of traffic movements, services at rest areas, quality of system condition).

performance period. Length of time a pavement is expected to provide a minimum level of serviceability before major rehabilitation is required.

performance target. Threshold value of a performance measure.

preoverlay repair. Improvements performed on an existing pavement prior to the placement of an overlay.

present serviceability index (PSI). A subjective rating of the pavement condition made by a group of individuals riding over the pavement, ranging from 0 (impassable) to 5 (perfect).

punchout. A major structural distress in continuously reinforced concrete pavement (CRCP) caused by loss of materials under the slab and loss of aggregate interlock at one or two closely spaced cracks.

raveling. The wearing away of a bituminous pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder.

remaining service life (RSL). The number of years before a pavement reaches an unacceptable serviceability level.

rigid pavement. A pavement structure composed of a portland cement concrete (PCC) surface and an aggregate or stabilized base.

roughness. Distortions of the road surface that contribute to an undesirable, unsafe, uneconomical, or uncomfortable ride.

routine maintenance. Planned work that is performed on a routine basis to maintain and preserve the condition of the highway system or respond to specific conditions and events that restore the highway system to an adequate level of service.

rubberized asphalt chip seal. A variation on conventional chip seals in which the asphalt emulsion is replaced with a blend of ground tire rubber (or latex rubber) and asphalt cement to enhance the elasticity and adhesion characteristics of the binder. Aggregate is typically precoated and hot applied.

rutting. A surface depression in the wheelpath caused by a permanent deformation in any of the pavement layers or subgrade.

sand seal. An application of asphalt emulsion covered with fine aggregate. It may be used to improve the skid resistance of slippery pavements and to seal against air and water intrusion.

sandwich seal. A surface treatment that consists of application of a large aggregate, followed by a spray of asphalt emulsion that is in turn covered with an application of smaller aggregate. Sandwich seals are used to seal the pavement surface and to improve skid resistance.

scrub seal. The application of a polymer-modified asphalt emulsion to the bituminous surface, followed by the broom-scrubbing of the emulsion into cracks and voids, followed by the application of an even coat of sand or small aggregate, and finally a second brooming of the aggregate and asphalt mixture. This seal is then rolled with a pneumatic tire roller.

serviceability. The ability of a pavement to serve the purpose for which it was designed and constructed.

skid resistance. See *pavement friction.*

slurry seal. A mixture of quick- or slow-setting emulsified asphalt, well-graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of bituminous pavements, to restore a uniform surface texture, to seal the surface to prevent moisture and air intrusion into the pavement, and to provide skid resistance.

spalling. The breakdown of the slab edges within 2 ft (0.6 m) of the side of the joint caused by excessive stresses at the joint or crack or poor joint forming or sawing practices.

stone matrix asphalt (SMA). A hot-mix asphalt consisting of a mix of asphalt cement, stabilizer material, mineral filler, and gap-graded aggregate. A gap-graded aggregate is similar to an open-graded material but is not quite as open.

structural distress. Deterioration caused by excessive loading, insufficient thickness, or lack of structural support. Pavements with considerable structural distress are not good candidates for preservation treatments.

subbase. Layer of material in a pavement structure immediately beneath the base course.

subgrade soil. The native soil prepared and compacted to support a pavement structure.

thin HMA overlays. Plant-mixed combinations of asphalt cement and aggregate that are commonly placed in thicknesses between about 19 and 38 mm (0.75 and 1.50 in.).

transverse cracking. Cracking in a pavement surface that is oriented perpendicular to the direction of travel.

treatment category. A group of treatments with similar overall objectives and applied at similar times. For example, preventive maintenance treatments are intended to preserve pavement integrity and prevent or retard future pavement deterioration.

treatment type. A specific work activity performed on a roadway pavement that is intended to treat one or more of the pavement's deficiencies. Examples include crack sealing, thin HMA overlay applications, and diamond grinding.

ultra-thin bonded wearing course. A preservation treatment for flexible pavements consisting of a layer of gap-graded, polymer-modified hot-mix asphalt (HMA) material placed over a heavy, polymer-modified emulsified asphalt tack coat. Sometimes called ultra-thin friction course.

ultra-thin whitetopping (UTW). Thin PCC overlays of existing HMA pavements that consist of very thin (50 to 100 mm [2 to 4 in.]) layers of PCC bonded to an existing HMA pavement.

undersealing. Also called subsealing, pressure grouting, or slab stabilization, this process consists of the pressure insertion of a flowable material used to fill voids beneath PCC slabs.

user benefits. Economic gains to transportation users resulting from a project or investment strategy. It may include monetary value of travel time savings, accident reductions, reduced vehicle operating costs, and savings or advantages gained from more reliable transportation services.

user costs. Costs incurred by highway users traveling on the facility and the excess costs incurred by those who cannot use the facility because of either agency or self-imposed detour requirements. User costs are typically composed of vehicle operating costs, crash costs, and user delay costs.

weathering. The hardening and aging of the asphalt binder.

APPENDIX A

Annotated Bibliography

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Austroads Inc. ***Fibre-Reinforced Seals.*** **Austroads, Inc., Sydney, Australia, 2005.**
No abstract available.

Beatty, T. L., D. C. Jackson, D. A. Dawood, R. A. Ford, and J. S. Moulthrop. ***Pavement Preservation Technology in France, South Africa, and Australia.*** **Report FHWA-PL-03-001. FHWA, U.S. Department of Transportation, 2002.**
An increasing number of highway agencies have found that applying relatively low-cost surface preservation treatments can extend the service life of a pavement. The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study of France, South Africa, and Australia to investigate innovative programs for pavement preservation. The U.S. delegation observed that the countries visited are committed to designing and building long-lasting structural pavement sections on their national roadway networks. The countries focus on road maintenance, using low-cost seals and thin overlays on surfaces to protect their investment in underlying layers, rather than on more costly rehabilitation. The scanning team's recommendations for U.S. application include developing demonstration projects using deep-subbase and deep-base roadway designs, testing innovative procedures to improve chip seal performance, conducting a best-practices seminar on long-term maintenance contacts, and evaluating pavement condition survey vehicles.

Bemanian, S., P. Polish, and G. Maurer. State-of-the-Practice on CIR and FDR Projects by Nevada DOT. Presented at 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.
One of the biggest challenges that public agencies face is how to optimize available funding. With the price of bituminous materials 70% higher than in the preceding 2 years and increased demand for capacity-improvement projects, it is more important than ever to use in-place materials when rehabilitating pavement structural sections. Cold in-place recycling (CIR) and full-depth reclamation (FDR) are two pavement rehabilitation strategies that the Nevada Department of Transportation (NDOT) has used for more than 20 years. These strategies have allowed NDOT to save more than $600 million over the past 20 years compared with complete-reconstruction costs. In addition, traffic interruptions are minimized during construction, and natural resources are preserved. According to the Highway Performance Monitoring System data, NDOT has the highest percentage of its combined National Highway System Interstate and other roadways rated in the "good" category. The reason for this achievement is that NDOT uses a proactive pavement management system (PMS) to prioritize its pavement preservation projects. A considerable amount of CIR and FDR rehabilitation work is performed in conjunction with the proactive PMS. Because these strategies are more cost-effective than overlay, mill and overlay, or reconstruction, NDOT can rehabilitate more roads with less money. This report describes how to select, design, and construct successful CIR and FDR projects. The performances of the strategies are evaluated, and life-cycle cost analysis is developed to demonstrate the cost-benefit of CIR and FDR versus conventional rehabilitation strategies.

California Department of Transportation (Caltrans). ***Maintenance Technical Advisory Guide (MTAG): Volume I—Flexible Pavement Preservation,*** **2nd ed. Caltrans, Sacramento, Calif., 2008. www.dot.ca.gov/hq/maint/MTA_GuideVolume1Flexible.html.**
This publication was prepared by HQ Maintenance to assist in making better and more informed decisions on maintenance practices. It is designed for several levels of use, ranging from general instruction to specific work practice descriptions. It should be of use to district maintenance managers, maintenance supervisors, superintendents, and field personnel. Construction personnel and designers may also find use for the information. This publication consists of several parts. The first chapter is a review of pavement preservation and maintenance principles, as well as a detailed technical discussion on the materials used in maintenance treatments. This is followed by a chapter describing a simplified treatment-selection process. The remaining Chapters 3–8 describe the various maintenance treatments currently in use by Caltrans and provide information on how to design and construct them. Chapters 3–8 can be used as stand-alone documents for the respective treatments. Other chapters on new treatments may be added at a later time.

Chen, D. H., D. F. Lin, and H. L. Luo. Effectiveness of Preventive Maintenance Treatments Using Fourteen SPS-3 Sites in Texas. *Journal of Performance of Constructed Facilities.* Vol. 17, No. 3, 2003, pp. 136–143.

Fourteen Texas SPS-3 test sites were studied to determine effectiveness of preventative maintenance treatments (PMTs). These sections were built on four highway classifications (IH, US, SH, and FM) in different climates and with different levels of traffic and subgrade support. Almost all 14 SPS-3 sites were given PMTs (thin overlay, slurry seal, crack seal, and chip seal) in fall 1990. The distress score concept used by the Texas Department of Transportation (TxDOT) was adopted in this study to judge the effectiveness of PMTs. TxDOT has used this concept since the early 1980s, though the utility factors have been revised a few times. The distress score quantifies the visible surface wear due to traffic and environmental influences. Only very few sections experienced premature failures on the SPS-3 sites in Texas. In many cases, superior underlying pavement conditions have been found. The chip seal has the most sites in which it is rated the best performer. The chip seals performed well on a wide range of pavement conditions. In fact, chip seals have the highest distress score for both high- and low-traffic areas. When initial cost is considered, crack seal provides the best alternative for low-traffic routes that have a sound underlying pavement structure. For high-traffic routes, chip seal is a better choice. However, a thin overlay is the most effective for rut resistance. Since the thin overlay has the highest initial cost, it is best used on high-traffic routes where rutting is a major concern. If rutting is not a concern, chip seal is the best choice for a high-traffic area. The treatments applied to US84 sections were too late and did not reach 7 years of life as normally was expected, which reconfirms that the timing for PMT is important.

Chou, E. Y., D. Datta, and H. Pulugurta. *Effectiveness of Thin Hot Mix Asphalt Overlay on Pavement Ride and Condition Performance.* Report FHWA/OH-2008/4. Ohio Department of Transportation, Columbus, Ohio, and FHWA, U.S. Department of Transportation, 2008.

The objectives of this study were (1) to determine the cost-effectiveness of thin hot-mix asphalt (HMA) overlays as a maintenance technique; (2) to determine under what conditions a thin overlay would be suitable; (3) to determine the timing of constructing a thin overlay to maximize its benefits; and (4) to develop a prototype aggregate source information system to correlate aggregate source quality to pavement performance. Performance data for thin overlays constructed by ODOT since 1990 were collected to study the cost-effectiveness of thin overlay. The average thin overlay project cost is about 40% of the average minor rehabilitation project cost for the Priority System, and approximately 60% for the General System pavements. In contrast, the average service life of a thin overlay is generally more than 70% of that of a minor rehabilitation. Therefore, most of the thin overlays are deemed cost-effective. Thin overlay projects that are not cost-effective tend to be those performed on very poor pavements and with insufficient thickness. Thin overlays are most likely to be cost-effective if the existing pavement's PCR score is between 70 and 90 for Priority System and between 65 and 80 for General System pavements. A prototype aggregate source GIS system was developed. Higher aggregate soundness loss correlates with higher pavement deterioration rate. A thin HMA overlay is generally a cost-effective maintenance treatment. Employed properly, thin overlay provides a relatively low-cost alternative in preserving and extending the service life of the existing pavement.

Correa, A. L., and B. Wong. *Concrete Pavement Rehabilitation Guide for Diamond Grinding.* Report FHWA-SRC-1/10-01(5M). FHWA, U.S. Department of Transportation, 2001.

This technical bulletin recommends procedures for selecting, designing, and constructing diamond grinding in portland cement concrete pavements. Diamond grinding consists of removing surface irregularities from concrete pavements that are often caused by faulting, curling, and warping of the slabs. The main benefits of properly using this technique include smoother ride, reduced road noise, and improved friction. Diamond grinding can be used as a stand-alone rehabilitation technique. However, FHWA recommends its use as part of a comprehensive concrete pavement rehabilitation (CPR) program. Information regarding cost and performance is also included in this document. This document has been prepared in part with information collected under the sponsorship of FHWA's Special Project 205, Quality Concrete Pavement Rehabilitation. Other documents to provide similar guidance in other CPR techniques will follow.

Croteau, Jean-Martin, Peter Linton, J. Keith Davidson, and Gary Houston. Seal Coat Systems in Canada: Performances and Practice. Presented at 2005 Annual Conference of the Transportation Association of Canada, Calgary, Alberta, 2005.

This paper describes how seal coat systems have been used in Canada and other countries for many decades. In fact, the development of the seal coat system is closely associated with the increased usage of the automobile. Today, seal coating it is the most common type of roadway surfacing in Canada. Seal coat is a thin wearing course made of superimposed layers of aggregate and bituminous binder. This type of treatment may be used to restore the surface characteristics of existing worn-out roadway or to waterproof and preserve an existing roadway. They may be applied onto an existing bound material or an unbound road base. This type of treatment forms an impervious thin overlay over an existing bound or unbound surface. Seal coat systems may be divided into two families of treatments: the chip seal system and graded seal systems. Chip seals combine the application of a layer of calibrated chips onto a layer of a cationic rapid setting bitumen emulsion, whereas the graded seals are systems that combine the application of a dense-graded or gap-graded aggregate onto a layer of anionic high float type bitumen emulsion. Each system may be applied as a single application or a multiple application. Seal coat systems may be applied at spread rates that range from 14 kg/m^2 for a single chip seal applied onto an existing bituminous surface to 40 kg/m^2 for a double high float seal treatment applied onto an unbound granular base. Many parameters, such as the traffic and the existing surface conditions, must be considered in the design of a specific seal coat system for a given roadway. Field adjustments are also important; field conditions such as ambient temperature, the time of the year, and the sun/cloud conditions must be taken into account as well. The success of this type of treatment is not only associated with the selection of an optimal design but also with the close attention to the local conditions during the field application. This paper presents an overview of the seal coating technologies and a discussion on the state of the practice, including design practices and construction procedures of these surface treatments in Canada and abroad. In addition, the paper introduces new concepts related to the selection of seal coating systems as well as the emerging chip sealing systems now available in North America.

Cuelho, E., R. Mokwa, and M. Akin. *Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice.* Report FHWA/MT-06-009/8117-26. Montana Department of Transportation, Helena, Mont., and FHWA, U.S. Department of Transportation, 2006.

An extensive literature review was conducted to synthesize past and ongoing research related to highway pavement maintenance and preservation techniques. The literature review was augmented with a web-based e-mail survey that was distributed to all 50 states, Washington, D.C., and 11 Canadian provinces, for a total of 62 recipients. The literature review and survey results provide interesting qualitative overviews of the state of the practice of preventive maintenance treatments and how these treatments are instigated, managed, and accessed by transportation department personnel throughout North America. This report focuses on studies that quantified the performance of various preventive maintenance treatments, including the effect these treatments have on pavement performance. The study indicates that ranges of reported life expectancies for treatment systems vary widely, as does reported unit costs. The lack of conclusive quantitative data is attributed to variations in the many aspects of treatment systems. Additional research is needed to quantify and enhance our understanding of the short- and long-term effects that treatment systems have on highway pavement surfaces. State- or region-specific research is critically important to ensure that funds are wisely used for extending the life of a pavement section or for repairing ailing pavement surfaces.

Dunn, L., and S. Cross. *Basic Asphalt Recycling Manual.* Asphalt Recycling and Reclaiming Association, Annapolis, Md., 2001.
The growing demand on our nation's roadways over that past couple of decades, decreasing budgetary funds, and the need to provide a safe, efficient, and cost-effective roadway system has led to a dramatic increase in the need to rehabilitate our existing pavements. The last 25 years has also seen a dramatic growth in asphalt recycling and reclaiming as a technically and environmentally preferred way of rehabilitating the existing pavements. Asphalt recycling and reclaiming meets all of our societal goals of providing safe, efficient roadways, while at the same time drastically reducing both the environmental impact and energy (oil) consumption compared to conventional pavement reconstruction.

Eltahan, A. A., J. F. Daleiden, and. A. L. Simpson. Effectiveness of Maintenance Treatments of Flexible Pavements. *Transportation Research Record: Journal of the Transportation Research Board, No. 1680,* TRB, National Research Council, Washington, D.C., 1999, pp. 18–25.
To achieve effective pavement maintenance, the life expectancy and timing of treatment applications need to be determined. The Long-Term Pavement Performance (LTPP) program includes the Specific Pavement Study-3 (SPS-3), which focuses on this subject. The treatments applied are chip seals, crack seals, slurry seals, and thin overlays. In studying the life expectancy, it is not feasible to wait for all the sections in the experiment to fail. Thus, there is a need to determine the life expectancy while making efficient use of the available data-collection funds. Survival data analysis is a statistical technique that meets this need by accounting for the portion of the sections in which the exact time the treatment lasted is not known. The application of this technique to flexible-pavement maintenance is presented. In addition, some results of the LTPP SPS-3 experiment are presented to the highway community. The focus is on the LTPP Southern Region (Alabama, Arkansas, Florida, Mississippi, Oklahoma, Tennessee, and Texas). The results showed that the probability of failure was two to four times higher for the sections that were in poor condition at the time the treatment was applied than those sections that were in better condition. The median survival times for thin overlays, slurry seals, and crack seals were 7, 5.5, and 5 years, respectively. The chip-seal sections had not yet reached the 50% failure probability after 8 years of the SPS-3 experiment. Accordingly, chip seals appear to have outperformed the other treatments investigated in this study in delaying the reappearance of distress.

Federal Highway Administration (FHWA). *2002 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance.* Report FHWA-PL-03-003. FHWA, U.S. Department of Transportation, 2002.
The report provides Congress and other decision makers with an objective appraisal of highway, bridge, and transit physical conditions; operational performance; financing mechanisms; and future investment requirements.

Federal Highway Administration (FHWA) and Foundation for Pavement Preservation (FP[2]). *A Pocket Guide to Asphalt Pavement Preservation.* Foundation for Pavement Preservation and FHWA, U.S. Department of Transportation, 2005.
No abstract available.

Galehouse, L. *Development of a Pavement Preventive Maintenance Program for the Colorado Department of Transportation.* Report CDOT-DTD-R-2004-17. Colorado Department of Transportation. Denver, Colo., 2004.
The National Center for Pavement Preservation was contracted to review the Colorado Department of Transportation's preventive maintenance program. Each region was visited to discuss various preventive maintenance treatments and examine current maintenance practices. Areas requiring further action before implementing a successful preventive maintenance program were identified. This document contains field reports for each of the six regions visited. Also included in this report are Appendix A, Preventive Maintenance Program Guidelines, and Appendix B, Distress Manual for HMA and PCC Pavements.

Galehouse, L., J. S. Moulthrop, and R. G. Hicks. Principles of Pavement Preservation: Definitions, Benefits, Issues, and Barriers. *TR News,* No. 228, Sept.–Oct., 2003, pp. 4–9.
Americans are accustomed to easy mobility on safe, smooth, and well-maintained roads. These same roads play a critical role in the nation's economy, bolstering agriculture, industry, commerce, and recreation. During the 1990s, the nation's highways experienced a 29% increase in use, and growth is expected in the next 10 years. Large commercial truck traffic increased by nearly 40%, with growth projected to continue at more than 3% per year during the next 20 years. In addition, more than 95% of personal travel is by automobile. Increasing the capacity of highways, therefore, is important in meeting the nation's needs. But can the United States finance future highway capacity while addressing the needs of the current system? Yes—by developing a strategic plan that includes pavement preservation.

Geiger, D. Memorandum: Pavement Preservation Definitions. FHWA, U.S. Department of Transportation, 2005. www.fhwa.dot.gov/pavement/preservation/091205.cfm.
No abstract available.

Geoffroy, D. N. *NCHRP Synthesis of Highway Practice 223: Cost-Effective Preventive Pavement Maintenance.* TRB, National Research Council, Washington, D.C., 1996.
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. 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.

Gilbert, T. M., P. A. Olivier, and N. E. Galé. Ultra Thin Friction Course: Five Years on in South Africa. *Proc., 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04),* Sun City, South Africa, 2004.

In the past 5 years, ultra-thin friction course has been successfully paved on some of the heaviest trafficked national highways in South Africa, as well as on other national routes, provincial highways, provincial rural roads, urban major and minor arterials, and urban industrial roads and local roads. Ultra-thin friction coarse (UTFC) is ultimately a very thin asphalt layer paved at between 15 mm and 20 mm thick while spraying a thick tack-coat to the road surface all in one pass. It has a number of functional properties and advantages over other conventional asphalt paving procedures and products, which are mentioned later on in the paper. The essence of this paper describes the origin and history of UTFC, its various applications over the past 5 years in South Africa, including the performance and nonperformance thereof, with recommendations for future use in Southern Africa.

Gransberg, D. D. Chip Seal Program Excellence in the United States. *Transportation Research Record: Journal of the Transportation Research Board, No. 1933,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 72–82.

A survey of U.S. public highway and road agencies that use chip seals as a part of their roadway maintenance program was developed and conducted to identify best practices in chip seal design and construction. A total of 72 individual responses from 42 states and 12 U.S. cities and counties were received; of those, nine respondents reported that they were getting excellent results from their chip seal programs. Those responses were grouped together and analyzed by the case study method to identify trends that lead to consistently excellent chip seal results. The study found that the successful chip seal programs had much in common. They use chip seals as a preventive maintenance tool, applying them to roads before distress levels were classified as moderate. They require their contractors to use the latest technology, and they exploit advances in materials science, such as the use of modified binders. And most of them use chip seals on both high- and low-volume roads.

Gransberg, D., and D. M. B. James. *NCHRP Synthesis of Highway Practice 342: Chip Seal Best Practices.* Transportation Research Board of the National Academies, Washington, D.C., 2005.

This synthesis report provides an overview of successful chip seal practices in the United States, Canada, and overseas. Although not meant to be an exhaustive study, it covers the spectrum of chip seal practice and presents, where possible, the state of the art, as reported in the literature and survey responses. The report presents ways to assist in the development and implementation of pavement preservation programs by identifying the benefits of using chip seal as part of a preventive maintenance program. Innovative and advanced chip seal programs from around the world were identified with respect to critical factors that can be incorporated by other transportation agencies. Approximately 40 best practices were identified in the areas of chip seal design methods, contract administration, equipment practices, construction practices, and performance measures. The increased use of chip seals for maintenance can be a successful, cost-effective way of using preventive maintenance to preserve both low-volume and higher-volume pavements.

Grogg, M., K. D. Smith, S. B. Seeds, T. E. Hoerner, D. G. Peshkin, and H. T. Yu. *HMA Pavement Evaluation and Rehabilitation: Reference Manual.* National Highway Institute, FHWA, U.S. Department of Transportation, 2001.

This document serves as the reference manual for the FHWA/NHI training course HMA Pavement Evaluation and Rehabilitation. The course provides detailed information to assist pavement engineers in identifying and selecting the reliable and cost-effective rehabilitation alternatives for existing HMA pavements. It addresses the rehabilitation process for conventional HMA pavements in a logical sequence, from a detailed functional and structural evaluation of the existing pavement, to a needs assessment and development of feasible alternatives, to the selection of the preferred rehabilitation alternative. The course combines lectures and workshop sessions to provide participants with hands-on experience with the techniques for HMA pavement rehabilitation. Although any individual associated with pavement rehabilitation will benefit from this course, the primary audience is roadway design, construction, and maintenance engineers who are responsible for developing and selecting an agency's pavement rehabilitation alternatives. This reference manual contains four blocks of material. The first block contains an introduction to the course, as well as an introduction to HMA pavements. Block 2 discusses the pavement evaluation process, describing ways of evaluating and characterizing the condition of the existing HMA pavement. Block 3 presents key design and construction information on common HMA pavement maintenance and rehabilitation activities, such as crack sealing, surface treatments, overlays, and recycling. Finally, Block 4 describes a methodology for selecting the preferred rehabilitation alternative from a short list of feasible alternatives, featuring the use of life-cycle cost analysis. Two other documents accompany this reference manual for the training course. A participant's workbook has been developed to assist participants in following the presentation of the course materials and to facilitate the comprehension of the information. It also contains the four workshop problems that are intended to enhance participants' understanding of the technical material presented in the course. An instructor's guide has been assembled to assist instructors in presenting the training course, and it contains supplemental notes on the presentation and workshop materials.

Hall, K. T., C. E. Correa, and A. L. Simpson. *NCHRP Web Document 47: LTPP Data Analysis—Effectiveness of Maintenance and Rehabilitation Options.* Transportation Research Board of the National Academies, Washington, D.C., 2002.

This report finds that overlay thickness and preoverlay roughness level were the two factors that most influenced the performance of asphalt overlays of asphalt pavements.

Hein, D., and J. M. Croteau. The Impact of Preventive Maintenance Programs on the Condition of Roadway Networks. Presented at 2004 Annual Conference of the Transportation Association of Canada, Québec City, Québec, 2004.

This paper describes the best practice for the use of thin surface restoration techniques for the preservation of bituminous pavements developed as a part of the Canadian National Guide for Sustainable Municipal Infrastructure (NGSMI). Thin surface restoration techniques are treatments applied to the pavement surface that increase pavement thickness by less than 40 mm. This distinction is made because overlays that are 40 mm thick or more are usually associated with routine paving operations. The following treatments are described in this paper: (1) thin hot-mix overlay (less than 40 mm); (2) hot-in-place recycling; (3) microsurfacing; (4) slurry seal; (5) seal coat; (6) restorative seal; and (7) texturization. Thin surface restoration techniques do not significantly increase the strength of the pavement but benefit pavements by protecting the pavement structure from premature deterioration or by improving or restoring the pavement surface. Thin pavement surface restoration techniques are also well suited as temporary treatments until a permanent treatment can be implemented. The benefits of using thin surface restoration techniques can be realized in several ways. The paper describes the technology of thin surface restoration techniques for bituminous pavements, including materials and construction techniques,

expected service life and costs, surface preparation requirements, detailed procedures for choosing between alternative treatments, examples of use by Canadian municipalities, potential challenges, and new developments. The use of thin surface restoration techniques promotes the use of preventive maintenance for pavement preservation. It describes how to use thin surface restoration techniques as preventive maintenance treatments, and provides guidelines on how to incorporate the use of these treatments into existing pavement management procedures. Provided in this paper are guidelines for the systematic evaluation of the performance of new treatments. The use of thin surface restoration techniques should be part of the pavement preservation toolbox of all municipal agencies.

Hicks, R. G. Treatment Selection for Flexible Pavements. Presented at California Pavement Preservation Conference, Newport Beach, Calif., 2008.
No abstract available.

Hicks, R. G., and R. Marsh. Pavement Preservation Sub-Group on Strategy Selection and Evaluation. Presentation to Caltrans, 2005. www.dot.ca.gov/hq/maint/PavePres/04pptg.pdf.
No abstract available.

Hicks, R. G., S. B. Seeds, and D. G. Peshkin. Selecting a Preventive Maintenance Treatment for Flexible Pavements. Presented at Foundation for Pavement Preservation Conference, 1999.
No abstract available.

Hicks, R. G., S. B. Seeds, and D. G. Peshkin. *Selecting a Preventive Maintenance Treatment for Flexible Pavements.* Report FHWA-IF-00-027. Foundation for Pavement Preservation (FP²), Washington, D.C., and FHWA, U.S. Department of Transportation, 2000.
Maintenance engineers have been applying treatments to both flexible and rigid pavements for as long as such pavements have existed. The types and application of various treatments for both corrective and preventive maintenance have been the subject of research studies over a number of years, and many publications have reported these findings. Recently, the Federal Highway Administration (FHWA) has initiated an effort to encourage DOTs (state and local) to begin, or extend, the practice of preventive maintenance, since there simply is not enough money available to continue the types of maintenance currently employed. This report specifically addresses flexible pavement preventive maintenance, including the types of pavements that are candidates for preventive maintenance, the available treatments, where and when they should be used, their cost-effectiveness, the factors to be considered in selecting the appropriate treatment strategy, and a methodology to determine the most effective treatment for a particular pavement.

Hoerner, T. E., K. D. Smith, H. T. Yu, D. G. Peshkin, and M. J. Wade. *PCC Pavement Evaluation and Rehabilitation: Reference Manual.* National Highway Institute, FHWA, U.S. Department of Transportation, 2001.
This document serves as the reference manual for the FHWA/NHI training course PCC Pavement Evaluation and Rehabilitation. The course provides detailed information to assist pavement engineers in identifying and selecting the reliable and cost-effective rehabilitation alternatives for existing PCC pavements. It addresses the rehabilitation process for conventional PCC pavements in a logical sequence, from a detailed functional and structural evaluation of the existing pavement, to a needs assessment and development of feasible alternatives, to the selection of the preferred rehabilitation alternative. The course combines lectures and workshop sessions to provide participants with hands-on experience with the techniques for PCC pavement rehabilitation. Although any individual associated with pavement rehabilitation will benefit from this course, the primary audience is roadway design, construction, and maintenance engineers who are responsible for developing and selecting an agency's pavement rehabilitation alternatives. This reference manual contains four blocks of material. The first block contains an introduction to the course, as well as an introduction to PCC pavements. Block 2 discusses the pavement evaluation process, describing ways of evaluating and characterizing the condition of the existing PCC pavement. Block 3 presents key design and construction information on common PCC pavement maintenance and rehabilitation activities, such as crack sealing, surface treatments, overlays, and recycling. Finally, Block 4 describes a methodology for selecting the preferred rehabilitation alternative from a short list of feasible alternatives, featuring the use of life cycle cost analysis. Two other documents accompany this reference manual for the training course. A participant's workbook has been developed to assist participants in following the presentation of the course materials and to facilitate the comprehension of the information. It also contains the four workshop problems that are intended to enhance participants' understanding of the technical material presented in the course. An instructor's guide has been assembled to assist instructors in presenting the training course, and it contains supplemental notes on the presentation and workshop materials.

Huddleston, I. J., H. Zhou, and R. G. Hicks. Evaluation of Open-Graded Asphalt Concrete Mixtures Used in Oregon. *Transportation Research Record 1427,* TRB, National Research Council, Washington, D.C., 1993, pp. 5–12.
Open-graded friction course (OGFC) is characterized by the use of large percentage of coarse aggregate in the mix without a significant proportion of fines as commonly found in dense-graded mix. In an attempt to assess the performance of the open-graded mixes, a survey was made of some of the older OGFC projects and their performance was compared to projects paved with dense-graded asphalt concrete mixes. The evaluation demonstrated that all of the open-graded projects had improved performance when compared to dense-graded projects. This included: resistance to cracking, a slightly increased resistance to rutting, and improved skid gradient. The evaluation supports the continued use of open-graded mixture and additionally, the assessment provided the opportunity to develop new and improved guidelines for the use of those mixes.

Illinois Department of Transportation (Illinois DOT). Chapter 52: Pavement Preservation. *Design and Environment Manual.* Illinois DOT, Springfield, Ill., 2009.
The manual has been prepared to provide uniform practices for the department and consultant personnel preparing Phase I studies and reports and contract plans for department projects. The manual presents most of the information normally required in the development of a typical roadway project. The designer should attempt to meet all criteria and practices presented in the manual; however, the manual should not be considered a standard that must be met regardless of impacts. The designer should develop roadway designs that meet the department's operational and safety requirements while preserving the aesthetic, historic, or cultural resources of an area. Designers must exercise good judgment on individual projects and, frequently, they must be innovative in their approach to roadway design. This may require, for example, additional research into the highway literature.

International Grinding and Grooving Association (IGGA). Rigid Pavement Distress and Strategy Selection. Presented at 2009 California Pavement Preservation Conference, Oakland, 2009.
No abstract available.

Jackson, N., and J. Puccinelli. *Long-Term Pavement Performance (LTPP) Data Analysis Support: National Pooled Fund Study TPF-5(013)—Effects of Multiple Freeze Cycles and Deep Frost Penetration on Pavement Performance and Cost.* Report FHWA-HRT-06-121. FHWA, U.S. Department of Transportation, 2006.

The objectives of this study are to (1) quantify the effects of frost penetration on pavement performance in climates with deep, sustained frost as compared to environments with multiple freeze-thaw cycles; (2) investigate the effect that local adaptations have on mitigating frost penetration damage; and (3) estimate the associated cost of constructing and maintaining pavements in freezing climates. The approach consisted of modeling various pavement performance measures using both climatic and nonclimatic input variables and performance data collected as part of the Long-Term Pavement Performance program. Five climatic scenarios are defined in terms of climatic input variables for the models. Predicted performance measures are presented for each of the climatic scenarios and compared at a 95% confidence interval to determine statistically significant performance differences. Participating pooled-fund states (PFS) were queried as to standard specifications, standard designs, average life expectancies, and construction costs specific to each state highway agency (SHA). These data, along with information acquired through literature review of SHA standard practices, are summarized with consideration given to the mitigation of frost-related damage. Life-cycle cost analysis for each climatic scenario using predicted performance to determine average life and average agency construction costs for standard pavement sections is also discussed and compared. The use of the performance models for local calibration as required in the *National Cooperative Highway Research Program Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures* is explored along with the possible application of the performance models in pavement management systems.

Jahren, C. T., K. L. Bergeson, A. Al-Hammadi, S. Celik, G. Lau, and H. Quintero. Interim Guidelines for Thin Maintenance Surfaces in Iowa. *Proc., 2000 Mid-Continent Transportation Research Symposium,* Center for Transportation Research and Education, Iowa State University, Ames, Iowa, 2000.

The first phase of a two-phase research project was conducted to develop guidelines for Iowa transportation officials on the use of thin maintenance surfaces (TMS) for asphaltic concrete and bituminous roads. Thin maintenance surfaces are seal coats (chip seals), slurry seals, and microsurfacing. Interim guidelines were developed to provide guidance on which roads are good candidates for TMS, when TMS should be placed, and what type of thin maintenance surface should be selected. The guidelines were developed specifically for Iowa weather, traffic conditions, road-user expectations, and transportation official expectations.

Jahren, C. T., W. A. Nixon, and K. L. Bergeson. *Thin Maintenance Surfaces: Phase Two Report with Guidelines for Winter Maintenance on Thin Maintenance Surfaces.* Project TR-435. Iowa Department of Transportation and Iowa Highway Research Board, 2003.

In recent years, there has been renewed interest in using preventive maintenance techniques to extend pavement life and to ensure low life-cycle costs for Iowa's road infrastructure network. Thin maintenance surfaces can be an important part of a preventive maintenance program for asphalt cement concrete roads. The Iowa Highway Research Board has sponsored Phase 2 of this research project to demonstrate the use of thin maintenance surfaces in Iowa and to develop guidelines for thin maintenance surface uses that are specific to Iowa. This report documents the results of test section construction and monitoring started in Phase 1 and continued in Phase 2. The report provides a recommended seal coat design process based on the McLeod method and guidance on seal coat aggregates and binders. An update on the use of local aggregates for microsurfacing in Iowa is included. Winter maintenance guidelines for thin maintenance surfaces are also reported. Finally, Phase 1's interim, qualitative thin maintenance surface guidelines are supplemented with Phase 2's revised, quantitative guidelines. When thin maintenance surfaces are properly selected and applied, they can improve the pavement surface condition index and the skid resistance of pavements. For success to occur, several requirements must be met, including proper material selection, design, application rate, workmanship, and material compatibility, as well as favorable weather during application and curing. Specific guidance and recommendations for many types of thin maintenance surfaces and conditions are included in the report.

Johnson, A. M. *Best Practices Handbook on Asphalt Pavement Maintenance.* Report MN/RC-2000-04. University of Minnesota Center for Transportation Studies, Minneapolis, Minn., 2000.

The purpose of this handbook is to provide background information about the importance of pavement preservation and preventive maintenance, as well as present maintenance techniques for a variety of distresses and conditions. The major focus of this handbook is on preventive maintenance activities, which are performed while the roadway is still in good condition with only minimal distress, before the pavement falls into a condition where structural overlays, major milling or reclaiming, or replacement is necessary. The most common flexible pavement distresses are cracking, roughness, weathering, raveling, rutting, and bleeding. If the distresses identified in a pavement are related to structural deficiencies, the pavement section is most likely not a candidate for preventive maintenance treatment, and should be scheduled for rehabilitation or reconstruction. Maintenance treatments covered in this handbook include crack repair with sealing, including clean and seal, saw and seal, and rout and seal; crack filling; full-depth crack repair; fog seal; seal coat; double chip seal; slurry seal; microsurfacing; thin hot-mix overlays; and potholes and pavement patching. Tables are outlined giving the most common flexible pavement distresses, along with the best practices for rehabilitation for each. Also given are recommended applications for crack sealers and fillers, surface treatments, and pothole patching. Specifications, technical memoranda and special provisions are included for all treatment methods recommended in the handbook.

Kandhal, P. S., and R. B. Mallick. *Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book.* Report FHWA-SA-98-042. FHWA, U.S. Department of Transportation, 1997.

Recycling or reuse of existing asphalt pavement materials to produce new pavement materials has the following advantages: reduced costs of construction, conservation of aggregate and binder, preservation of the existing pavement geometrics, preservation of the environment, and conservation of energy. This document was prepared to provide the following information on recycling of asphalt pavements: performance data, legislation/specification limits, selection of pavement for recycling and recycling strategies, economics of recycling, and structural design of recycled pavements. The following recycling methods have been included: hot-mix asphalt recycling (both batch and drum plants), asphalt surface recycling, hot in-place recycling, cold-mix asphalt recycling, and full depth reclamation. Materials and mix design, construction methods and equipment, case histories and quality control/quality assurance have been discussed for all recycling methods. This participant's reference book was developed to support a 2-day workshop on pavement recycling guidelines for state and local governments.

Kentucky Transportation Cabinet (KYTC). *Pavement Management Field Handbook: KYTC Pavement Distress Identification Manual and Guideline for Preventive Maintenance Treatments.* KYTC, Frankfort, Ky., 2009.
Each year the Operations and Pavement Management Branch performs detailed pavement condition evaluations of all Interstate and parkway pavements and one-third of the remaining system (state primary, state secondary, and supplemental roads). The evaluations are used to document roadway deterioration, recommend pavement rehabilitation treatments, and prioritize projects. In order for evaluation data to be useful for predictive measures, consistent methods of distress identification and recording are critical. The *Pavement Distress Identification Manual* will foster more uniform and consistent pavement distress evaluations by providing identification definitions and guidelines. The manual is intended to be a training aid for pavement raters and a field reference during the rating process. The manual can also be used with completed evaluations to describe the typical condition of a roadway section.

Koch Materials Company (Koch). Innovation for Performance. Presentation. 2001. www.pavementpreservation.org/library/getfile.php?journal_id=201.
No abstract available.

Kuennen, T. Making High-Volume Roads Last Longer. In *Pavement Preservation Compendium II,* Publication FHWA-IF-06-049, FHWA, U.S. Department of Transportation, 2006, pp. 36–44. www.fhwa.dot.gov/pavement/preservation/ppc06.pdf.
This article reports on techniques to preserve high-volume roads so they last longer. The techniques—crack sealing, chip seals, slurry surfacings, and overlays—are the same as those that are standard for low-volume, secondary roads. But they need precision applications and disciplined choice of tactics to succeed. Instead of intuitively timed applications of off-the-shelf materials for a chip and seal repair, the same type of repair for a high-volume road will be designed in a laboratory based on existing conditions, climate, and traffic loads, with a binder and chip that are tailored to the demands of that particular pavement. When properly designed and judiciously applied, they can outperform the standard, more costly asphalt overlay after years of minimal care. The changes comes after the advent of the Strategic Highway Research Program (1988–1993), which demonstrated that high-volume roads can benefit from this sort of attention. The article includes a list of preservation methods developed by FHWA and descriptions of a few specific projects.

Kuennen, T. Pavement Preservation: Techniques for Making Roads Last. In *Pavement Preservation Compendium II,* Publication FHWA-IF-06-049, FHWA, U.S. Department of Transportation, 2006, pp. 12–14. www.fhwa.dot.gov/pavement/preservation/ppc06.pdf.
No abstract available.

Kuennen, T. When Prevention is the Cure. In *Pavement Preservation Compendium II,* Publication FHWA-IF-06-049, FHWA, U.S. Department of Transportation, 2006, pp. 86–91. www.fhwa.dot.gov/pavement/preservation/ppc06.pdf.
No abstract available.

Labi, S., M. Mahmodi, C. Fang, and C. Nunoo. Cost-Effectiveness of Microsurfacing and Thin Hot-Mix Asphalt Overlays: Comparative Analysis. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
Microsurfacing and thin hot-mix asphalt (HMA) overlays are categories of flexible pavement preventive maintenance that involve an aggregate-bituminous mix laid over the entire carriageway width. This paper presents and demonstrates a methodology for comparing the long-term cost-effectiveness of two competing pavement treatments using three measures of effectiveness (MOE)—treatment service life, increase in average pavement condition, and area bounded by the performance curve—and two measures of cost—agency cost only and total cost (agency plus user costs). Only non-Interstate pavement sections are considered in the study, and each MOE is expressed in terms of international roughness index (IRI) values. For all measures of treatment effectiveness where costs are expressed only in terms of agency cost irrespective of climate severity and traffic loading, it was found that microsurfacing is consistently more cost-effective compared with thin HMA overlays. An exception occurs when increase in pavement condition is used as the MOE and when both traffic volume and climate severity are high. Under these conditions, thin HMA overlay appears to be more cost-effective. The superiority of microsurfacing in terms of cost is most evident when treatment life is the measure of effectiveness that is used and least evident when increased pavement condition is used. Microsurfacing also appears to be more cost-effective under low traffic loading and low climatic severity. The study methodology results offer significant implications in the field of pavement design, engineering, and management. Highway agencies are continuously striving to develop decision trees and matrices for intervention, and it is sought to carry out these tasks on the basis of rational cost and effectiveness analysis rather than subjective opinion. The development of such decision mechanisms can facilitate the design of preventive maintenance strategies for more cost-effective decisions that are based on life-cycle costs and benefits.

Lamptey, G., S. Labi, M. Ahmad, and K. Sinha. *Life Cycle Cost Analysis for INDOT Pavement Design Procedures.* Report FHWA/IN/JTRP-2004/28. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Ind., 2005.
Given the aging of highway pavements, high traffic levels, and uncertainty of sustained preservation funding, there is a need for balanced decision-making tools such as life-cycle cost analysis (LCCA) to ensure long-term and cost-effective pavement investments. With driving forces such as Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the National Highway System (NHS) Act of 1995, and the Transportation Equity Act for the 21st Century (TEA-21), LCCA enables evaluation of overall long-term economic efficiency between competing alternative investments and consequently has important applications in pavement design and management. It has been shown in past research that more effective long-term pavement investment could be made at lower cost using LCCA. Current LCCA-based pavement design and preservation practice in Indiana could be further enhanced by due consideration of user costs. Also, the existing FHWA LCCA software could be further enhanced for increased versatility, flexibility, and more specific applicability to the needs of Indiana, particularly with regard to treatment cost estimation and development of alternative feasible preservation strategies (rehabilitation and maintenance types and timings). The study documented and developed several sets of alternative pavement design and preservation strategies consistent with existing and foreseen Indiana practice. The preservation strategies were developed using two alternative criteria—trigger values (pavement condition thresholds) and predefined time intervals (based on treatment service lives)—and are intended for further study before they can be used for practice. These strategies were developed on the basis of historical pavement management data, existing Indiana Department of Transportation (INDOT) Design Manual standards, and a survey of experts. The study also found that with a few enhancements, FHWA's current LCCA methodology and software (*RealCost*) could be adapted for use by INDOT for purposes of decision support for pavement investments and proceeded to make such enhancements. The resulting software product

(*RealCost-Indiana*) is more versatile, flexible, and specific to Indiana practice. The enhancements made include a mechanism by which the user can estimate the agency cost of each pavement design or preservation activity on the basis of line items and their unit rates, and a set of menus showing default or user-defined strategies for pavement preservation. Other enhancements made to the software include improved graphics, enhanced reporting of analysis results, and capability to simultaneously carry out analysis for more than two pavement design and preservation alternatives. A user manual was prepared to facilitate the use of the enhanced software, and a technical manual was prepared to provide for the user a theoretical basis for various concepts used in the software. The enhanced LCCA methodology and software are useful for (1) identifying alternative INDOT pavement designs, (2) identifying or developing alternative strategies for pavement rehabilitation and maintenance for a given pavement design, (3) estimating the life-cycle agency and user costs associated with a given strategy, and (4) comparative evaluation of alternative pavement designs. The enhanced methodology and software are applicable to existing pavements in need of some rehabilitation treatment, and also for planned (new) pavements. Future enhancements to the LCCA methodology and software may include a way to duly penalize parsimonious preservation strategies that are presently not adequately penalized for their resulting inferior pavement condition over the life cycle.

Li, J., J. Mahoney, S. Muench, and L. Pierce. Bituminous Surface Treatment Protocol for the Washington State Department of Transportation. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
To help the Washington State Department of Transportation (WSDOT) enhance its pavement preservation program through an improved understanding of the use of bituminous surface treatment (BST), the Highway Development and Management System (HDM-4) was used as an analytical tool to test the AADT and equivalent single-axle load (ESAL) levels appropriate as criteria for selecting the application of BST resurfacings to WSDOT pavements. It verified the feasibility of using BSTs to maintain pavements with higher traffic levels than have been applied in the past. Results also suggested that alternating the application of BST resurfacings and 45-mm hot-mix asphalt (HMA) overlays is an effective rehabilitation strategy. Finally, the study results were used to estimate the impacts that increased use of BST surfaces would have on the performance of the state-owned route system.

Li, J., S. T. Muench, J. P. Mahoney, L. M. Pierce, and N. Sivaneswaran. Calibration of the Rigid Pavement Portion of the NCHRP 1-37A Software for Use by the Washington State Department of Transportation. *Transportation Research Record: Journal of the Transportation Research Board, No. 1949,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 43–53.
A significant amount of Washington State Department of Transportation (WSDOT) portland cement concrete (PCC) pavement that was placed in the 1960s is nearing the end of its serviceable life and must soon be rehabilitated or replaced. Initial WSDOT estimates place the cost of the anticipated work at more than $600 million. A tool to predict PCC pavement deterioration and ultimate failure is needed to prioritize rehabilitation and reconstruction efforts best. The software associated with NCHRP Project 1-37A was chosen as a promising tool worthy of assessment for this application. The urgency of the situation necessitated its use, despite the lack of formal calibration guidance, some software bugs, and isolated model inconsistencies. A procedure was developed and used to calibrate the rigid pavement portion of the NCHRP 1-37A software to data obtained from the Washington State Pavement Management System (WSPMS). Significant findings resulted: (a) the rigid pavement portion of the software was calibrated successfully; (b) WSDOT pavements require calibration factors significantly different from default values; (c) the software does not model longitudinal cracking, which is significant in WSDOT pavements; (d) WSPMS does not separate longitudinal and transverse cracking, a lack that makes calibration of the software's transverse cracking model difficult; and (e) the software does not model studded tire wear, which is significant in WSDOT pavements. Results indicate that the calibrated software can be used to predict future deterioration caused by faulting, but it cannot be used to predict cracking caused by the transverse or longitudinal crack issues.

Morian, D. A., J. A. Epps, and S. D. Gibson. *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations, National Report.* Report FHWA-RD-96-208. FHWA, U.S. Department of Transportation, 1997.
This report presents an evaluation of the performance of Strategic Highway Research Program (SHRP) SPS-3 and SPS-4 experiment sites based on field reviews after 5 years of performance. Condition evaluation of the sections and Expert Task Group performance estimates are the basis for treatment assessments.

Morian, D. A., S. D. Gibson, and J. A. Epps. *Maintaining Flexible Pavements—The Long Term Pavement Performance Experiment: SPS-3 5-Year Data Analysis.* FHWA-RD-97-102. FHWA, U.S. Department of Transportation, 1998.
The Strategic Highway Research Program developed and coordinated construction of test sections for flexible pavement maintenance throughout the United States and Canada. Test sites included specific test sections for evaluation of the performance of crack sealing, slurry seals, chip seals, and thin hot-mix overlays as maintenance treatments. Each site also included an untreated control section. This report discusses the project background and analysis of monitoring data collected over a 5-year period by the Long-Term Pavement Performance project at SPS-3 sites throughout the United States and Canada. The analysis considers three important characteristics of the maintenance treatments: treatment performance, timing of application, and cost-effectiveness. In addition to data analysis results, the report conclusions include information from *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations, National Report* (May 1997).

Morian, D. A., J. W. Mack, and T. Chowdhury. The Role of Pavement Preservation in Privatized Maintenance. In *Transportation Research Circular E-C078: Roadway Pavement Preservation 2005,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 173–183. http://onlinepubs.trb.org/onlinepubs/circulars/ec078.pdf.
The concept of privatized maintenance took hold in the late 1980s when the Virginia Department of Transportation awarded the first such contract, and within 2 years a second contract, for the preservation of 350 centerline miles of Interstate highways 95 (I-95), I-77, and I-81 in Virginia. The idea of these privatized maintenance contracts was to provide the contractor a fixed level of funding, and to establish a minimum pavement performance level that had to be maintained. While some sections required rehabilitation work, maximizing the use of pavement preservation strategies for suitable pavement sections is a key to successfully managing a pavement system with fixed funds. This paper discusses the application of pavement preservation strategies, such as timely crack sealing, chip seals, and microsurfacing, and the valuable role pavement preservation has played in achieving the pavement performance and budget management objectives of privatized maintenance contracts. The discussion includes criteria for identifying the appropriate application of specific pavement preservation treatments. Pavement performance

monitoring information from the project pavement management system is also provided, documenting the success of these treatments in preserving pavement condition level in a cost-effective manner, while at the same time providing an excellent tool for cash flow management.

Morian, D. A., J. Oswalt, and A. Deodhar. Experience with Cold In-Place Recycling as a Reflective Crack Control Technique: Twenty Years Later. *Transportation Research Record: Journal of the Transportation Research Board, No. 1869,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 47–55.
Cold in-place recycling (CIR) of existing hot-mix asphalt materials has been an available treatment for more than 20 years. A study evaluated the performance of CIR projects and materials over that period. Contractors in northwestern Pennsylvania have constructed a total of 44 pavement sections. Ninety additional sections have been recycled as part of maintenance activities. (The latter are not included among the study sections.) A subset of these projects has been evaluated to determine performance characteristics and cost-effectiveness of the treatment and the material. The treatment is used typically on rehabilitation projects of roadways with 8,000 average daily traffic (ADT) or less but has been used on projects with up to 13,000 ADT. The performance of CIR in resisting reflective cracking from underlying concrete pavements and material properties over time is discussed. Material layer stiffness was evaluated using back-calculation of deflection measurement methods. Additionally, the cost of constructing these rehabilitation projects and their average cost-effectiveness are discussed.

National Cooperative Highway Research Program (NCHRP). *Synthesis of Highway Practice Topic 24-10: Asphalt Surface Treatments and Thin Overlays.* Unpublished Report. TRB, National Research Council, Washington, D.C., 1997.
No abstract available.

New York State Department of Transportation (NYSDOT). Pavement Preservation Strategy. PowerPoint Presentation. NYSDOT, Albany, N.Y., 2008.
No abstract available.

Newcomb, D. E. *Information Series 135: Thin Asphalt Overlays for Pavement Preservation.* National Asphalt Pavement Association, Lanham, Md., 2009.
No abstract available.

Ohio Department of Transportation (ODOT). *ODOT Pavement Preventive Maintenance Guidelines.* ODOT, Columbus, Ohio, 2001.
Preventive maintenance (PM) is a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, extends the service life, and maintains or improves the functional condition of the system without substantially increasing structural capacity. Pavement PM treatments reduce the amount of water infiltrating the pavement structure, protect the pavement system, slow the rate of deterioration, or correct surface deficiencies such as roughness and non-load-related distress. These treatments contribute little or no improvement to the pavement structure. They are not applicable and should never be applied if fatigue-related distress exists in the pavement.

Okpala, D., R. Schimiedlin, and S. Shober. *Fine Tooth Milling Treatment of Rutted Asphaltic Concrete Pavements.* Report WI-13-99. Wisconsin Department of Transportation. Madison, Wis., 1999.
The Portland cement concrete (PCC) pavement on Interstate I-94 between the Minnesota state line and Osseo, Wisconsin, was resurfaced with asphalt concrete (AC) between 1983 and 1990. The section completed between 1983 and 1986 showed early signs of distress with rutting in the driving-lane wheel paths. As a result, a milling technique for rut removal was used to rehabilitate this stretch of highway. The intended benefits were to improve the ride and texture of the surface and enhance safety by removing areas of potential water ponding. Different milling techniques were evaluated to identify the most effective method of achieving the desired results. Fine tooth milling was finally selected as the best available milling method for this stretch of highway. Rut, noise, and ride or international roughness index (IRI) were measured and analyzed, while the pavement distress index (PDI) values were extracted from WisDOT historical data. Measured rut values on the milled surfaces indicated minor rutting up to the third year after milling. The rutting progressively deteriorated up to the sixth year when the highway was fine-tooth milled a second time. PDI slightly decreased after milling, but in less than 1 year, became similar to the results obtained prior to milling. As a result, the district responsible for this stretch of highway recommended that subsequent fine tooth milling include adequate crack treatment. Ride as measured by IRI did not show any significant differences between pre- and postrut milling. Noise measurements indicated that the fine tooth milling does not affect significantly the interior and exterior average noise levels. The noise measuring equipment used, however, may not have isolated the discrete tone referred to as "whine," which is objectionable to auditory senses. Hence, the noise measurement results may be inconclusive. Cost analysis, based on WisDOT bid tabulations, and using the equivalent uniform annual cost method, showed that resurfacing would cost about 14 times more than milling without crack treatment and 10 times more with crack treatment. Available results, therefore, indicate that fine tooth milling is a viable rehabilitation technique for PCC pavements with AC overlay that has experienced premature rutting. It is a recommended treatment for use on this type of pavement when the desired service life is 6 years or less; however, caution and judgment should be exercised on using this technique on older, more "brittle" pavements.

Page, G. C. Open-Graded Friction Courses: Florida's Experience. *Transportation Research Record 1427,* TRB, National Research Council, Washington, D.C., 1993, pp. 1–4.
The Florida Department of Transportation began its development of open-graded mixes in 1970 to provide improved wet-weather vehicular safety. Florida's FC-2 open-graded friction course is currently required for all multilane primary and Interstate highways of which the design speed is greater than 72 km/hr (45 mph). This mix uses locally available aggregates and is produced at a reasonable cost. Changes and additions to specification criteria have been made over the years to address undesirable results. Maintenance, rehabilitation techniques, and improved performance are being studied. Asphalt additives show promise to increase the design life of open-graded mixes.

Peshkin, D. G. *Selecting a Preventive Maintenance Treatment for Flexible Pavements.* Brochure. SemMaterials, Tulsa, Okla., 2000.
No abstract available.

Peshkin, D. G., and T. E. Hoerner. *Pavement Preservation: Practices, Research Plans, and Initiatives.* Final Report, NCHRP Project 20-07, Task 184. Transportation Research Board of the National Academies, Washington, D.C., 2005. http://maintenance.transportation.org/Documents/NCHRP20-07184FinalReport.pdf.
This report identifies and documents pavement preservation research needs. The primary sources of information used to develop this report include a comprehensive survey of state highway agency (SHA) practice and a review of recent literature on the topic. SHAs and four Canadian provinces were asked to provide detailed responses to a 33-question survey; the 35 responses that were received are viewed as an accurate representation of the current state of the practice.

Peshkin, D. G., T. E. Hoerner, and K. A. Zimmerman. *NCHRP Report No 523: Optimal Timing of Pavement Preventive Maintenance Treatment Applications.* Transportation Research Board of the National Academies, Washington, D.C., 2004.

This report describes a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements. The methodology is also presented in the form of a macro-driven Microsoft Excel Visual Basic Application—designated OPTime—available to users by accessing the National Cooperative Highway Research Program (NCHRP) website (http://trb.org/news/blurb_detail.asp?id=4306). The methodology is based on the analysis of performance and cost data and applies to any of the treatments and application methods that are used by highway agencies. A plan for constructing and monitoring experimental test sections is also provided to assist highway agencies in collecting the necessary data if such data are not readily available. The report is a useful resource for state and local highway agency personnel and others involved in pavement maintenance and preservation.

Peshkin, D. G., K. D. Smith, K. A. Zimmerman, and D. N. Geoffroy. *Pavement Preventive Maintenance: Reference Manual.* Publication FHWA-HI-00-004. National Highway Institute, FHWA, U.S. Department of Transportation, 1999.

This document serves as the participant's reference manual for a FHWA/NHI training course on pavement preventive maintenance. Preventive maintenance, often summed up as "applying the right treatment to the right pavement at the right time," is becoming increasingly popular in highway agencies interested in overall pavement preservation. The objectives of this manual and course are to introduce the components of a pavement preventive maintenance program, to define potential treatment techniques and materials, to describe the relationship between pavement management and pavement preventive maintenance, and to explain cost/benefit concepts of preventive maintenance to decision makers. The material is organized into seven modules that are intended to meet the above-stated objectives. The first module is an overview of pavement preventive maintenance. This is followed by background information on the current status of preventive maintenance, appropriate definitions, objectives of preventive maintenance programs, and barriers to success. The next module introduces the most commonly used maintenance treatments for both asphalt-concrete-surfaced and PCC pavements. Because economic analyses are important in evaluating the cost-effectiveness of treatments, a module on cost analyses is included.

Peshkin, D. G., K. A. Zimmerman, T. E. Freeman, and K. D. Smith. *Pavement Preservation: Preventive Maintenance Treatment, Timing, and Selection.* Participant Workbook. NHI Course No. 131115. Publication FHWA-NHI-08-007. National Highway Institute, FHWA, U.S. Department of Transportation, 2007.

Pavement Preservation: Preventive Maintenance Treatment, Timing, and Selection is a combination and update of two existing pavement preservation courses, NHI Course 131054 on preventive maintenance program concepts and implementation, and NHI Course 131058 on treatment timing and project selection. The general goal of this course is to improve the skills of those involved in implementing pavement preservation programs. This includes improving the selection of pavement preventive maintenance projects and the selection of preventive maintenance treatments. The target audience for this course is mid- or upper-level highway agency or public works professionals responsible for pavement preservation, maintenance, and management, although anyone who is involved in the evaluation of pavements for preventive maintenance treatments, project selection, or treatment selection will find its content to be of interest and value. The course presentation is divided into nine distinct sessions: Introduction and Course Overview, Components of Preventive Maintenance Programs, How Pavements Perform, Selecting the Right Pavement, Preventive Maintenance Treatments, Preventive Maintenance Treatment Timing and Project Selection, The "Best" Treatment, Integrating Preventive Maintenance and Pavement Preservation, and Course Wrap-Up and Evaluation. It is taught over the course of two 8-hour days, and includes many group activities to present the course content and to improve the learning experience of participants.

Rao, S. P., H. T. Yu, and M. I. Darter. *The Longevity and Performance of Diamond-Ground Pavements.* Portland Cement Association, Skokie, Ill., 1999.

Diamond grinding restores a smooth riding surface with desirable friction characteristics on concrete pavements. This technique was first used in 1965 on a 19-year-old section of I-10 in southern California to eliminate excessive faulting. Since then, diamond grinding has become an important element of concrete pavement restoration. The study involved conducting a comprehensive review of existing information on diamond grinding, data collection, data analysis, and documentation of the study findings. Extensive field surveys were conducted to obtain the performance data needed for the analysis. In all, 60 pavement sections in 18 states were surveyed. In addition, performance data for 133 sections were obtained from an earlier study of the performance of diamond ground pavements. The data from the Long-Term Pavement Performance sections (concrete pavement rehabilitation) were also used to conduct direct side-by-side comparisons of the performance of diamond-ground pavement sections and other rehabilitation alternatives. Various analyses were conducted to document the performance of diamond-ground pavements, including an evaluation of faulting performance, longevity of diamond-ground texture, and the effects of diamond grinding on service life. Diamond-ground surfaces were demonstrated to provide several years of service. No evidence of any deleterious effects of diamond grinding was observed at any field site.

Raza, H. *An Overview of Surface Rehabilitation Techniques for Asphalt Pavements.* Report FHWA-PD-92-008. FHWA, U.S. Department of Transportation, 1992.

Nearly all highway agencies use some kind of conventional surface rehabilitation or maintenance technique (such as seal coats, chip seals, and thin overlays) to maintain and even extend the service life of their asphalt pavements. The application of these techniques, however, has generally been limited to low-volume roads. On occasion, a state may use a particular surface rehabilitation technique to address specific distress or as a short-term fix on the more heavily travelled routes. The follow-up evaluation and performance documentation, however, is not always done. During 1990, several preventive maintenance treatments, including slurry seals, chip seals, and thin hot-mix overlays, were applied to the existing pavements under the Strategic Highway Research Program's specific pavement studies experiment entitled Flexible Pavement Treatments (SPS-3). The treatments were applied throughout the United States and Canada to evaluate the effectiveness of maintenance strategies on pavement service life. A total of 81 test sites were selected to cover various climates and pavement conditions as well as moderate- to heavy-traffic-volume roads. Besides traditional surface rehabilitation techniques, many other approaches are now being pursued, particularly in Europe. These new techniques employ different additives or modifiers and aggregate composition as ways to attain increased pavement service life. This paper discusses various types of conventional surface rehabilitation techniques, along with many of the emerging techniques. The discussion includes information on usage, composition, construction, and (when available) performance and cost. This paper complements the work that SHRP has undertaken in this area. The compilation of such information should assist the designer (or manager) when selecting the type of rehabilitation or maintenance technique for higher-volume roads to meet both the system need (budget) and project performance criteria.

Raza, H. *State-of-the-Practice Design, Construction, and Performance of Micro-Surfacing.* Report FHWA-SA-94-051. FHWA, U.S. Department of Transportation, 1994.
This document is a comprehensive overview of the terminology, design, construction, application, and performance of microsurfacing paving technology. This technology consists of polymer-modified asphalt emulsion, 100% crushed aggregate, mineral filler, water, and field control additives as needed. Microsurfacing is primarily used to improve surface friction and to fill wheel ruts. When properly designed and constructed, it has shown good performance for 4 to 7 years. Since microsurfacing is applied in a thin layer, 10 to 13 mm, its use should be limited to structurally sound pavements. The one unresolved engineering issue concerning this technology is the lack of standard mixture design test procedures. Although the current testing procedures have resulted in microsurfacing systems that have generally provided good performance, there is a need to validate and standardize the existing test procedures and adjust design standards to better reflect the effect of various material combinations. Standardized mixture design procedures and state acceptance criteria will further enhance the acceptance of this technology by the highway community.

Reed, C. M. Seven-Year Performance Evaluation of Single Pass, Thin Lift Bituminous Concrete Overlays. *Transportation Research Record 1454,* TRB, National Research Council, Washington, D.C., 1994.
In the mid-1980s, the Illinois Department of Transportation (IDOT) faced the challenge of maintaining an aging highway network at an acceptable level of service with limited finances. Programming rehabilitation for rural highways was difficult under the existing rehabilitation policies. To minimize the required maintenance effort on these highways and maximize the available rehabilitation dollars, IDOT initiated a single-pass, thin-lift bituminous concrete overlay policy. The new rehabilitation strategy, Surface Maintenance at the Right Time (SMART), was designed for rural highways with low levels of traffic, which otherwise probably would not be rehabilitated under the current rehabilitation policy. Pavements chosen for rehabilitation under SMART ideally would have age-related distresses, with few indications of structural failure. Project rehabilitation consists of pavement patching, milling, and reflective crack control treatments where necessary, followed by a 30- to 40-mm (1.25- to 1.50-in.) bituminous concrete overlay. The SMART program has been very successful. Performance is high; rehabilitations are expected to last 7 to 10 years. Through proper project selection and construction, this program is a cost-effective method for reducing the number of highway kilometers needing rehabilitation.

Romero, P., and D. Anderson. *Life Cycle of Pavement Preservation Seal Coats.* Report UT-04.07. Utah Department of Transportation, Salt Lake City, Utah, 2005.
The use of preservation seals on asphalt pavements is a crucial part of any effective pavement management program. It is important to optimize the use of available budgets to extend the life of our pavements as much as possible. The nation's highway system is one of our most valuable assets. Analysis of the performance of surface treatments on Utah pavements indicates that open graded surface courses (OGSC) have an average life, based on skid resistance, of almost 9 years and that chip seal courses (CSC) have a significantly longer life. Out of all the factors analyzed, traffic has the most significant effect on the performance of the treatment. Factors such as aggregate source and asphalt supplier were also investigated, but lack of data prevented from reaching any significant conclusion. Based on the relative cost of both treatments and the performance observed through this study, it is recommended that Utah Department of Transportation (UDOT) expand the use of CSC to certain roads with AADT counts up to 20,000 vpd and continue the existing procedure of using CSC in highway sections with AADTs below 5,000. It is also recommended that UDOT modify the existing policies and limit the use of OGSC where the running speeds are 55 mph or greater and AADTs are in excess of 25,000 vehicles. Medium-volume facilities (5,000 to 25,000 AADT) should be sealed with treatments new to UDOT but proven in other states. An initial cost analysis showed that the implementation of the changes suggested as part of this report will result in savings of over $2 million per year in the maintenance budget, thus allowing for better use of resources while still serving the traveling public.

Shatnawi, S., R. Marsh, R. G. Hicks, and H. Zhou. Pavement Preservation Strategy Selection in California. In *Transportation Research Circular E-C098: Maintenance Management 2006,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 29–44. http://onlinepubs.trb.org/onlinepubs/circulars/ec098.pdf.
The California Department of Transportation (Caltrans) has embarked on an ambitious program for pavement preservation and has established a pavement preservation task group (PPTG) to handle activities related to this program. One of the subgroups is charged with improving the pavement preservation strategy selection process for both asphalt and portland cement concrete (PCC) pavements. This paper describes the pavement preservation strategy selection process currently used by Caltrans for flexible pavements. It identifies the many factors that are considered in the process of selecting an appropriate maintenance treatment for a pavement. These factors include pavement age and condition, traffic levels, expected future plans, as well as available funding and agency policy. For a properly constructed new pavement, typical pavement preservation treatments include those to delay the onset of distresses or to slow down the progress of the distresses. As the pavement ages, the pavement may become a candidate for routine and contract maintenance (e.g., crack sealing, grinding, seal coats, or thin hot-mix overlays), minor or major rehabilitation, and eventually reconstruction. Determining the appropriate maintenance treatment, based on the pavement condition index of the existing pavement and cost-effectiveness of the treatment, also depends on the timing of the treatment. Once a pavement has been identified for pavement maintenance, a specific treatment is selected to address the specific distress mechanism for the pavement. The most important factors considered when choosing a maintenance treatment include the following: Will the treatment address the distresses present? Can the required preparation for the treatment be carried out? Is the treatment cost-effective? Can the treatment be applied before the situation being addressed changes? A discussion of the basic steps in the pavement preservation strategy selection process is presented in this paper. These steps include the following: (1) assess the existing pavement conditions: the pavement distress mechanisms are identified from field pavement surveys along with the use of a field distress identification manual; (2) determine the feasible treatment options: the feasibility is determined by a treatments ability to address the functional and structural condition of the pavement while also meeting any future needs; at this stage, the primary purpose of selecting feasible treatments is to determine if the identified maintenance treatments work for the pavement conditions; and (3) analyze and compare the feasible options with each other: the feasible options are further compared in terms of cost, life expectancy of the treatment, and extended pavement life benefits due to treatment; to determine cost-effectiveness of each treatment, a life cycle or other cost-effectiveness measure should be made. This

paper also addresses proposed changes to the selection process to include treatments for PCC pavements and to include a more detailed cost-effectiveness approach using life-cycle cost analysis.

Shatnawi, S., and B. D. Toepfer. *Pavement Preservation Treatment Construction Guide.* Online Guide. FHWA, U.S. Department of Transportation, 2006. http://fhwapap34.fhwa.dot.gov/NHI-PPTCG/index1.htm.
No abstract available.

Shober, S., and D. Friedrichs. Pavement Preservation Strategy. *Transportation Research Record 1643,* TRB, National Research Council, Washington, D.C., 1998, pp. 44–53.
An effective pavement management system requires a comprehensive pavement preservation strategy (PPS). Wisconsin's PPS is guided by a philosophy whose goal is to optimize pavement performance to provide the highest quality service to the customer per unit of expenditure. The PPS is customer oriented and views "service" in terms of user comfort, convenience, and safety. The strategy is broad scoped and considers all pavement management activities, from "do nothing" to reconstruction. Wisconsin's PPS has program values that are based on solid research that has been field verified. The treatment alternatives recommended for any particular pavement problem address the causes, not the symptoms, of that particular problem—thus, the root cause of the problem is addressed, and funds are not used to treat merely a symptom. Accordingly, the PPS is termed a cause-based instead of a schedule-based strategy (applying treatments on a predetermined schedule), or a "worst first" strategy (treating the worst pavements first). The PPS follows a logical progression through a series of evaluations to convert a set of raw, field-collected data (ride and distress) to, ultimately, a set of recommended actions. The process moves from raw data to an evaluation of the level of the distress. Combinations of distress levels are used to identify specific pavement problems. In turn, these pavement problems are evaluated as a family to generate appropriate, cost-beneficial solutions.

Shuler, S. Design and Construction of Chip Seals for High Traffic Volume. In *Flexible Pavement Rehabilitation and Maintenance* (P. S. Kandhal and M. Stroup-Gardiner, eds.), Publication STP 1348, American Society for Testing and Materials, West Conshohocken, Pa., 1998.
No abstract available.

Shuler, S. *Evaluation of the Performance, Cost-Effectiveness, and Timing of Various Preventive Maintenances.* Interim Report. Report CDOT-DTD-R-2006-6. Colorado Department of Transportation, Denver, Colo., 2006.
This research is intended to determine the most economical means of extending pavement life through preventive maintenance treatments in Colorado. The process proposed to accomplish this includes a survey of current published literature and interviews with individuals responsible for preventive maintenance, installation of experimental test pavements to measure performance under local conditions, and recommendations based on the findings. This report documents the progress made for the first 18 months of a 5-year study. This includes a survey of the literature, interviews with maintenance and construction personnel, the draft of a best practices manual, and the installation of most of the test pavements.

Smith, K. D., T. E. Hoerner, and D. G. Peshkin. *Concrete Pavement Preservation Workshop: Reference Manual.* FHWA, U.S. Department of Transportation, 2008.
This document serves as the reference manual for the 1½-day FHWA workshop on concrete pavement preservation. The purpose of the document is to provide the most up-to-date information available on the design, construction, and selection of cost-effective concrete pavement preservation strategies. It concentrates primarily on strategies and methods that are applicable at the project level, and not at the network level, where pavement management activities function and address such issues as prioritizing and budgeting. Detailed information is presented on seven specific concrete pavement preservation treatments: slab stabilization, partial-depth repairs, full-depth repairs, retrofitted edge drains, load transfer restoration, diamond grinding, and joint resealing. In addition, information is provided on pavement evaluation techniques and strategy selection procedures.

Strategic Highway Research Program (SHRP 2). Project R26: Preservation Approaches for High Traffic Volume Roadways. SHRP 2 Request for Proposals. 2007. http://onlinepubs.trb.org/onlinepubs/shrp2/R26RFP.pdf.
To address the challenges of moving people and goods efficiently and safely on the nation's highways, Congress has created the second Strategic Highway Research Program (SHRP 2). SHRP 2 is a targeted, short-term research program carried out through competitively awarded contracts to qualified researchers in the academic, private, and public sectors. SHRP 2 addresses four strategic focus areas: the role of human behavior in highway safety (Safety); rapid highway renewal (Renewal); congestion reduction through improved travel time reliability (Reliability); and transportation planning that better integrates community, economic, and environmental considerations into new highway capacity (Capacity). Under current legislative provisions, SHRP 2 will receive approximately $170 million, with total program duration of 7 years. Additional information about SHRP 2 can be found on the program's website at www.TRB.org/SHRP2.

United States Army Corps of Engineer (USACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineering Support Agency (AFCESA). *Unified Facilities Criteria (UFC): Airfield Pavement Condition Survey Procedures Pavements.* Publication UFC 3-260-16FA. U.S. Department of Defense, 2004.
No abstract available.

University of Washington Pavement Tools Consortium (PTC). *Pavement Guide Interactive.* 2009. http://training.ce.washington.edu/PGI/.
This guide is a multimedia CD-ROM whose primary purpose is to provide a general pavement overview covering all aspects from materials to design to construction to maintenance. It functions as a "website" that resides on a CD-ROM and requires only a PC/Mac and minimal freeware to access the information. It consists of 275 web pages, 2,500 images, 50 animations, 14 videos, and 11,000 hyperlinks.

Wade, M., R. DeSombre, and D. Peshkin. *High Volume/High Speed Asphalt Roadway Preventive Maintenance Surface Treatments.* Final Report. Report SD99-09. South Dakota Department of Transportation, Pierre, S.Dak., 2001.
The South Dakota Department of Transportation (SDDOT) has made extensive use of chip seal and sand seal surface treatments in the maintenance of their asphalt concrete (AC) pavements. Such surface treatments have been found to provide a cost-effective means of extending the life of AC pavements in South Dakota. Although chip seals and sand seals have for the most part been reliable treatments, there have been some notable failures, especially on high-volume, high-speed roadways. This project was undertaken to investigate the use of chip seals for such applications and to make recommendations to improve their performance. This project also involved the development of guidelines for the design and construction of chip seals. To evaluate the use of chip seals in South Dakota, several efforts were undertaken. First, an extensive literature review was conducted to develop an understanding of the latest

practices and experiences. Second, interviews were conducted with SDDOT from all departments involved in the chip seal process to investigate their practices and to determine areas for improvement. Finally, test sections were constructed to evaluate the performance of standard and modified chip-seal designs. The test sections consisted of 12 chip-seal designs and included two aggregate types (quartzite and natural aggregate) and alternate chip-seal designs with new gradations and other modifications and enhancements. Based on these efforts, recommendations are provided to improve chip seal performance. In addition, guidelines were developed to select feasible surface treatments for a specific project.

Zimmerman, K., and D. Peshkin. The Seven Stallers. In *Pavement Preservation Compendium II,* Publication FHWA-IF-06-049, FHWA, U.S. Department of Transportation, 2006, pp. 59–64. www.fhwa.dot.gov/pavement/preservation/ppc06.pdf.

This article addresses seven of the most deadly misconceptions about pavement preventive maintenance. These misconceptions are deadly because any one of them is enough to stop a program in its tracks. Therefore, suggestions for addressing each misconception also are provided, based on the authors' experiences working with agencies that have been using preventive maintenance concepts for years as well as with agencies that are just beginning to implement these programs.

APPENDIX B

Preservation Questionnaire Survey Form

Introduction

The practice of pavement preservation in general and preventive maintenance in particular is a growing trend among transportation agencies around the United States. Over the past decade alone, a number of state highway agencies (SHA) have created or formalized their preservation programs. At the same time, other agencies that might have been practicing preservation for a longer time have extended their programs to cover a greater proportion of their pavement network than ever before. Still other agencies are today in the process of creating formal preservation programs.

While many agencies are in the process of formalizing, extending, or developing their pavement preservation programs, there is a need for further information regarding the use of preservation on high-traffic-volume roadways. The practices used on these facilities are viewed by some as not as widespread or well documented as on lower-volume roadways. The Strategic Highway Research Program 2 (SHRP 2) Renewal Project R26 is addressing the need for this important information in the following manner:

- Synthesizing the current state of the practice for preservation approaches for high-traffic-volume roadways;
- Developing guidelines on pavement preservation strategies for high-traffic-volume roadways; and
- Identifying promising pavement preservation strategies for application on high-traffic-volume roadways that might not commonly be used.

Purpose of Questionnaire

The purpose of this questionnaire is to obtain information on current pavement preservation practices for high-traffic-volume roadways from North American and international practitioners. Techniques used for lower-volume roadways may not be appropriate for high-traffic-volume roadways, because as less time is available to construct the treatments and night work may not be feasible. Responses collected from this questionnaire will be used to develop a comprehensive summary of the current state of practice for both portland cement concrete (PCC) and hot-mix asphalt (HMA) surfaced pavements. The survey results will also be used to develop guidelines for the use of these treatments that can be implemented by public agencies.

You are being asked to complete this questionnaire because of your background and familiarity with your agency's pavement preservation practices. Your response is very important. It will lead to improved guidance on the use of pavement preservation for high-traffic-volume roadways, which in turn should contribute to improved pavement performance and lower costs to maintain these important pavements. If, however, you feel that someone else in your organization is more qualified to respond to this request for information, please pass this on to them. Thank you in advance for your assistance.

Questionnaire Respondent Information

Please provide some general information about yourself and your experience with pavement preservation:

Name

____

Title

____

Address

____

Phone

____

E-mail

____

Pavement preservation experience/background (e.g., I have been involved in . . . ; responsibilities in pavement preservation include . . .):

Definitions Used in the Survey

Several terms are used throughout this questionnaire. The following definitions are provided for the sake of consistency and not as an attempt to impose on an agency a specific definition of any of these terms.

Pavement Preservation—A program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety, and meet motorist expectations.

Pavement Preventive Maintenance—A planned strategy of cost-effective treatments applied to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity).

Preventive Maintenance Treatment—Any individual maintenance activity that is used in a preventive manner (i.e., applied to a pavement in relatively good condition as defined by the agency), while not adding any structural capacity to the pavement. Examples, of preventive maintenance treatments include crack sealing and joint resealing, fog seals, chip seals, slurry seals, microsurfacing, dowel bar retrofitting, diamond grinding, and combinations of these types of actions.

Functional Condition—The condition of the roadway which enables it to provide safe, unimpeded service. Functional condition is measured by factors such as surface distress, smoothness, and skid resistance. The functional condition of a roadway does not include consideration of the pavement's load carrying, or structural, condition.

Contract Maintenance—Contract maintenance is the use of a contract to outsource maintenance activities (either to the private sector or to another public agency) that had been done by the agency itself. Contract maintenance, also known as maintenance-by-contract and privatized maintenance, addresses the transfer of work traditionally conducted by the public sector to the private sector.

Warranties—Warranties provide contracting agencies with another level of protection against early contractor failure or default, construction problems, or other performance issues. Simply put, a warranty is an assurance to any agency that the work completed by the contractor was constructed in a sound manner and that it will remain in acceptable condition for a stated period of time.

Performance Specifications—The performance criteria should describe the outcome that is being sought from the contractor in each year of the contract period and provide the contractor with the autonomy needed to achieve the results specified. When setting the criteria, the agency should ensure that the state goals are achievable over the contracting period: they should be at least as high as the standards observed by the agency itself.

Quality Control/Quality Assurance (QC/QA)—Quality control generally refers to testing by the contractor for the purpose of process control and to ensure meeting or exceeding specifications. Quality assurance typically involves testing by the agency or its representative to determine compliance with specifications.

Questions

1. Please provide details of the typical average daily traffic (ADT) values associated with the traffic classifications of low, medium, and high traffic volume for rural and urban roadways in your agency. These classifications will be used as the basis for further questions in the questionnaire.

Rural, Low Volume is less than or equal to	
Rural, Medium Volume range is (e.g., . . . to . . .)	
Rural, High Volume is greater than or equal to	
Urban, Low Volume is less than or equal to	
Urban, Medium Volume range is (e.g., . . . to . . .)	
Urban, High Volume is greater than or equal to	

2. There are a variety of factors that influence the selection of a preventive maintenance treatment. Please rank the following 18 factors in terms of the level of importance that your agency places on each factor when selecting the most appropriate preventive maintenance treatment.

Factor	Not Important	Low Priority	Medium Priority	High Priority
Agency experience with treatment	☐	☐	☐	☐
Material availability	☐	☐	☐	☐
Previous treatment failure	☐	☐	☐	☐
Alternate route availability	☐	☐	☐	☐
Safety concerns	☐	☐	☐	☐
Perception	☐	☐	☐	☐
Noise	☐	☐	☐	☐
Work zone	☐	☐	☐	☐
Treatment cost	☐	☐	☐	☐
Traffic volume	☐	☐	☐	☐
Experienced contractor availability	☐	☐	☐	☐
Bias against treatment	☐	☐	☐	☐
Traffic control requirements	☐	☐	☐	☐
Closure time	☐	☐	☐	☐
Liability concerns	☐	☐	☐	☐
Durability/expected treatment life	☐	☐	☐	☐
Production rates	☐	☐	☐	☐
Time before trafficking	☐	☐	☐	☐
Risk associated with treatment failure	☐	☐	☐	☐
Climate	☐	☐	☐	☐

Rural Roads

3. Using the traffic classifications you defined in question 1, which of the following treatments does your agency apply in a preventive manner (i.e., to pavements in good condition) on RURAL roadways? Check all boxes that apply or mark "not used" if this treatment is not used by your agency.

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Low Traffic	Medium Traffic	High Traffic	Not Used
Crack fill	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

Treatments for Portland Cement Concrete (PCC) Pavements	Low Traffic	Medium Traffic	High Traffic	Not Used
Concrete joint resealing	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

Urban Roads

4. Using the traffic classifications you defined in question 1, which of the following treatments does your agency apply in a preventive manner (i.e., to pavements in good condition) on URBAN roadways? Check all boxes that apply or mark "not used" if this treatment is not used by your agency.

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Low Traffic	Medium Traffic	High Traffic	Not Used
Crack fill	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ________________________________	☐	☐	☐	☐

Treatments for Portland Cement Concrete (PCC) Pavements	Low Traffic	Medium Traffic	High Traffic	Not Used
Concrete joint resealing	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [<1 in.])	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5-in.])	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ________________________________	☐	☐	☐	☐

5. Do you use a different set of treatments on RURAL high-traffic-volume roads than on RURAL low-traffic-volume roads? (Check the one answer that is most representative).

   If answer is yes, then proceed to "RURAL ROADS." If answer is no, then you may skip to question 6.

   ☐ No
   ☐ Yes

Rural Roads

Please check those treatments that you don't consider applicable for RURAL high-traffic-volume roadways.

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Not Applicable
Crack fill	☐
Crack seal	☐
Cape seal	☐
Fog seal	☐
Scrub seal	☐
Slurry seal	☐
Rejuvenators	☐
Single-course microsurfacing	☐
Multiple-course microsurfacing	☐
Single-course chip seal	☐
Multiple-course chip seal	☐
Chip seals with polymer-modified asphalt binder	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐
Profile milling (diamond grinding)	☐
Ultra-thin whitetopping	☐
Drainage preservation	☐
Other: ______________________	☐

Treatments for Portland Cement Concrete (PCC) Pavements	Not Applicable
Concrete joint resealing	☐
Concrete crack sealing	☐
Diamond grinding	☐
Diamond grooving	☐
Partial-depth concrete pavement patching	☐
Full-depth concrete pavement patching	☐
Dowel bar retrofit (load-transfer restoration)	☐
Thin PCC overlays	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐
Drainage preservation	☐
Other: ______________________	☐

6. Do you use a different set of treatments on URBAN high-traffic-volume roads than on URBAN low-traffic-volume roads? (Check the one answer that is most representative).

   If answer is yes, then proceed to "URBAN ROADS." If answer is no, then you may skip to question 7.

   ☐ No
   ☐ Yes

Urban Roads

Please check those treatments that you don’t consider applicable for URBAN high-traffic-volume roadways.

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Not Applicable
Crack fill	☐
Crack seal	☐
Cape seal	☐
Fog seal	☐
Scrub seal	☐
Slurry seal	☐
Rejuvenators	☐
Single-course microsurfacing	☐
Multiple-course microsurfacing	☐
Single-course chip seal	☐
Multiple-course chip seal	☐
Chip seals with polymer-modified asphalt binder	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐
Profile milling (diamond grinding)	☐
Ultra-thin whitetopping	☐
Drainage preservation	☐
Other: ________________________________	☐

Treatments for Portland Cement Concrete (PCC) Pavements	Not Applicable
Concrete joint resealing	☐
Concrete crack sealing	☐
Diamond grinding	☐
Diamond grooving	☐
Partial-depth concrete pavement patching	☐
Full-depth concrete pavement patching	☐
Dowel bar retrofit (load-transfer restoration)	☐
Thin PCC overlays	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐
Drainage preservation	☐
Other: ____________________________	☐

Truck Traffic

7. Please indicate whether you are more or less likely to use each treatment on high-traffic-volume roads that have HIGH TRUCK traffic volumes as compared to those with little truck traffic. If you do not use the treatment, then indicate that it is a treatment that is not used by your agency.

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	More Likely	No Difference	Less Likely	Not Used
Crack fill	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

Treatments for Portland Cement Concrete (PCC) Pavements	More Likely	No Difference	Less Likely	Not Used
Concrete joint resealing	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

Rural Roads

8. For those treatments that were checked as "Not Used" on RURAL high-traffic-volume roadways under question 3, please indicate the reason(s) it is not being used. Check all boxes that apply.

HMA-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate
Crack fill	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ____________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

PCC Pavement Treatments for RURAL High-Traffic-Volume Roadways	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate
Concrete joint resealing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ____________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Urban Roads

9. For those treatments that were checked as “Not Used” on URBAN high-traffic-volume roadways under question 4, please indicate the reason(s) it is not being used. Check all boxes that apply.

HMA-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate
Crack fill	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

PCC Pavement Treatments for URBAN High-Traffic-Volume Roadways	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate
Concrete joint resealing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

10. In addition to the treatments included in questions 3 or 4, are there other treatments that you are considering using, but have not?

If answer is yes, then proceed. If answer is no, then skip to question 11.

☐ No
☐ Yes

You stated that there are other treatments that you are considering using. Please identify any treatments that you considered using but the treatment is not fully developed, does not yet have proven performance, or was not used because of another reason.

	Reasons the Treatment Are Not Currently Used		
Other Considered Treatment Types	**Not Fully Developed**	**No Proven Performance**	**Other Reason**
____________	☐	☐	____________
____________	☐	☐	____________
____________	☐	☐	____________
____________	☐	☐	____________
____________	☐	☐	____________

Rural Roads

11. Please list the three MOST successful pavement preservation treatment types used on your RURAL high-traffic-volume roadways, starting with the most successful, and briefly explain why each treatment is successful for your agency.

Treatment 1	
Treatment 2	
Treatment 3	

Urban Roads

12. Please list the three MOST successful pavement preservation treatment types used on your URBAN high-traffic-volume roadways starting with the most successful and briefly explain why each treatment is successful for your agency.

Treatment 1	
Treatment 2	
Treatment 3	

Rural Roads

13. Please list the three LEAST successful pavement preservation treatment types used on your RURAL high-traffic-volume roadways starting with the least successful and briefly explain why each treatment is unsuccessful for your agency.

Treatment 1	
Treatment 2	
Treatment 3	

Urban Roads

14. Please list the three LEAST successful pavement preservation treatment types used on your URBAN high-traffic-volume roadways starting with the least successful and briefly explain why each treatment is unsuccessful for your agency.

Treatment 1	
Treatment 2	
Treatment 3	

Rural Roads

15. Available facility closure time is an important consideration when selecting the most appropriate treatment for a pavement section. Please use the following to indicate under which of the following available closure time scenarios you consider using the listed treatments on RURAL roadways.

HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Crack fill	☐	☐	☐
Crack seal	☐	☐	☐
Cape seal	☐	☐	☐
Fog seal	☐	☐	☐
Scrub seal	☐	☐	☐
Slurry seal	☐	☐	☐
Rejuvenators	☐	☐	☐
Single-course microsurfacing	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐
Single-course chip seal	☐	☐	☐
Multiple-course chip seal	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐
Drainage preservation	☐	☐	☐
Other: ______________________________	☐	☐	☐

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Concrete joint resealing	☐	☐	☐
Concrete crack sealing	☐	☐	☐
Diamond grinding	☐	☐	☐
Diamond grooving	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐

(continued on next page)

(continued from page 119)

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐
Thin PCC overlays	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Drainage preservation	☐	☐	☐
Other: ______________________________	☐	☐	☐

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

Urban Roads

16. Please use the following to indicate under which of the following available closure time scenarios you consider using the listed treatments on URBAN roadways.

HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Crack fill	☐	☐	☐
Crack seal	☐	☐	☐
Cape seal	☐	☐	☐
Fog seal	☐	☐	☐
Scrub seal	☐	☐	☐
Slurry seal	☐	☐	☐
Rejuvenators	☐	☐	☐
Single-course microsurfacing	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐
Single-course chip seal	☐	☐	☐
Multiple-course chip seal	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐
Drainage preservation	☐	☐	☐
Other: ______________________________	☐	☐	☐

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Concrete joint resealing	☐	☐	☐
Concrete crack sealing	☐	☐	☐
Diamond grinding	☐	☐	☐

(continued on next page)

(continued from page 120)

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift	Weekend	Longer
Diamond grooving	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐
Thin PCC overlays	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐
Drainage preservation	☐	☐	☐
Other: ______________________________	☐	☐	☐

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

17. Please check any of the following contracting mechanisms that your agency uses to help ensure the quality and future performance of the following treatments on your high-traffic-volume roadways. Please check all that apply.

	Contracting Mechanisms Used			
HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	QC/QA	Performance Specifications	Warranties	Contract Maintenance
Crack fill	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

PCC Pavement Treatments for High-Traffic-Volume Roadways	Contracting Mechanisms Used			
	QC/QA	Performance Specifications	Warranties	Contract Maintenance
Concrete joint resealing	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐
Other:______________________________	☐	☐	☐	☐

18. Does your agency have QC/QA procedures for preventive maintenance applications in place?

    If answer is no, proceed. If answer is yes, skip to question 19.

    ☐ No
    ☐ Yes. If possible, provide a copy of the procedures (by faxing, e-mailing, or providing a URL link).
    ____

    As indicated by a "No" response to question 18, you do not currently have QC/QA procedures for preventive maintenance treatments in place. Do you have plans for implementing them?

    ☐ No
    ☐ Yes. Specify:____

    As indicated by a "No" response to question 18, you indicated that your agency does not use warranty specifications on any of your preventive maintenance treatments. Do you have any plans/interest in the use of warranties?

    ☐ No
    ☐ Yes. Which treatments?____

19. If you indicated that agency has implemented performance-related specifications for preventive-maintenance treatments, briefly describe your experience with these specifications.

20. If you indicated that you do not have performance-related specifications, what are your plans for implementing them?

Rural Roads

21. For RURAL high-traffic-volume roadways, which treatments do you use to address the following pavement performance issues. Please check all that apply.

HMA-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress
Crack fill	☐	☐	☐	☐	☐	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ________________________	☐	☐	☐	☐	☐	☐	☐	☐	☐

PCC-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress
Concrete joint resealing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐	☐	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐

(continued on next page)

(continued from page 123)

PCC-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress
Full-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ____________________	☐	☐	☐	☐	☐	☐	☐	☐	☐

Urban Roads

22. For URBAN high-traffic-volume roadways, which treatments do you use to address the following pavement performance issues. Please check all that apply.

HMA-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress
Crack fill	☐	☐	☐	☐	☐	☐	☐	☐	☐
Crack seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fog seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Scrub seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rejuvenators	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course microsurfacing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Single-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multiple-course chip seal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip seals with polymer-modified asphalt binder	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., NovaChip)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold milling and HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot in-place HMA recycling (<50 mm [<1.95 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold-in-place recycling (<100 mm [<4.0 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Profile milling (diamond grinding)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin whitetopping	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ____________________	☐	☐	☐	☐	☐	☐	☐	☐	☐

PCC-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress
Concrete joint resealing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Concrete crack sealing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grinding	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diamond grooving	☐	☐	☐	☐	☐	☐	☐	☐	☐
Partial-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐
Full-depth concrete pavement patching	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dowel bar retrofit (load-transfer restoration)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin PCC overlays	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thin HMA overlay (<40 mm [<1.5 in.])	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: ________________________	☐	☐	☐	☐	☐	☐	☐	☐	☐

23. Does your agency consider user costs in the treatment selection process for preventive maintenance applications? (Check the one answer that is most representative.)

If you answered yes, proceed to *a*. If you answered no, skip to *b*.

☐ No
☐ Yes

a. Are user costs quantified numerically in your treatment selection process?

☐ No
☐ Yes

b. Does your agency have plans to begin considering (or incorporating) user costs in the treatment selection process?

☐ No
☐ Yes. Please explain: ____

24. There are a number of reasons why agencies may not be performing pavement preservation on high-traffic-volume roadways. Please prioritize the additional guidance that you feel is needed for the successful implementation of preservation strategies on high-traffic-volume roadways.

1 = No guidance needed
2 = Some guidance
3 = Significant guidance needed

_____ Other agency experience with treatment
_____ Experienced contractor availability list
_____ List of material availability
_____ Typical traffic control requirements
_____ Typical closure time information
_____ Durability/expected treatment life
_____ Typical noise associated with treatment
_____ Treatment production rates
_____ Time needed before trafficking
_____ Typical treatment costs by region
_____ Applicable traffic volumes
_____ Appropriate climatic regions for treatments

APPENDIX C

Summary of Preservation Questionnaire Responses

SHRP 2 Project R26 Questionnaire Start Date: 8/20/2008
End Date: 12/31/2008
Total Respondents Completed: 57
Partial Completions: 1

1.0 Pavement Preservation Experience/Background

As shown below, respondents had a wide range of experience in pavement preservation. Not all respondents noted their years of experience.

Range in Years of Experience	Number of Respondents
<5	7
6 to 10	7
11 to 15	3
16 to 20	4
>20	7

2.0 Questions

Question 1

Please provide details of the typical average daily traffic (ADT) values associated with the traffic classifications of low, medium, and high traffic volume for rural and urban roadways in your agency. These classifications will be used as the basis for further questions in the questionnaire.

Rural, Low Volume is less than or equal to
Rural, Medium Volume range is (e.g., . . . to . . .)
Rural, High Volume is greater than or equal to
Urban, Low Volume is less than or equal to
Urban, Medium Volume range is (e.g., . . . to . . .)
Urban, High Volume is greater than or equal to

Table C.1 presents the 58 agency responses regarding high-traffic-volume classification for rural and urban roadways.

Table C.1. Categorical Summary of Agency Designations for High-Volume Rural and Urban Roadways

High-Traffic-Volume Categorizations		
Low ADT (<10,000 vpd)	**Medium ADT (10,000 to 19,999 vpd)**	**High ADT (≥20,000 vpd)**
Louisiana DOT (7,000)	Alaska DOT (10,000)	Connecticut DOT (30,000)
Michigan DOT (3,400 est.)	Hawaii DOT (10,000)	Rhode Island DOT (30,000)
Missouri DOT (1,000)	Maine DOT (10,000)	South Carolina DOT (20,000)
Montana DOT (6,000)	Minnesota DOT (10,000)	British Columbia (100,000)
New York DOT (4,000/lane)	New Hampshire (10,000)	
Pennsylvania DOT (2,000)	Oklahoma DOT (10,000)	
South Dakota DOT (1,500)	Ontario (10,000)	
Washington DOT (5,000)		
Alberta (5,000)		
FHWA-CFLHD (4,000)		
For agencies that make a distinction between rural and urban traffic volume categorizations:		
Georgia DOT (5,000 rural/8,000 urban)	Wyoming DOT (10,000 rural/15,000 urban)	Virginia DOT (20,000 rural/40,000 urban)
Iowa DOT (3,500 rural)	Iowa DOT (11,500 urban)	
	Florida DOT (10,000 rural)	Florida DOT (40,000 urban)
Kansas DOT (3,000 rural)		Kansas DOT (20,000 urban)
Kentucky DOT (5,000 rural)	Kentucky DOT (10,000 urban)	
Mississippi DOT, Newton (3,000–7,000 rural)		Mississippi DOT, Newton (20,000 urban)
Mississippi DOT, Batesville (2,000 rural)	Mississippi DOT, Batesville (10,000 urban)	
Mississippi DOT, Tupelo (3,000–7,000 rural)		Mississippi DOT, Tupelo (20,000 urban)
	Nevada DOT (10,000 rural)	Nevada DOT (100,000 urban)
New Mexico DOT (5,000 rural)	New Mexico DOT (15,000 urban)	
North Carolina DOT (5,000 rural)	North Carolina DOT (10,000 urban)	
Tennessee DOT (5,000 rural)	Tennessee DOT (10,000 urban)	
Texas DOT (1,000 rural)	Texas DOT (10,000 urban)	
Manitoba (4,000 rural)	Manitoba (10,000 urban)	
Quebec (8,000 rural)		Quebec (20,000 urban)

Organizations: NAPA (10,000); NACE (15,000 rural/60,000 urban).
Other: Colorado DOT categorizes by ESALs. Caltrans categorizes by traffic index, TI: TI ≤ 18 rural and TI ≤ 15 urban, where $TI = 9.0 \times (ESAL \div 10^6)^{0.119}$. Utah DOT (Region 4) categorizes by Interstate or non-Interstate (25,000 ADT and 2,500 ADT, respectively). City of Phoenix, Ariz., categorizes by 20,000 ADT rural, 50,000 ADT urban.

Question 2

There are a variety of factors that influence the selection of a preventive maintenance treatment. Please rank the following 18 factors in terms of the level of importance that your agency places on each factor when selecting the most appropriate preventive maintenance treatment.

Table C.2 presents the 58 agency responses and includes summary statistics associated with the answers.

Table C.2. Summary of Factors Influencing Agency Selection of Preventive Maintenance Treatment

Factor	Not Important % Response	Low Priority % Response	Medium Priority % Response	High Priority % Response	Number of Respondents
Agency experience with treatment	2	5	40	53	58
Material availability	2	7	48	43	58
Previous treatment failure	0	7	41	52	58
Alternate route availability	26	40	28	7	58
Safety concerns	0	3	21	76	58
Perception	2	36	50	12	58
Noise	19	39	40	2	57
Work zone	2	22	59	17	58
Treatment cost	0	0	26	74	58
Traffic volume	0	7	40	53	57
Experienced contractor availability	5	14	60	21	58
Bias against treatment	12	32	45	11	56
Traffic control requirements	2	24	55	19	58
Closure time	2	17	57	24	58
Liability concerns	4	21	42	33	57
Durability/expected treatment life	0	2	35	63	57
Production rates	9	29	52	10	58
Time before trafficking	3	21	55	21	58
Risk associated with treatment failure	2	5	57	36	58
Climate	7	28	44	21	57

Question 3

Using the traffic classifications you defined in question 1, which of the following treatments does your agency apply in a preventive manner (i.e., to pavements in good condition) on RURAL roadways? Check all boxes that apply or mark "not used" if this treatment is not used by your agency.

Tables C.3 and C.4 present the 58 agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.3. Summary of Preventive Maintenance Treatments Used on HMA RURAL Roadways Distinguished by Traffic Volume Classifications Defined in Question 1

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Low Traffic % Response	Medium Traffic % Response	High Traffic % Response	Not Used % Response	Number of Respondents
Crack fill	74	74	74	19	58
Crack seal	83	88	86	9	58
Cape seal	9	14	9	79	58
Fog seal	45	26	14	48	58
Scrub seal	14	16	2	83	58
Slurry seal	35	25	11	54	57
Rejuvenators	16	18	11	77	57
Single-course microsurfacing	42	60	54	26	57
Multiple-course microsurfacing	31	51	44	42	55
Single-course chip seal	88	62	24	12	58
Multiple-course chip seal	55	43	11	39	56
Chip seals with polymer-modified asphalt binder	64	57	31	22	58
Ultra-thin bonded wearing course (e.g., NovaChip)	16	33	48	48	58
Thin HMA overlay (<40 mm [<1.5 in.])	64	71	66	16	58
Cold milling and HMA overlay (<40 mm [<1.5 in.])	55	67	64	22	58
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	24	22	22	66	58
Hot in-place HMA recycling (<50 mm [<1.95 in.])	22	21	19	67	58
Cold-in-place recycling (<100 mm [<4.0 in.])	41	38	29	45	58
Profile milling (diamond grinding)	17	28	41	57	58
Ultra-thin whitetopping	10	17	16	72	58
Drainage preservation	50	50	59	43	56
Other (see below)	46	38	31	54	13

Other Treatments (Table C.3):

- Our minimum HMA depth is 1.5 in., which we would use on any traffic volume. We have experimented with 4.75 mm "sand" mixes less than this, but not typically used.
- Rubber chip seals.
- 1.5 in. HMA mill and fill.
- Spot strip sealing.
- HMA thin overlay <60 mm.

Agency Comments (Table C.3):

- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.
- All state chip seal receive fog seal.

Table C.4. Summary of Preventive Maintenance Treatments Used on PCC RURAL Roadways Distinguished by Traffic Volume Classifications Defined in Question 1

Treatments for Portland Cement Concrete (PCC) Pavements	Low Traffic % Response	Medium Traffic % Response	High Traffic % Response	Not Used % Response	Number of Respondents
Concrete joint resealing	39	55	73	25	56
Concrete crack sealing	42	56	71	24	55
Diamond grinding	27	48	77	25	56
Diamond grooving	5	12	34	66	56
Partial-depth concrete pavement patching	36	51	69	29	55
Full-depth concrete pavement patching	38	62	84	16	56
Dowel bar retrofit (load-transfer restoration)	14	32	59	39	56
Thin PCC overlays	5	9	16	80	55
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	11	18	27	71	56
Thin HMA overlay (<40 mm [<1.5 in.])	15	31	31	58	55
Drainage preservation	28	39	54	44	54
Other: (see below)	0	0	8	92	12

Other Treatments (Table C.4):
- HMA from 40 to 60 mm.

Agency Comments (Table C.4):
- We only have 154 lane miles of PCC pavements [. . .], mostly in [. . .] metropolitan area[s].
- No concrete roads [. . .].
- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.

Question 4

Using the traffic classifications you defined in question 1, which of the following treatments does your agency apply in a preventive manner (i.e., to pavements in good condition) on URBAN roadways? Check all boxes that apply or mark “not used” if this treatment is not used by your agency.

Tables C.5 and C.6 present the 58 agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.5. Summary of Preventive Maintenance Treatments Used on HMA URBAN Roadways Distinguished by Traffic Volume Classifications Defined in Question 1

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Low Traffic % Response	Medium Traffic % Response	High Traffic % Response	Not Used % Response	Number of Respondents
Crack fill	71	71	75	18	56
Crack seal	84	88	88	7	56
Cape seal	9	11	5	84	57
Fog seal	28	19	11	65	57
Scrub seal	14	9	2	84	57
Slurry seal	25	25	16	58	57
Rejuvenators	14	16	12	80	56
Single-course microsurfacing	53	58	46	28	57
Multiple-course microsurfacing	36	47	42	44	55
Single-course chip seal	69	38	13	31	55
Multiple-course chip seal	43	30	4	57	54
Chip seals with polymer-modified asphalt binder	60	37	18	37	57
Ultra-thin bonded wearing course (e.g., NovaChip)	18	40	47	49	57
Thin HMA overlay (<40 mm [<1.5 in.])	67	64	55	25	55
Cold milling and HMA overlay (<40 mm [<1.5 in.])	68	70	66	20	56
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	30	27	27	59	56
Hot in-place HMA recycling (<50 mm [<1.95 in.])	25	19	14	70	57
Cold-in-place recycling (<100 mm [<4.0 in.])	30	26	16	63	57
Profile milling (diamond grinding)	15	26	39	61	54
Ultra-thin whitetopping	14	26	18	65	57
Drainage preservation	48	46	52	46	54
Other (see below)	33	11	11	67	9

Other Treatments (Table C.5):

- Our minimum HMA depth is 1.5 in., which we would use on any traffic volume. We have experimented with 4.75 mm "sand" mixes less than this, but not typically used.
- Rubber chip seals.
- 1.5 in. HMA mill and fill.
- Spot strip sealing.

Agency Comments (Table C.5):

- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.

Table C.6. Summary of Preventive Maintenance Treatments Used on PCC URBAN Roadways Distinguished by Traffic Volume Classifications Defined in Question 1

Treatments for Portland Cement Concrete (PCC) Pavements	Low Traffic % Response	Medium Traffic % Response	High Traffic % Response	Not Used % Response	Number of Respondents
Concrete joint resealing	45	64	78	20	55
Concrete crack sealing	47	62	73	22	55
Diamond grinding	29	51	75	25	55
Diamond grooving	8	12	31	69	52
Partial-depth concrete pavement patching	38	53	62	35	55
Full-depth concrete pavement patching	44	64	82	18	55
Dowel bar retrofit (load-transfer restoration)	18	31	55	42	55
Thin PCC overlays	4	9	11	85	55
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	11	18	21	71	56
Thin HMA overlay (<40 mm [<1.5 in.])	17	28	26	63	54
Drainage preservation	31	38	48	50	52
Other (see below)	0	0	0	100	12

Agency Comments (Table C.6):

- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.
- Don't have urban PCC pavements.

Question 5

Do you use a different set of treatments on RURAL high-traffic-volume roads than on RURAL low-traffic-volume roads? If "Yes," please check those treatments that you don't consider applicable for RURAL high-traffic-volume roadways.

Based on 56 total responses, the following percentages of "Yes" and "No" were observed:

- Yes: 62%
- No: 38%

The 56 respondents who answered "Yes" to question 5 were asked to answer the multiple parts of question 5. These detailed results are provided below in Tables C.7 and C.8. Additional agency comments are also included.

Table C.7. Summary of Preventive Maintenance Treatments Considered Not Applicable for HMA RURAL Roadways

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Not Applicable % Checked
Crack fill	6
Crack seal	6
Cape seal	70
Fog seal	51
Scrub seal	54
Slurry seal	51
Rejuvenators	34
Single-course microsurfacing	20
Multiple-course microsurfacing	20
Single-course chip seal	83
Multiple-course chip seal	80
Chip seals with polymer-modified asphalt binder	71
Ultra-thin bonded wearing course (e.g., NovaChip)	26
Thin HMA overlay (<40 mm [<1.5 in.])	26
Cold milling and HMA overlay (<40 mm [<1.5 in.])	9
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	40
Hot in-place HMA recycling (<50 mm [<1.95 in.])	46
Cold-in-place recycling (<100 mm [<4.0 in.])	49
Profile milling (diamond grinding)	37
Ultra-thin whitetopping	57
Drainage preservation	9
Other (see below)	3

Agency Comments (Table C.7):

- Marked treatments we currently use and don’t consider applicable.

Table C.8. Summary of Preventive Maintenance Treatments Considered Not Applicable for PCC RURAL Roadways

Treatments for Portland Cement Concrete (PCC) Pavements	Not Applicable % Checked
Concrete joint resealing	8
Concrete crack sealing	8
Diamond grinding	4
Diamond grooving	33
Partial-depth concrete pavement patching	17
Full-depth concrete pavement patching	8
Dowel bar retrofit (load-transfer restoration)	21
Thin PCC overlays	62
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	75
Thin HMA overlay (<40 mm [<1.5 in.])	62
Drainage preservation	8
Other (see below)	4

Agency Comments (Table C.8):

- We do not use concrete on these roads.

Question 6

Do you use a different set of treatments on URBAN high-traffic-volume roads than on URBAN low-traffic-volume roads? If "Yes," please check those treatments that you don't consider applicable for URBAN high-traffic-volume roadways.

Based on 57 total responses, the following percentages of "Yes" and "No" were observed:

- Yes: 54%
- No: 46%

The 57 respondents who answered "Yes" to question 6 were asked to answer the multiple parts of question 6. These detailed results are provided in Tables C.9 and C.10.

Table C.9. Summary of Preventive Maintenance Treatments Considered Not Applicable for HMA URBAN Roadways

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	Not Applicable % Checked
Crack fill	9
Crack seal	6
Cape seal	50
Fog seal	69
Scrub seal	72
Slurry seal	62
Rejuvenators	50
Single-course microsurfacing	28
Multiple-course microsurfacing	22
Single-course chip seal	91
Multiple-course chip seal	88
Chip seals with polymer-modified asphalt binder	84
Ultra-thin bonded wearing course (e.g., NovaChip)	31
Thin HMA overlay (<40 mm [<1.5 in.])	28
Cold milling and HMA overlay (<40 mm [<1.5 in.])	12
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	38
Hot in-place HMA recycling (<50 mm [<1.95 in.])	53
Cold-in-place recycling (<100 mm [<4.0 in.])	59
Profile milling (diamond grinding)	28
Ultra-thin whitetopping	44
Drainage preservation	9
Other (no comments)	0

Table C.10. Summary of Preventive Maintenance Treatments Considered Not Applicable for PCC URBAN Roadways

Treatments for Portland Cement Concrete (PCC) Pavements	Not Applicable % Checked
Concrete joint resealing	5
Concrete crack sealing	5
Diamond grinding	5
Diamond grooving	23
Partial-depth concrete pavement patching	14
Full-depth concrete pavement patching	5
Dowel bar retrofit (load-transfer restoration)	23
Thin PCC overlays	55
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	73
Thin HMA overlay (<40 mm [<1.5 in.])	55
Drainage preservation	14
Other (no comments)	5

Question 7

Please indicate whether you are more or less likely to use each treatment on high-traffic-volume roads that have HIGH TRUCK traffic volumes as compared to those with little truck traffic. If you do not use the treatment, then indicate that it is a treatment that is not used by your agency.

Tables C.11 and C.12 present the 57 agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.11. Summary of Comparative Use of Preventive Maintenance Treatment for High-Traffic-Volume HMA Roads with High Truck Traffic Compared with Those with Low Truck Traffic

Treatments for Hot-Mix Asphalt (HMA)–Surfaced Pavements	More Likely % Response	No Difference % Response	Less Likely % Response	Not Used % Response	Number of Respondents
Crack fill	2	80	0	18	56
Crack seal	2	91	0	7	56
Cape seal	0	16	5	79	57
Fog seal	0	28	11	61	57
Scrub seal	0	16	5	79	57
Slurry seal	0	19	21	60	57
Rejuvenators	0	19	5	75	57
Single-course microsurfacing	7	50	16	27	56
Multiple-course microsurfacing	14	45	5	36	56
Single-course chip seal	0	38	32	30	56
Multiple-course chip seal	4	27	23	46	56
Chip seals with polymer-modified asphalt binder	19	30	16	35	57
Ultra-thin bonded wearing course (e.g., NovaChip)	14	35	5	46	57
Thin HMA overlay (<40 mm [<1.5 in.])	9	58	14	19	57
Cold milling and HMA overlay (<40 mm [<1.5 in.])	21	20	12	16	56
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	4	30	11	56	57
Hot in-place HMA recycling (<50 mm [<1.95 in.])	4	30	4	63	57
Cold-in-place recycling (<100 mm [<4.0 in.])	4	33	18	46	57
Profile milling (diamond grinding)	9	38	0	53	55
Ultra-thin whitetopping	14	20	11	55	56
Drainage preservation	6	59	0	35	54
Other (see below)	0	31	8	62	13

Agency Comments (Table C.11):

- Rubberized surface treatment.
- 1.5 in. HMA mill and fill.
- Fog seal on all chip seals.

Table C.12. Summary of Comparative Use of Preventive Maintenance Treatment for High-Traffic-Volume PCC Roads with High Truck Traffic Compared to Those with Low Truck Traffic

Treatments for Portland Cement Concrete (PCC) Pavements	More Likely % Response	No Difference % Response	Less Likely % Response	Not Used % Response	Number of Respondents
Concrete joint resealing	7	75	0	18	55
Concrete crack sealing	5	73	2	20	55
Diamond grinding	13	65	0	22	55
Diamond grooving	6	39	2	54	54
Partial-depth concrete pavement patching	4	67	4	25	55
Full-depth concrete pavement patching	11	73	2	15	55
Dowel bar retrofit (load-transfer restoration)	24	40	2	35	55
Thin PCC overlays	0	22	9	69	55
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	2	29	5	64	55
Thin HMA overlay (<40 mm [<1.5 in.])	4	31	15	51	55
Drainage preservation	4	61	0	35	54
Other (no comments)	0	17	0	83	12

Question 8

For those treatments that were checked as "Not Used" on RURAL high-traffic-volume roadways under question 3, please indicate the reason(s) it is not being used. Check all boxes that apply.

Tables C.13 and C.14 present the 57 agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.13. Summary of Reasons Why Preventive Maintenance Treatment for RURAL High-Traffic-Volume HMA Roads Are Not Used

HMA-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Percent Responses																
	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate	Number of Responses
Crack fill	56	22	0	11	0	0	11	0	0	0	44	11	22	0	22	0	9
Crack seal	0	0	0	0	0	0	33	0	0	0	33	0	33	0	67	0	3
Cape seal	87	38	3	15	3	5	3	8	3	3	23	0	0	3	26	0	39
Fog seal	53	22	0	28	16	12	12	12	47	31	34	0	0	9	6	0	32
Scrub seal	82	32	2	16	0	7	0	5	7	7	23	0	0	2	5	0	44
Slurry seal	51	26	0	23	11	6	6	11	17	9	40	0	0	9	6	0	35
Rejuvenators	79	18	3	26	8	3	5	8	23	21	28	0	0	0	5	0	39
Single-course microsurfacing	43	21	7	43	7	7	0	7	7	0	64	0	0	0	14	0	14
Multiple-course microsurfacing	65	18	6	29	6	6	0	6	0	0	29	0	0	0	24	0	17
Single-course chip seal	12	4	0	32	40	36	16	20	28	52	44	16	0	8	4	0	25
Multiple-course chip seal	14	4	0	25	32	29	14	14	21	43	43	11	0	4	14	0	28
Chip seals with polymer-modified asphalt binder	25	8	0	25	25	29	12	17	25	46	33	8	0	8	8	0	24
Ultra-thin bonded wearing course (e.g., NovaChip)	62	48	10	19	10	5	5	0	0	0	5	0	0	0	52	0	21
Thin HMA overlay (<40 mm [<1.5 in.])	29	0	7	21	0	7	0	0	0	0	64	0	0	0	14	0	14
Cold milling and HMA overlay (<40 mm [<1.5 in.])	29	0	0	14	0	14	0	0	0	0	71	0	0	0	14	0	14
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	56	6	6	12	0	12	3	0	0	3	53	0	0	0	12	0	32
Hot in-place HMA recycling (<50 mm [<1.95 in.])	49	46	0	24	19	11	3	3	0	0	27	0	0	0	19	3	37
Cold-in-place recycling (<100 mm [<4.0 in.])	56	30	0	26	7	11	4	11	0	0	22	0	0	7	15	0	27
Profile milling (diamond grinding)	69	12	0	12	4	0	0	0	0	0	23	0	0	0	23	4	26
Ultra-thin whitetopping	68	26	0	15	3	6	0	15	0	0	24	0	0	0	29	3	34
Drainage preservation	93	36	0	21	0	0	0	0	0	0	7	0	7	0	7	0	14
Other (see below)	50	0	0	50	50	50	50	50	50	50	50	0	0	50	0	0	2

Agency Comments (Table C.13):

- Rubberized chip seal.
- Generally, the techniques are not available in Québec.
- Basically, not enough volume of work to support all the different types of treatments.
- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.

Table C.14. Summary of Reasons Why Preventive Maintenance Treatment for RURAL High-Traffic-Volume PCC Roads Are Not Used

PCC Pavement Treatments for RURAL High-Traffic-Volume Roadways	Percent Responses																
	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate	Number of Responses
Concrete joint resealing	33	0	0	33	33	0	0	0	0	0	0	0	0	0	67	0	3
Concrete crack sealing	33	0	0	33	33	0	0	0	0	0	0	0	0	0	67	0	3
Diamond grinding	75	25	0	25	0	0	0	0	0	0	0	0	0	0	50	0	4
Diamond grooving	86	18	0	9	0	0	0	0	0	0	5	5	0	0	23	0	22
Partial-depth concrete pavement patching	43	14	0	29	29	0	0	0	0	0	57	0	14	0	71	0	7
Full-depth concrete pavement patching	60	0	0	20	0	0	0	0	0	0	20	0	0	0	40	0	5
Dowel bar retrofit (load-transfer restoration)	69	15	0	8	15	8	8	8	0	0	8	0	0	0	38	0	13
Thin PCC overlays	56	18	0	15	3	6	3	18	0	3	35	0	0	12	32	0	34
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	59	15	0	19	7	4	0	0	0	4	48	0	0	0	22	4	27
Thin HMA overlay (<40 mm [<1.5 in.])	32	0	0	23	14	14	0	0	0	0	64	0	0	0	5	0	22
Drainage preservation	71	29	0	21	7	0	0	0	0	0	14	0	7	0	21	0	14
Other (see below)	100	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Agency Comments (Table C.14):

- Generally, the techniques are not available in Québec.
- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventivemaintenance but rather major rehab.
- We have only 1 PCC section (5.8 km long).
- Maine DOT has very few PCC pavements.
- No PCC pavements.

Question 9

For those treatments that were checked as "Not Used" on URBAN high-traffic-volume roadways under question 4, please indicate the reason(s) it is not being used. Check all boxes that apply.

Tables C.15 and C.16 present the 57 agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.15. Summary of Reasons Why Preventive Maintenance Treatment for URBAN High-Traffic-Volume HMA Roads Are Not Used

	Percent Responses																
HMA-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate	Number of Responses
Crack fill	62	25	0	12	12	0	12	0	12	0	38	0	12	0	0	0	8
Crack seal	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	2
Cape seal	86	31	0	11	3	6	6	6	3	3	14	0	0	6	11	0	35
Fog seal	56	19	0	22	9	9	16	16	31	25	31	0	0	9	0	0	32
Scrub seal	79	21	0	10	0	5	3	5	8	8	28	0	0	3	0	0	39
Slurry seal	61	21	0	9	6	0	6	12	15	12	36	0	0	9	3	0	33
Rejuvenators	83	17	3	11	0	6	6	9	11	17	26	0	0	0	0	0	35
Single-course microsurfacing	50	17	0	33	0	17	0	8	0	0	58	0	0	0	17	0	12
Multiple-course microsurfacing	65	18	0	24	6	6	0	6	0	0	35	0	0	0	12	0	17
Single-course chip seal	7	4	0	36	32	46	14	18	25	57	54	14	0	7	4	0	28
Multiple-course chip seal	13	6	0	32	19	32	13	13	19	52	42	10	0	3	10	0	31
Chip seals with polymer-modified asphalt binder	23	7	0	30	23	37	13	17	23	53	37	10	0	7	10	0	30
Ultra-thin bonded wearing course (e.g., NovaChip)	63	42	0	21	5	0	0	0	0	0	11	0	0	0	53	0	19
Thin HMA overlay (<40 mm [<1.5 in.])	25	6	6	19	0	6	0	0	6	0	69	0	0	0	12	0	16
Cold milling and HMA overlay (<40 mm [<1.5 in.])	42	0	0	8	0	8	0	0	8	0	58	0	0	0	33	0	12
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	59	14	3	17	0	7	0	0	3	3	48	0	0	0	14	0	29
Hot in-place HMA recycling (<50 mm [<1.95 in.])	48	36	0	18	9	6	0	3	3	0	24	0	0	0	18	3	33
Cold-in-place recycling (<100 mm [<4.0 in.])	48	19	0	19	4	7	7	11	0	0	30	0	0	11	22	0	27
Profile milling (diamond grinding)	70	9	0	17	0	0	0	0	0	0	17	0	0	0	22	0	23
Ultra-thin whitetopping	68	26	0	13	6	13	6	13	0	0	26	0	3	10	16	0	31
Drainage preservation	92	33	0	25	0	0	0	0	0	0	0	0	0	0	0	0	12
Other (see below)	50	0	0	50	50	50	50	50	50	50	50	0	0	50	0	0	2

Agency Comments (Table C.15):

- Rubberized chip seal.
- Generally the techniques are not available in Québec.
- Not enough volume of work to use all the different treatments.
- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.

Table C.16. Summary of Reasons Why Preventive Maintenance Treatment for URBAN High-Traffic-Volume PCC Roads Are Not Used

PCC Pavement Treatments for URBAN High-Traffic-Volume Roadways	Percent Responses																Number of Responses
	Lack of Agency Experience	Lack of Experienced Contractors	Lack of Materials	Bias Against Treatment	Previous Failure	Increased Risk if Failure Occurs	Needed Traffic Control	Closure Time	Safety Concerns	Liability Concerns	Durability/ Expected Life	Noise	Production Rates	Time before Trafficking	Treatment Cost	Climate	
Concrete joint resealing	33	0	0	33	33	0	0	0	0	0	0	0	0	0	33	0	3
Concrete crack sealing	50	0	0	25	25	0	0	0	0	0	0	0	0	0	25	0	4
Diamond grinding	60	20	0	20	0	0	0	0	0	0	0	0	0	0	40	0	5
Diamond grooving	81	14	0	14	0	0	0	0	0	0	0	10	0	0	29	0	21
Partial-depth concrete pavement patching	22	11	0	22	33	0	0	0	0	0	44	0	11	0	33	0	9
Full-depth concrete pavement patching	50	0	0	25	0	0	0	0	0	0	0	0	0	0	25	0	4
Dowel bar retrofit (load-transfer restoration)	60	7	0	13	13	20	13	13	0	0	27	0	0	7	33	0	15
Thin PCC overlays	58	12	0	24	3	15	3	12	0	0	33	0	0	9	33	0	33
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	59	15	0	26	7	4	0	0	0	0	41	0	0	0	7	0	27
Thin HMA overlay (<40 mm [<1.5 in.])	33	0	0	17	21	4	0	0	4	0	62	0	0	0	4	0	24
Drainage preservation	67	25	0	33	8	0	0	0	0	0	17	0	0	0	17	0	12
Other (see below)	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Agency Comments (Table C.16):
- Generally the techniques are not available in Québec.
- Crack treatments not a systematic process. Some districts perform work via maintenance personnel. Diamond grinding seldom used. Have recently applied OGFC (¾ in.) to a few projects. Whitetopping seldom used due to high cost. Not considered preventive maintenance but rather major rehab.
- We have no urban PCC highways.
- No PCC pavements.
- Little experience with PCC pavements.

Question 10

In addition to the treatments included in questions 3 or 4, are there other treatments that you are considering using, but have not? If "Yes," please identify any treatments that you considered using but the treatment is not fully developed, does not yet have proven performance, or was not used because of another reason.

Based on 56 total responses, the following percentages of "Yes" and "No" were observed:

- Yes: 12%
- No: 88%

Other considered treatment types listed included:

- Most of the other treatments that are checked as not used.
- Hot in-place recycling.
- Microsurfacing (2 respondents).
- Chip seals for high-volume roads.
- Cold in-place recycling (2 respondents).
- 1 in. HMA overlay.
- Fog seal shoulders.
- Incorporate crack filling and sealing into systematic program.

Reasons cited for the above treatments not currently being used were as follows (based on 11 respondents):

- Not fully developed: 27%
- No proven performance: 9%
- Other reasons: 64%

Agency Comments:
- Cannot use those treatments with dedicated funding.
- Not fully accepted yet (2 respondents).
- No proven performance and inexperienced contractors.
- Allocation of limited funding (2 respondents).
- Lack of local capacity.

Question 11

Please list the three MOST successful pavement preservation treatment types used on your RURAL high-traffic-volume roadways, starting with the most successful, and briefly explain why each treatment is successful for your agency.

Treatment 1

- Crack seal. MDT has aggressively sealed cracks for about 8–9 years. Keeping water out of the base and subgrade has improved performance. Of course timing is critical. MDT tries to make sure that all cracks are sealed prior to placing a chip seal.
- Bituminous resurfacing. Relatively less risk, 8–12 years life.
- Cold in-place recycling.

- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements. Surface sealing (crack seals, chip seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life.
- Thin overlays with fabric reinforcement. Restores ride, eliminates ruts, and extends life.
- Mill and HMA overlay.
- Crack sealing. Best value for the cost, first line of defense in pavement preservation, retards future deterioration.
- Mill 2 in. and put back 2 in. of HMA, followed by open graded friction course. This is probably not really a preventive maintenance treatment.
- Thin mill (profile up to 1.5 in.) and HMA overlay, 1.5 in. This is our standard treatment, high degree of familiarity, large contractor capability.
- Thin hot-mix overlays. Lots of experience, a variety of mixes that can be used for different applications, dense graded, permeable friction courses, SMA.
- 1 in. rubber modified AC overlay has allowed the asphalt to remain flexible and strong given our extremely high temperatures.
- Crack sealing. It keeps moisture out of the pavement structure. This moisture can cause stripping in HMA pavements as well as localized pavement failure due to wet subgrades.
- Crack seal/fill. Studies prove this treatment extends the life of the pavement if treatment applied at the right time.
- Milling with thin asphalt overlay. Removes surface distresses, improves ride, preserves geometrics. Lower life-cycle cost than other treatments.
- Crack and/or joint sealing. Very cost-effective method to extend pavement life utilizing our own forces and some contractor's when necessary.
- Cold in-place recycling with an overlay. Note: we do not consider this a preservation treatment, but rather a cost-effective rehabilitation. These treatments have had outstanding performance for us. With a 3 to 4 in. recycling depth and a designed overlay thickness (typically 2 to 4 in.), we have achieved in access of 20 years of performance life. Additionally, the reliability of this treatment has been very good. We have not experienced any significant premature failures with this treatment.
- Cold plane and overlay. Large number of experienced contractors.
- Chip sealing. MN/DOT has spent a large amount of time developing better methods, specifications, and training on chip sealing.
- Rubberized asphalt chip seal—cracking.
- Cold milling, HMA overlay <1.5 in. for rutting.
- Chip seal with flush coat. Lower cost, reasonable service life.
- Chip seal. Cost-effective.
- Microsurfacing. Good bond with pavement. Fast application.
- Mill and overlay with HMA 1.5 to 2 in. Successful due to good durability and experienced contractors.
- Surface prep (milling or leveling) and a 2 in. overlay. Surface prep is often needed to allow a high level of smoothness. Higher-quality construction and better performance with 2 in. lift overlays than 1.5 in. overlays.
- Thin hot-mix overlay (AK, polymer).
- Crack filling/sealing. Detour water from base.
- Rubberized slurry seal. Familiar with its limits, increased longevity compared to conventional slurry seal.
- Seal coat: Long history of good performance, >35 years. Candidate selection criteria through PMS. Excellent QA process, 2 provincial crews (in house).
- Crack sealing. Economic and good strategy.
- Diamond grooving of PCC. Life of treatment exceeded expectations.
- Thin HMA OL (2 in. or less). Capable of adding structure.
- Chip seals with polymer-modified asphalt binder with lightweight aggregate. Seals cracks and keeps the water out at a relatively minimal expense and extends the life of the previous treatment. Also doesn't raise the grade of the roadway much.
- Thin HMA overlay.
- Thin lift overlay.
- Cold milling and HMA overlay 1.5 in.
- Crack sealing. Good cost-to-benefit ratio.

- Crack filling. Cost-efficient, easy to realize, performance.
- Crack and joint sealing. First step in pavement preservation. Keep the water out.
- Fog seal. Inexpensive, retards oxidation.
- Chip seals. Coat, protect, and rejuvenate existing pavement, retard the rate of oxidation and asphalt hardening with age, seal narrow cracks in the pavement from infiltration of water, stops raveling and restores pavement friction.
- Crack fill/seal. Keeps moisture out.
- Chip seal with polymer. Good experience and durability.
- Cold milling/overlay. Ability to reuse milled pavement in recycled mix. Able to remove surface distress while strengthening road.
- Cold milling and overlay at least 2 in. Restores pavement section and eliminates variation of compaction due to rutting.
- Seal coat. Provides needed water seal and good friction course.
- Cold mill and thin overlay. Restores pavement to near new condition. Cheaper than full rehab on roads with adequate structural capacity or strength.
- 1.8 in. HMA overlay on HMA. Where appropriate, adds life to highways at relatively low cost.
- Chip seal. Seals deficiency in pavement such as segregation and provides wet weather and winter skid enhancement.
- Crack seal/fills. This is our most prevalent preservation technique, but success is anecdotal. We do not monitor for cracking in pavement management.
- 1 to 1.5 in. HMA. Both our contractors and agency personnel have a lot of experience with this treatment.
- Crack sealing. Significant experience within CDOT maintenance forces.
- Thin HMA overlay. Provides for longest expected life.
- 1.5 in. HMA overlay with shim. Experienced contractors and agency personnel. It's a known material.

Treatment 2

- Chip seal. MDT places chip seals on pavements that are 5–7 years old (time since last overlay or rehabilitation). This has been a very effective treatment.
- Crack sealing. Inexpensive, prolongs life of surface.
- Chip seal.
- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements. Surface sealing (crack seals, chip seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life.
- Open graded friction course. Lasts a long time when put on AC in good condition.
- Mill, asphalt rubber crack relief layer and HMA overlay.
- Thin HMA overlay, 40 mm. Most widely used, looked at as most failure proof. Known treatment, inspires confidence.
- HMA overlay >1.5 in. but <2.00 in. We don't place overlays less than 1.5 in. on our high-volume roads. These overlays are successful because they do add some structure back to the pavement. Therefore they may not be considered as preventive maintenance by some.
- Microsurfacing (single or multiple). Avoids ADA requirements. Often "misused" as a band-aid to avoid ADA or combined sewer issues that must be addressed with a higher level of treatment.
- Mill and hot-mix overlay.
- Crack filling. Reduces infiltration of moisture into the pavement structure and slows the rate of pavement deterioration.
- Drainage preservation. Important to maintain adequate drainage.
- Thin asphalt overlays. Lower cost and longer life than microsurfacing. Longer life than seals. Improves ride quality.
- Chip seals. Very cost-effective method of pavement overlay, extends the life of existing road surface, seals and prevents moisture penetration and is a method that we can accomplish with our own forces.
- Chip sealing. We do not chip seal routes with the extreme high volumes (i.e., 50,000 ADT). However, we have been successful chip sealing roads in the 4,000 to 5,000 ADT range. The costs for chip sealing are relatively low and the performance has been good. There is generally good availability of contractors to complete the work and the use of chip sealing is well established; dating back 40 or more years.
- Ultra-thin (NovaChip). With increased use, process is now competitive.
- Microsurfacing. MN/DOT has spent a large amount of time developing microsurfacing, which include strong specifications, improved methods and training.

- Thin HMA overlay extends surface life.
- Thin SMA overlay. Rut resistant, long lived.
- Crack seal. Best in conjunction with a chip seal.
- Slurry seal. Inexpensive, fast application.
- Overlay with HMA 1.5 to 2 in. Successful due to good durability if existing surface is not deteriorated.
- Microsurfacing. Fills minor rutting, restores friction, good overall performance, and rapid construction.
- Ultra-thin bonded wearing course (AR, polymer).
- Deep base patching. Spot repair of base failures in roadway.
- Microsurfacing. Candidate selection thru PMS. Warranty by contractor, good QA process. Conscientious contractor.
- Graded aggregate seal. Not chip economic and works.
- Diamond grinding of PCC. Life of treatment exceed expectations.
- Fine graded polymer AC OL (0.75 in.). Decent life extension for the cost.
- Crack sealing. First action taken on a newer overlay to keep the water out and prevent the cracks from getting wider and depressing due to stripping of the asphalt.
- Cold milling and HMA overlay.
- Mill and overlay.
- Profile milling diamond grinding.
- Patching.
- Cold milling. Cost-efficient, good restoration of the pavement, impact on life of pavement.
- Microsurfacing/NovaChip. Restore skid numbers. Provide protection and wearing surface.
- Microseal. Durable, quick to open to traffic.
- Microsurfacing. Restores ride/comfort, seals minor cracking, fills ruts, opens up quickly to traffic.
- Full/partial depth concrete patching. Prevents additional deterioration.
- Single micro. Good experience for rut control.
- Microsurfacing. Economical for relieving surface distress without major repairs.
- 2 in. min. overlay. OK in cases where there is sound base and little or no rutting.
- Microsurface. Provides friction course and rut repair.
- Graded aggregate seal coat. Seals cracks. Low cost. Can be done in-house or contracted out.
- 1.8 in. inlay on HMA.
- Spray patching. Can seal and repair deteriorated transverse (low temperature) cracks for 2–3 years when workmanship is good.
- Chip seal and high float. This is really the only true preservation technique that we have historically applied and again success is anecdotal and not robustly monitored as part of a preservation program. Applicability of chip seals on HMA is variable throughout the state as some areas are unacceptable candidates due to unstable foundations (permafrost) and high rates of rutting due to surface wear and studded tire action.
- Diamond grinding. Although we have very little concrete pavement, much of it is on our parkway system, which does not carry extremely high volume of traffic. When pavements are ground in a timely manner, we can retard deterioration and delay costly repairs.
- Chip seals. Significant experience within CDOT maintenance forces.
- Crack seal. Very effective in keeping water out.
- Mill and fill. Agency and contractor experience and comfort level.

Treatment 3

- Thin overlay (<60 mm). Thin overlays are placed on pavements that are 12–15 years old and show little or no fatigue cracking. MDT estimates that the life of a 20-year design HMA pavement can be extended to around 30 years with regularly scheduled pavement preservation treatments.
- Microsurfacing. Relatively inexpensive compared to added life.
- Flush seal.
- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements. Surface sealing (crack seals, chip seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life.

- Microsurface. Extends life, seals cracks, fills some ruts.
- HMA overlay.
- Multiple-course microsurfacing. Best value for surface sealing.
- Crack sealing and crack filling. We have had good success with rubberized materials applied in an overbanding technique. We have used this material on both asphalt and PCC pavements.
- Ultra-thin bonded wearing course. Same as microsurfacing above.
- Microsurfacing. We have a warranty spec for microsurfacing that the districts like to use.
- Microsurfacing. This treatment extended the life of some pavements that were beginning to exhibit premature surface deterioration.
- Microsurfacing. It is a proven preservation treatment.
- Ultra-thin asphalt overlays.
- Slurry or microsurfacing. Provides a moisture barrier, improved riding surface, and extends life of existing roadway structure at a price less than conventional asphalt paving.
- Thin overlays. Although higher in costs than some other preservation treatments, the improved smoothness, durability, nighttime construction option, and longer construction season that these treatments offer has made them a successful alternative in some locations.
- Microsurfacing. Beginning to reuse this treatment this year.
- Ultra-thin bonded wearing. MN/DOT has built many test section over the last 10 years and performance has been great. MN/DOT will use the model to promote UTBWC.
- Ultra-thin HMA <.75 in. extends surface life.
- Crack seal and fill. Keep water out, extend life.
- 1.5 in. HMA overlay. Best for lane leveling.
- Chip seal. Inexpensive, problems with chip loss.
- Diamond grinding. Increase in ride quality while improving the life of pavement by decreasing dynamic loading.
- Diamond grinding.
- Spot strip sealing. Spot treatments to prevent base failures.
- Rout and seal: Provincial crew. Used on young pavements 1–3 years old; Long history of use.
- Thin overlay. Good strategy but costs are high.
- 1.5 in. HMA mill and fill.
- Microsurfacing. Decent life extension for the cost.
- 2 in. hot in-place recycling with a polymer-modified chip seal. 100% recycle of the current surface and the seal doesn't raise the grade of the roadway very much. Don't have to overlay the shoulder is the road has them.
- Full-depth concrete patching.
- Thin-bonded wearing course and 1.5-in. overlays. Good functional benefits.
- Cold mix. Cost-efficient, restoration of the surface.
- Diamond grinding. Reduce dynamic loading.
- Thin HMA overlay. Open graded friction course (rubber).
- Overlays. Adds structural strength, corrects surface defects such as deep rutting and minor cracking and extends pavement life.
- Microsurfacing. Reduces ruts and seals surface, improves ride.
- Cape seal. Good fix for curbed area to maintain drainage control.
- Crack sealing. Economical preventative measure to prolong pavement life.
- Chip seal. Where pavement is sound except some cracking not subject to crack seal.
- Crack seal. Decrease water infiltration into base. Buys time.
- Microsurfacing (two passes: first for rutting and second for overall). Fills ruts, improves ride, low cost.
- Dowel bar retrofit. Early dowel bar retrofits where done on highway segments with significant faulting, and gave 10–15+ years additional life. We expect at least as much from highway segments with aggregate interlock just failing.
- "Blow and fill" crack sealing using rout and seal crack sealer but without rutting has been found cost-effective and better sealant performance than crack filler.
- Double lift microsurfacing. We have very little experience with this application, and have just completed our first project on one of our parkways. So far it appears to be doing well, but it is too early to judge for certain.
- Ultra-thin HMA overlay. Provides the most cost-effective treatment.
- Crack sealing. Agency experience and comfort. Inexpensive.

Question 12

Please list the three MOST successful pavement preservation treatment types used on your URBAN high-traffic-volume roadways, starting with the most successful, and briefly explain why each treatment is successful for your agency.

Treatment 1

- Crack seal. MDT has aggressively sealed cracks for about 8–9 years. Keeping water out of the base and subgrade has improved performance. Of course timing is critical. MDT tries to make sure that all cracks are sealed prior to placing a chip seal.
- Bituminous resurfacing. Relatively less risk, 8–12 years life.
- NovaChip. Long-lasting treatment.
- Microsurfacing.
- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements, which is often the case with urban high-traffic roadways. Surface sealing (crack seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life. Chip seals are not used on urban high-volume routes.
- Dowel bar retrofit. Extends the life of our old jointed plain concrete pavements.
- Mill and HMA overlay.
- Crack sealing. Best value for the cost, first line of defense in pavement preservation, retards future deterioration.
- Mill and fill with HMA overlay >1.5 in. but < 2.00 in.
- HMA mill/fill.
- Thin hot-mix overlay.
- 1 in. rubber modified AC overlay has allowed the asphalt to remain flexible and strong given our extremely high temperatures.
- Crack sealing. It keeps moisture out of the pavement structure. This moisture can cause stripping in HMA pavements as well as localized pavement failure due to wet subgrades.
- Crack seal/fill. Studies prove this treatment extends the life of the pavement if treatment applied at the right time.
- Milling with thin asphalt overlay. Removes surface distresses, improves ride, preserves geometrics. Lower life-cycle cost than other treatments.
- Cold milling and HMA overlays. Removes alligator cracked and oxidized surface, and reuses it in recycle mix to provide lower cost. Provides method to improve roadway cross section and maintain existing drainage elevations.
- Mill and overlay. On our very high-volume routes (i.e., 50,000 ADT), this is the treatment of choice due to reduced disruption to traffic (because of allowance for nighttime construction). Additionally, milling allows for minimal elevation changes where existing features such as curb and gutter exist. Smoothness can also be improved with this treatment.
- Cold plane and overlay. Large number of experienced contractors.
- Chip sealing. MN/DOT has spent a large amount of time developing better methods, specifications, and training on chip sealing.
- Paver-placed elastomer surface treatment. Retards cracking.
- Cold milling, HMA overlay <1.5 in. for rutting.
- Chip seal with flush coat. Lower cost, reasonable service life.
- Bonded wearing course. Holds up better then chip seal under high traffic.
- Microsurfacing.
- Mill and overlay with HMA 1.5 to 2 in. Successful due to good durability and experienced contractors.
- Mill and 2 in. pavement. Often mill into curb and gutter only, with little or no milling at center line. Restores surface without a grade change.
- Diamond grinding.
- Mill/inlay. Provides better joints on these high-volume roadways.
- Rubberized slurry seal. Familiar with its limits, increased longevity compared to conventional slurry seal.
- Seal coat: Long history of good performance, >35 years. Candidate selection criteria through PMS. Excellent QA process, 2 provincial crews (in house).
- Crack seal.
- Diamond grooving of PCC. Life of treatment exceeded expectations.

- Thin HMA OL (2 in. or less). Capable of adding structure.
- PCCP patching, diamond grinding, and resealing joints on PCCP. Reestablishes the ride quality of a deteriorated concrete pavement.
- Thin HMA overlay.
- Thin lift overlay.
- Cold milling and HMA overlay 1.5 in.
- Crack sealing.
- Cold milling and HMA. Cost-efficient, good restoration of the pavement, impact on life of pavement.
- Crack and joint sealing. First step in pavement preservation. Keep the water out.
- Thin HMA overlay (rubber). Noise reduction.
- Milling and hot-mix inlay/overlay. Removes upper layers of deteriorating pavement, corrects surface defects, maintains vertical alignment with curb and gutter.
- Crack fill/seal. Keeps moisture out.
- 4 in. whitetopping. Cost-effective long-term fix.
- Cold milling/overlay. Ability to reuse milled pavement in recycled mix. Able to remove surface distress while strengthening road.
- Cold milling and overlay at least 2 in. Restores pavement section and eliminates variation of compaction due to rutting.
- Microsurface. Good for rutting and increased friction. Also good in C&G areas (thin lift).
- Dowel bar retrofit.
- Ultra-thin whitetopping for rutted intersection has been used once very successfully (we have very little urban road).
- Overlays and mill and overlay are the most widely used most successful in extending remaining service life. Again, we do not yet have a robust monitoring program other than pavement management's automated collection of IRI and rutting data.
- Cold mill and 1.25 in. to 1.5 in. HMA. Much of our urban areas require milling in order to maintain grade for curb and gutter sections. Contractors and agency personnel have experience with this treatment, and there is generally good competition in the urban areas.
- Crack sealing. Significant experience within CDOT maintenance forces.
- Thin HMA overlay.
- 1.5 in. HMA overlay with shim. Experienced contractors and agency personnel. It's a known material.

Treatment 2

- Chip seal. MDT places chip seals on pavements that are 5–7 years old (time since last overlay or rehabilitation). This has been a very effective treatment.
- Crack sealing. Inexpensive, prolongs life of surface.
- Roadarmor. Preserve pavement for long time.
- Flush seal.
- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements, which is often the case with urban high-traffic roadways. Surface sealing (crack seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life. Chip seals are not used on urban high-volume routes.
- NovaChip. Have used this successfully on AC and PC pavements.
- Mill, asphalt rubber crack relief layer and HMA overlay.
- Thin HMA overlay, 40 mm most widely used, looked at as most failure proof. Known treatment, inspires confidence.
- HMA overlay >1.5 in. but <2.00 in.
- Microsurfacing.
- Partial depth repairs. Have been very successful in spall and joint repairs. We use a lot of polymer modified concrete.
- Crack filling. Reduces infiltration of moisture into the pavement structure and slows the rate of pavement deterioration.
- Drainage preservation. Important to maintain adequate drainage.
- Thin asphalt overlays. Lower cost and longer life than microsurfacing. Longer life than seals. Improves ride quality.
- Microsurfacing. Very quick method to address cracking, rutting, improving roadway profile and drainage at a cost less than traditional HMA overlays.

- Cold in-place recycling with an overlay. Note: We do not consider this a preservation treatment but rather a cost effective rehabilitation. These treatments have had outstanding performance for us. With a 3 to 4 in. recycling depth and a designed overlay thickness (typically 2 to 4 in.), we have achieved in access of 20 years of performance life. Additionally, the reliability of this treatment has been very good. We have not experienced any significant premature failures with this treatment.
- PCC patching and joint work. Have good details and a few experienced contractors.
- Microsurfacing. MN/DOT has spent a large amount of time developing microsurfacing which include strong specifications, improved methods and training.
- Thin SMA overlay. Rut resistant, long lived.
- Crack seal. Takes care of small cracks.
- Open grade surface course (OGSC). Spray during rain.
- Overlay with HMA 1.5 to 2 in. Successful due to good durability if existing surface is not deteriorated.
- Microsurfacing. Fills minor rutting, restores friction, good overall performance, and rapid construction.
- Thin HMA overlays.
- Crack filling/sealing. Detour water from base.
- Microsurfacing. Candidate selection thru PMS. Warranty by contractor, Good QA process. Conscientious contractor.
- Thin overlay.
- Diamond grinding of PCC. Life of treatment exceed expectations.
- Fine graded polymer AC OL (0.75 in.). Decent life extension for the cost.
- Ultra-thin bonded wearing course (NovaChip). It is a seal and hot-mix overlay in one and improves ride quality while sealing the water out, reduces water spray, and skid resistance of surface on either PCCP or asphalt roadways.
- Cold milling and HMA overlay.
- Mill and overlay.
- Crack seal.
- Patching.
- Cold mix. Cost-efficient, restoration of the surface, quickly to put in place.
- Microsurfacing/NovaChip. Restore skid numbers. Provide protection and wearing surface.
- Fog seal. Inexpensive, retards oxidation.
- Hot-mix overlay. Adds structural strength, corrects surface defects such as deep rutting and minor cracking and extends pavement life.
- Full/partial-depth concrete patching. Prevents additional deterioration.
- Two-course micro.
- Microsurfacing. Economical for relieving surface distress without major repairs.
- 2 in. min. overlay. OK in cases where there is sound base and little or no rutting.
- HMA. Less customer complaints due to low noise.
- HMA overlay.
- Crack seal/fills. This is our most prevalent preservation technique, but success is anecdotal. We do not monitor for cracking in pavement management.
- 1.25 in. to 1.5 in. HMA. Where milling is not necessary, a thin asphalt surface has been the primary treatment on urban roads. The ability of our forces to maintain asphalt pavements is one of the primary reasons for the widespread use of this treatment.
- PCCP panel repairs, includes crack sealing, dowel bar retrofit, partial panel replacement.
- Crack seal.
- Mill and fill. Agency and contractor experience and comfort level.

Treatment 3

- Thin overlay (<60 mm). Thin overlays are placed on pavements that are 12–15 years old and show little or no fatigue cracking. MDT estimates that the life of a 20 year design HMA pavement can be extended to around 30 years with regularly scheduled pavement preservation treatments.
- Microsurfacing. Relatively inexpensive compared to added life.
- Italgrip, Increased the surface friction.

- Chip seal.
- We have had success with the treatments we use. I wouldn't want to rank them in order. The one course mill and resurfaces and concrete pavement repairs are "high end" fixes for CPM and work well with more distressed pavements, which is often the case with urban high-traffic roadways. Surface sealing (crack seals, micro, ultra-thin HMA) are successful at sealing the pavement and extending service life. Chip seals are not used on urban high-volume routes.
- Thin overlays. Restores ride and extends life.
- HMA overlay.
- Tie: Multiple-course microsurfacing—best value for surface sealing; and thin-bonded overlay—quick time to resume normal traffic.
- Crack sealing and crack filling. We have had good success with rubberized materials applied in an overbanding technique. We have used this material on both asphalt and PCC pavements.
- Ultra-thin bonded wearing course.
- Full-depth repairs. Special attention is needed during construction for installation of the dowel bars, and type of epoxy used.
- Microsurfacing. This treatment extended the life of some pavements that were beginning to exhibit premature surface deterioration.
- Microsurfacing. It is a proven preservation treatment.
- Ultra-thin asphalt overlays.
- Thin HMA overlays, which add structural value to road, improving drainage profile, rideability, and moisture penetration.
- Thin overlays. Although higher in costs than some other preservation treatments, the improved smoothness, durability, nighttime construction option, and longer construction season that these treatments offer has made them a successful alternative in some locations.
- Ultra-thin bonded wearing. MN/DOT has built many test sections over the last 10 years and performance has been great. MN/DOT will use the model to promote UTBWC.
- Crack seal and fill. Keep water out, extend life.
- HMA overlay. Makes the ride smoother.
- Mill and overlay with HMA 1 to 1.5 in. Successful due to less cost but with less expected life than thicker overlays.
- Isolated full-depth fast-setting hydraulic cement repairs (slab replacement with rapid strength concrete). Min. strength 400 PSI.
- Deep base patching. Spot repair of base failures in roadway.
- Rout and seal: Provincial crew. Used on young pavements 1–3 years old. Long history of use.
- Hot in-place recycling.
- 1.5 in. HMA mill and fill.
- Microsurfacing. Decent life extension for the cost.
- Mill and inlay of asphalt surface. Milling supply's a source of quality RAP for up to 25% recycling and doesn't raise the grade of the roadway so we don't have to overlay the shoulders of they are in okay condition.
- Full-depth concrete patching.
- Thin-bonded overlay and 1.5-in. overlays.
- Diamond grinding. Reduce dynamic loading.
- Microseal. Durable and quick to open to traffic.
- Heater scarification and overlay. Removes and rejuvenates upper layers of deteriorating pavement, corrects surface defects, improves riding quality, opens up quickly to traffic.
- Microsurfacing. Reduces ruts and seals surface, improves ride.
- Polymer chip seal.
- Crack sealing. Economical preventative measure to prolong pavement life.
- Cold milling to daylight ruts on sound pavement and remove standing water. This is only done because our milling machines produce very fine textured surface that doesn't do much to change noise levels and maintains good skid numbers.
- HMA inlay.
- Chip seal and high float. This is really the only true preservation technique that we have historically applied and again success is anecdotal and not robustly monitored as part of a preservation program. Applicability of chip seals on HMA is variable throughout the state as some areas are unacceptable candidates due to unstable foundations (permafrost) and high rates of rutting due to surface wear and studded tire action.

- Diamond grinding. Some of our urban areas have large concentrations of concrete pavements on the Interstate system. Diamond grinding provides a way to lengthen the life of these pavements before more costly repairs are needed.
- Ultra-thin overlay.
- Crack sealing. Agency experience and comfort. Inexpensive.

Question 13

Please list the three LEAST successful pavement preservation treatment types used on your RURAL high-traffic-volume roadways, starting with the most successful, and briefly explain why each treatment is successful for your agency.

Treatment 1

- Occasionally chip seals placed on high-volume routes will bleed due to poor construction practices or mix design. This occurs on approximately 5% or less on chip seal projects.
- Unknown, unsuccessful treatments done in the past are no long practice.
- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- Joint rehab on dowel mesh reinforced concrete pavement. Ride is still impaired.
- Thin concrete overlay. Poor performance and high cost.
- We don't use unsuccessful treatments. We have had performance problems with most of the treatments that we still use.
- NovaChip. I think the road was probably too far gone to be a good candidate. Crack reflected back through the surface in a short amount of time.
- Chip seal. Dust, bleeding, loose chips.
- Chip seals. Loose rock hitting windshields, flushing issues.
- Partial-depth patching. Patches did not perform as well as expected.
- Unable to rate unsuccessful treatments as our efforts focus are towards successful treatments.
- Ultra-thin PCC overlays. Problems with bonding, early failures and expensive.
- Fog seal. Reduced skip resistance.
- When treatments are not successful it is usually not the treatments fault. Rather it's generally due to poor treatment selection, poor construction quality, or poor timing. Of the treatments we use, we do not have any labeled as "unsuccessful." We have had problems with all of our treatments at one time or another, due to reasons stated in the first sentence, but nothing systemic.
- Chip seals. Tend to lose rock and break windshields; tend to ravel; proper construction techniques are sometimes lacking.
- Crack sealing has had more failures than are acceptable.
- Profile milling. Some locations have produced less than desirable surface conditions.
- Slurry seal. Short lived.
- Chip seal. Loss of chips—raveling.
- Crack sealing on PCC pavements with basic asphalt based sealants. High labor costs with little increase in pavement life.
- Chip seals. Chip loss bleeding and early failures. High degree of failure risk. Have had some catastrophic failures with chips and emulsion not curing properly and rolling up on tires.
- Calcium chloride PCC slab replacement (because of low strength) slow setting.
- Rubberized slurry seal. Familiar with its limits, increased longevity compared to conventional slurry seal.
- Crack sealing. When certain products are found to be ineffective. Only approved products are currently used that have demonstrated performance. Problem with what to do with rout and crack seal after life cycle.
- Cold in-place. Expensive and does not work well.
- NovaChip. Too expensive.
- Nothing: We have been at this a long time and so we know by now what we don't want to use.
- DMR product. Total failure. Had to mill off roadway and overlay with HMA. Probably placed when weather was too cold for successful application. Resulted in never to be used again.
- No other tried this district.
- Single-course chip seal.
- Do nothing.

- Crack filling. Cost-efficient, easy to realize, performance.
- Chip sealing. Failure of chip seals resulting in lower skid numbers and vehicle damage from flying rock.
- Chip seal, single app. Rock damage.
- Cold recycling. Comes apart.
- Chip seal. Does not hold up under traffic.
- Thin overlays. Reflective cracking.
- Microsurface. Cost is about the same as a 1.5 in. overlay and does little or nothing for strength.
- HMA. Cost. Some of our districts use this treatment to raise their ride score, but it is not cost-effective.
- Rubber crack fill. Lack of follow-up treatment after failure.
- Crack sealing using cold pour materials does not last more than one season. Seems to help prevent spalling at the crack but does not provide lasting seal to moisture infiltration.
- Chip seal. We had several chip seal projects that were considered failures by the public and agency officials. This treatment has a very poor reputation in the state.
- Hot in-place HMA recycling. Durability was low.
- Microsurfacing. Doesn't stand up well to aggressive snow plowing.

Treatment 2

- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- CPR on dowel mesh reinforced concrete pavement. Ride is still poor.
- Chip seal. Noisy, cracked windshields, short life.
- We do not use fog seals and rejuvenators on travel lanes due to possible friction problems.
- Chip seal. Traffic, especially trucks, dislodged most of the aggregate in several weeks. This was on an Interstate route and was done back in the mid 1980s. This experience has kept us from considering using chip seal on high-volume roads even though the new polymer-modified emulsions will probably perform better.
- Cold in-place recycling (stripping issues).
- Chip seals. Our design and construction staffs have limited experience with chip seals. Therefore, they are sometimes placed with excess cover aggregate, which results in damage to vehicles.
- Microsurfacing. Not much of an advantage over seals and much more expensive. Life expectancy about the same as seals.
- Hot in-place recycling. A lack of material consistency incorporated into the finished mat because of the presence of joint and crack seal material.
- Partial-depth PCC repairs. Due to high rate of subsequent failures.
- 1 in. or 1.5 in. overlays. Consider theses as reactive maintenance to address a problem until a rehab can be performed. Chance of success and life of overlay greatly increases with 2 in. lifts.
- Chip seal. Windshield damage.
- Hot in-place recycle. This section of roadway had to be milled and overlaid with HMA failure.
- Ultra-thin HMA overlay <.75 in.
- Chip seals. Poor surface characteristics and short life.
- Cold milling and HMA. Cost-efficient, good restoration of the pavement, impact on life of pavement.
- Thin overlay. Less than 3.75 in. Any thinner provides insufficient structural improvements and increases failure.
- Chip seal double app. Rock damage.
- Partial- and full-depth concrete slab repairs. Too expensive and takes too long.
- Slurry. Does not hold up.
- Chip seal. Public perception and opinion.
- Slurry seal. Only good to seal cracks, no strength added. Cost is important.
- Microsurface. Although we have great success with this treatment, we still have districts using it on roadways with bad FWD [falling weight deflectometer] numbers.
- Conventional crack fill. Short life due to changing seasons.
- Microsurfacing has been used on selective basis and has tended to wear off within about 3 years. We have since moved to a thicker application and larger top size.

- Partial-depth concrete patching. We have found that the cost of partial-depth patching was not significantly less than full-depth patching and therefore did not provide adequate savings to justify its use.
- Single-course chip seal. Durability was low.
- Rubber chip seal. Snowplow damage. Agency and contractor inexperience. We had to get out of state contractor to produce and lay down. Aggregate provided by local contractor.

Treatment 3

- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- Bonded overlay. Had early cracking.
- Microsurfacing. High cost, short life, rapid deterioration requiring quick repair.
- We do not use cold-in-place recycling on high-volume pavements due to traffic control issues and possible performance problems.
- Crack sealing. Usually just causes bumps and car paint problems.
- Joint and crack seal/fill, because of poor adhesion to the crack walls.
- Full-depth PCC repairs. These will work well but we have a history of diminished ride quality due to poor grade control.
- Slurries and fogs don't work.
- Hot in-place HMA. We use 2 in. hot in-place with an overlay.
- Cold in-place recycle. Rough ride and long cure time.
- Concrete.
- HMA less than .75 in. Durability.
- Cold-in-place recycling. The cost of mobilization (equipment and contractor) for small projects.
- Fog seal. There is an issue with traffic and curing time. The best time to apply is when crews are too busy with other work. In the off-season, curing time is long and an inconvenience to traffic and workers.
- Route and seal for cracks has been "hit and miss" for performance and when we have large amounts of sealant loss it creates a bigger problem than we started with.

Question 14

Please list the three LEAST successful pavement preservation treatment types used on your URBAN high-traffic-volume roadways, starting with the most successful, and briefly explain why each treatment is successful for your agency.

Treatment 1

- Occasionally chip seals placed on high-volume routes will bleed due to poor construction practices or mix design. This occurs on approximately 5% or less on chip seal projects.
- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- CPR without DBR on jointed concrete pavement. Ride still poor.
- Microsurfacing. High cost, short life, rapid deterioration requiring quick repair.
- We don't use unsuccessful treatments. We have had performance problems with most of the treatments that we still use.
- No horror stories to report here.
- Chip seals, loose rock hitting windshields, flushing issues.
- Partial-depth patching. Patches did not perform as well as expected.
- Unable to rate unsuccessful treatments as our efforts focus toward successful treatments.
- Ultra-thin PCC overlays. Problems with bonding, early failures, and expensive.
- When treatments are not successful it is usually not the treatments fault. Rather it's generally due to poor treatment selection, poor construction quality, or poor timing. Of the treatments we use, we do not have any labeled as unsuccessful. We have had problems with all of our treatments at one time or another, due to reasons stated in the first sentence, but nothing systemic.
- Crack sealing has had more failures than are acceptable.

- Microsurfacing. Too brittle.
- Profile milling. Some locations have produced less than desirable surface conditions.
- Slurry seal. Short lived.
- OGSC. Increased stripping issues, raveling.
- Partial-depth PCC repairs. Due to high rate of subsequent failures.
- Chip seals. Same as rural accept closure time and traffic issues play a larger role.
- Calcium chloride PCC slab replacement (because of low strength) slow setting.
- Rubberized slurry seal. Familiar with its limits, increased longevity compared to conventional slurry seal.
- Crack sealing. When certain products are found to be ineffective; only approved products are currently used that have demonstrated performance; problem with what to do with rout and crack seal after life cycle.
- Chip seals. Windshield damage and noise and rough road surface.
- NovaChip. Too expensive.
- Thin HMA overlays over PCCP. They don't last very long and have a tendency to debond and spall out in the winter.
- No other tried this district.
- Single-course chip seal.
- Do nothing.
- Crack filling. Cost-efficient, easy to realize, performance.
- Chip sealing. Failure of chip seals resulting in lower skid numbers and vehicle damage from flying rock.
- Chip seal, single app. Rock damage.
- Chip seals. Chips come loose with high-volume, high-speed traffic.
- Chip seal. Does not hold up under traffic.
- Thin overlays. Reflective cracking.
- Microsurface. No strength added.
- Seal coat. In areas where there is a lot of traffic turning movement.
- Partial-depth concrete patching. We have found that the cost of partial-depth patching was not significantly less than full depth patching, and therefore did not provide adequate savings to justify its use.
- Hot in-place HMA recycling.

Treatment 2

- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- Very thin AC overlays (1 in. or less). Rutting comes back too quickly.
- Hot in-place. Short life, high chance for failure.
- We do not use fog seals and rejuvenators on travel lanes due to possible friction problems.
- Skidabrader if aggregates are soft the restored skid will go down quickly.
- Thin HMA overlays. In urban applications, with slow moving traffic/trucks, these overlays can sometimes rut and shove.
- Microsurfacing. Not much of an advantage over seals and much more expensive. Life expectancy about the same as seals.
- Full-depth PCC repairs. These will work well but we have a history of diminished ride quality due to poor grade control.
- Thin overlays. 1 in. or 1.5 in. overlays. Consider these as reactive maintenance to address a problem until a rehab can be performed. Chance of success and life of overlay greatly increases with 2 in. lifts.
- Fog seal.
- Ultra-thin HMA overlay <.75 in.
- Microsurfacing. Poor surface characteristics.
- Cold milling and HMA. Cost-efficient, good restoration of the pavement, impact on life of pavement, restoration of surface characteristics.
- Thin overlay. Less than 3.75 in. Any thinner provides insufficient structural improvements and increases failure.
- Chip seal, double app. Rock damage.
- Slab jacking. Slabs rose unevenly.
- Slurry. Does not hold up.

- Chip seal. Public perception and opinion.
- Slurry. No strength added.
- Microsurface. In areas with bad FWD [falling weight deflectometer] numbers.
- Single-course chip seal.

Treatment 3

- If the right fix is done on the right road the treatment should be successful. Anything that is less effective I wouldn't attribute to the fix itself.
- Microsurface. Doesn't last long enough.
- Thin HMA overlay of deeply cracked pavement. Quick reflection of cracks.
- We do not use cold in-place recycling on high-volume pavements due to traffic control issues and possible performance problems.
- Crack sealing. Usually just causes bumps and car paint problems.
- Microsurfacing.
- Hot in-place HMA. We use 2 in. hot in-place with an overlay.
- Cold in-place recycle. Rough ride and long cure time.
- Partial- and full-depth concrete slab repairs. Too expensive and takes too long.
- HMA less than .75 in. Durability.
- Cold in-place recycling. The cost of mobilization (equipment and contractor) for small projects.
- Thin overlays. Not enough strength added.

Question 15

Available facility closure time is an important consideration when selecting the most appropriate treatment for a pavement section. Please use the following to indicate under which of the following available closure time scenarios you consider using the listed treatments on RURAL roadways.

Tables C.17 and C.18 present the agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.17. Summary of Closure Time Scenarios Considered When Using a Preventive Maintenance Treatment for RURAL High-Traffic-Volume HMA Roads

HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift % Response	Weekend % Response	Longer % Response	Number of Respondents
Crack fill	95	19	16	43
Crack seal	96	19	15	47
Cape seal	100	22	6	18
Fog seal	92	12	15	26
Scrub seal	87	13	20	15
Slurry seal	89	21	14	28
Rejuvenators	89	16	16	19
Single-course microsurfacing	95	24	15	41
Multiple-course microsurfacing	86	23	20	35
Single-course chip seal	95	8	11	37
Multiple-course chip seal	88	9	12	32
Chip seals with polymer-modified asphalt binder	94	12	9	32
Ultra-thin bonded wearing course (e.g., NovaChip)	92	22	17	36
Thin HMA overlay (<40 mm [<1.5 in.])	90	18	18	40
Cold milling and HMA overlay (<40 mm [<1.5 in.])	85	21	21	39
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	85	15	19	26
Hot in-place HMA recycling (<50 mm [<1.95 in.])	76	12	24	25
Cold-in-place recycling (<100 mm [<4.0 in.])	72	17	31	29
Profile milling (diamond grinding)	84	24	12	25
Ultra-thin whitetopping	42	27	54	26
Drainage preservation	93	22	22	27
Other (see below)	100	0	0	2

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

Agency Comments (Table C.17):

- Rubberized chip seal.
- Normally allow a long working day (7:00 a.m.–7:00 p.m.). Roadway must be open at night.
- 1.5 in. HMA mill and fill.
- Closure time is low priority in Manitoba.
- Ultra-thin whitetopping (major rehabilitation).
- Traffic accommodation is provided virtually 100% of the time. Not a significant factor in the Preservation "Decision Tree."

Table C.18. Summary of Closure Time Scenarios Considered When Using a Preventive Maintenance Treatment for RURAL High-Traffic-Volume PCC Roads

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift % Response	Weekend % Response	Longer % Response	Number of Respondents
Concrete joint resealing	85	30	22	40
Concrete crack sealing	85	25	22	40
Diamond grinding	85	30	28	40
Diamond grooving	89	19	15	27
Partial-depth concrete pavement patching	68	38	38	40
Full-depth concrete pavement patching	70	44	44	43
Dowel bar retrofit (load-transfer restoration)	70	42	39	33
Thin PCC overlays	35	30	57	23
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	82	23	9	22
Thin HMA overlay (<40 mm [<1.5 in.])	81	15	11	27
Drainage preservation	90	31	14	29
Other (see below)	50	50	0	2

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

Agency Comments (Table C.18):

- The items marked overnight would be allowed a long working day. If they are performed in conjunction with slab repairs, longer closures are allowed.
- Thin PCC overlays (major rehabilitation).

Question 16

Please use the following to indicate under which of the following available closure time scenarios you consider using the listed treatments on URBAN roadways.

Tables C.19 and C.20 present the agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.19. Summary of Closure Time Scenarios Considered When Using a Preventive Maintenance Treatment for URBAN High-Traffic-Volume HMA Roads

HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift % Response	Weekend % Response	Longer % Response	Number of Respondents
Crack fill	95	21	12	42
Crack seal	96	23	11	47
Cape seal	87	20	7	15
Fog seal	85	20	10	20
Scrub seal	79	21	7	14
Slurry seal	78	26	9	23
Rejuvenators	82	24	6	17
Single-course microsurfacing	87	36	15	39
Multiple-course microsurfacing	84	34	16	32
Single-course chip seal	90	20	10	30
Multiple-course chip seal	85	22	7	27
Chip seals with polymer-modified asphalt binder	90	17	10	29
Ultra-thin bonded wearing course (e.g., NovaChip)	94	27	15	33
Thin HMA overlay (<40 mm [<1.5 in.])	90	30	15	40
Cold milling and HMA overlay (<40 mm [<1.5 in.])	88	31	19	42
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	84	32	24	25
Hot in-place HMA recycling (<50 mm [<1.95 in.])	70	30	20	20
Cold-in-place recycling (<100 mm [<4.0 in.])	67	38	25	24
Profile milling (diamond grinding)	88	36	16	25
Ultra-thin whitetopping	32	45	55	22
Drainage preservation	93	32	18	28
Other (see below)	100	0	0	2

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

Agency Comments (Table C.19):

- Rubberized chip seal.
- Closure depends on number of lanes available and if there are increased levels of traffic at certain times.
- 1.5 in. HMA mill and fill.
- Ultra-thin whitetopping (major rehabilitation).

Table C.20. Summary of Closure Time Scenarios Considered When Using a Preventive Maintenance Treatment for URBAN High-Traffic-Volume PCC Roads

PCC Pavement Treatments for High-Traffic-Volume Roadways	Overnight OR Single Shift % Response	Weekend % Response	Longer % Response	Number of Respondents
Concrete joint resealing	92	30	12	40
Concrete crack sealing	92	32	15	40
Diamond grinding	95	36	13	39
Diamond grooving	91	30	4	23
Partial-depth concrete pavement patching	68	49	30	37
Full-depth concrete pavement patching	67	50	38	42
Dowel bar retrofit (load-transfer restoration)	65	44	44	34
Thin PCC overlays	39	30	57	23
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	87	26	4	23
Thin HMA overlay (<40 mm [<1.5 in.])	88	20	8	25
Drainage preservation	93	30	19	27
Other (see below)	0	0	0	0

Note: Overnight (e.g., from 10 p.m. to 6 a.m.); Single Shift (e.g., 9 a.m. to 4 p.m.); Weekend (e.g., from 8 p.m. on Friday to 5 a.m. on Monday); Longer (longer than 2 days).

Agency Comments (Table C.20):

- Depends on lanes available.
- Thin PCC overlays (major rehabilitation). Restrictions on construction time occur on extremely high-volume urban sections. Responses assume restrictions may occur on rural sections as well.

Question 17

Please check any of the following contracting mechanisms that your agency uses to help ensure the quality and future performance of the following treatments on your high-traffic-volume roadways? Please check all that apply.

Tables C.21 and C.22 present the agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.21. Summary of Contracting Mechanisms Used to Ensure Quality for a Preventive Maintenance Treatment for High-Traffic-Volume HMA Roads

HMA-Surfaced Pavement Treatments for High-Traffic-Volume Roadways	Contracting Mechanisms Used				Number of Respondents
	QC/QA	Performance Specifications	Warranties	Contract Maintenance	
Crack fill	50	41	9	44	34
Crack seal	51	41	13	46	39
Cape seal	70	30	20	50	10
Fog seal	47	20	0	53	15
Scrub seal	55	18	0	55	11
Slurry seal	74	32	11	47	19
Rejuvenators	54	38	0	46	13
Single-course microsurfacing	57	38	27	38	37
Multiple-course microsurfacing	67	26	26	33	27
Single-course chip seal	67	42	21	45	33
Multiple-course chip seal	64	43	18	39	28
Chip seals with polymer-modified asphalt binder	60	40	13	40	30
Ultra-thin bonded wearing course (e.g., NovaChip)	67	39	12	30	33
Thin HMA overlay (<40 mm [<1.5 in.])	84	44	23	37	43
Cold milling and HMA overlay (<40 mm [<1.5 in.])	82	51	26	31	39
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	76	43	19	33	21
Hot in-place HMA recycling (<50 mm [<1.95 in.])	72	40	12	36	25
Cold-in-place recycling (<100 mm [<4.0 in.])	82	36	14	36	28
Profile milling (diamond grinding)	55	59	0	27	22
Ultra-thin whitetopping	67	33	6	28	18
Drainage preservation	73	23	5	41	22
Other (see below)	100	0	0	0	3

Agency Comments (Table C.21):
- Rubberized chip seal.
- 1.5 in. HMA mill and fill.
- Ultra-thin whitetopping (major rehabilitation).

Table C.22. Summary of Contracting Mechanisms Used to Ensure Quality for a Preventive Maintenance Treatment for High-Traffic-Volume PCC Roads

	Contracting Mechanisms Used				
PCC Pavement Treatments for High-Traffic-Volume Roadways	**QC/QA**	**Performance Specifications**	**Warranties**	**Contract Maintenance**	**Number of Respondents**
Concrete joint resealing	56	31	6	39	36
Concrete crack sealing	56	31	6	42	36
Diamond grinding	59	38	6	35	34
Diamond grooving	55	40	5	30	20
Partial-depth concrete pavement patching	59	22	6	44	32
Full-depth concrete pavement patching	58	29	8	39	38
Dowel bar retrofit (load-transfer restoration)	58	32	6	35	31
Thin PCC overlays	56	38	0	38	16
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	72	33	6	33	18
Thin HMA overlay (<40 mm [<1.5 in.])	75	35	5	40	20
Drainage preservation	75	20	5	45	20
Other (see below)	100	0	0	50	2

Agency Comments (Table C.22):

- All concrete maintenance is performed by city crews.
- Dowel bar retrofit (have standard specification—seldom used). Thin PCC overlay (major rehabilitation).

Question 18

Does your agency have in place quality control/quality assurance (QC/QA) procedures for preventive maintenance applications? If "Yes," would you describe these QC/QA procedures as informal or formal?

Based on 57 total responses, the following percentages of "Yes" and "No" were observed:

- Yes: 51%
- No: 49%

If the agency responded "Yes," a follow-up question asks the respondent to, if possible, provide a copy of the procedures (by fax, e-mail, or URL link).

- Yes: If put out to bid; No: If done with state forces.
- http://www2.dot.state.fl.us/SpecificationsEstimates/Implemented/CurrentBK/Default.aspx?PageAddr=lt;a%20hrefeq;qt.
- Maintenance applications are covered the same as pavement used for rehabilitation.
- www.virginiadot.org/business/const/spec-default.asp.
- http://mdotwas1.mdot.state.mi.us/public/dessssp/.
- But only during placement.
- Normal construction/material specifications.
- Contractor needs ISO 9001 quality plan.
- Internal QC.
- 2006 LA Standard Specifications for Roads and Bridges; Materials Sampling Manual; Materials Testing Procedure Manual. www.dotd.la.gov/highways/project_devel/contractspecs/2006_STAND_SPECS.zip.
- https://www.raqsa.mto.gov.on.ca/techpubs/ops.nsf/OPSHomepage.
- www.ksdot.org.

Question 18 (continued)

As indicated by a "No" response to question 18, you do not currently have QC/QA procedures for preventive maintenance treatments in place. Do you have plans for implementing them?

Based on 24 responses, the following percentages of "Yes" and "No" were observed:

- Yes: 17%
- No: 83%

Individual statements included:

- Several years ago, we had a QA procedure for several maintenance activities. These have since been discontinued.
- Our maintenance forces complete most of the preventative maintenance items that have been discussed.
- Contractor to have a quality management program in place.
- We enforce QC/QA by using the Greenbook and our in-house materials laboratory.

As indicated by a "No" response to question 18, you indicated that your agency does not use warranty specifications on any of your preventive maintenance treatments. Do you have any plans/interest in the use of warranties?

Based on 23 responses, the following percentages of "Yes" and "No" were observed:

- Yes: 26%
- No: 74%

Individual comments included:

- 18 doesn't say anything about warranties. We require warranties for microsurface and UBWC.
- I am interested in looking at warranties on all four treatments that we allow, but no time frame as to when that would happen.
- HMA overlays.

Question 19

If you indicated that your agency has implemented performance-related specifications for preventive-maintenance treatments, briefly describe your experience with these specifications.

- We get a better product from contractors with specs in force.
- Mostly good experience.
- Our current standard specifications were our first attempt at performance specifications. It is not entirely performance based. The next version will work toward more performance specs. So far the majority of work done by performance specification has been good.
- We have a performance specification for chip seal, including conventional, polymer modified, fiberized, and rubberized chip seals. The contracts include warranty provisions. The contracting community proposed them and they have been very cooperative in addressing the problems on a small percentage of completed projects.
- Materials field testing of PG graded asphalt products as well as QA testing of the HMA.
- Ride specification (IRI). Very good experience.
- Good. If we have a problem such as not meeting density requirements, contractor is penalized or removed and replaced.
- We have warranties on the majority of CPM projects, generally 2 years for surface seals and 3 years for HMA overlays.
- Generally, we obtain good result, but sometimes, it is difficult to choose the right specification.
- We do have performance-related specifications for pavements in our total maintenance contracts. We have revised them through the years based on experience and I believe that they are working well.
- Good.
- They define proper materials and processes but need to be revisited to address issues that arise.
- These are specifications are more with performance, ride quality, etc. Our construction side of the house provides the inspection with these items.

- Warranties on chip seals. Volumetric Mix Design, Hamburg Rut Testing.
- Chip seal and micro must meet 1-year review by agency.
- We have 1- or 2-year warranties in place for many pavement preservation treatments. We are also trialing 3- and 7-year warranties for some pavement preservation treatments.
- Our performance-related specifications are only with hot-mix asphalt applications. These specifications were not developed specifically for preventive maintenance treatments but rather for overlays—both structural and thin PM overlays. We use the Superpave system with performance-graded binders, statistical acceptance for several key parameters, and incorporate pay factors. We also control the roughness using IRI and pay factors. We have been using these specifications for over 10 years with good success.
- The nationally certified Materials Lab for the City of Phoenix has a representative at a supply plant when a project is ongoing. The Materials Lab tests each sample to ensure that the mixes are within design specifications.
- Mostly ride specs on multiple layer projects like a 2 in. SR and NovaChip for HMA or ride spec on diamond grinding and concrete inlay.
- Generally the specifications represent procedures that have been proven to be successful over time. Materials and methods have to meet these specs or be replaced by the contractor or supplier.
- To my knowledge we only have performance related specs for microsurfacing. I am not familiar with spec.
- Standard specifications have been developed (and continue to be developed) for major treatments such as thin-lift AC overlays and full granular aggregate seal coats. They are reasonably successful in producing quality products.
- Inspect and test to insure specs are met.
- Performance related requirements that we have are pretty simple and simply require the product to perform to a certain level for 1 or 2 years. For example, for sealcoat, if there is a lack of aggregate coverage, the contractor is required to come back and correct the deficiency. Overall we get good performance but when not there can be disputes as to whether it is a workmanship issue or whether our snowplows were too rough on the seal (for example).
- Some HMA mill and overlay and overlay projects have smoothness specifications and joint density specifications.
- Most of our preventive maintenance treatments do not have performance related specifications. An exception to this is with diamond grind projects. Each project is tested for rideability prior to grinding, a simulation is performed to determine the expected IRI after grinding, and thresholds are set accordingly.
- They have made the contractor pay attention to details.

Question 20

If you indicated that you do not have performance-related specifications, what are your plans for implementing them?

- None at present.
- Uncertain.
- Possibly in the future for seal coat, fog seal, and rejuvenators.
- We have written performance based specs for crack sealing/crack filling, but they have not been used to date.
- I would like to review other states' warranties and see if it is something we can implement.
- We have no plans to implement performance-based specifications at present.
- No plans at this time.
- It is our desire to develop performance-related specifications as we gain more knowledge of the performance indicators and parameters.
- At this time, we will most continue to use QA/QC specifications.
- None.
- See previous question for my answer pertaining to QA/QC.
- Don't know.
- No current plans for implementation. Following national trends for future consideration.
- None at this time.
- Our specifications engineer is recommending moving to performance related specifications in the next major revision of our specification book.
- FLH has a study under way looking at the feasibility of using performance-related specifications for polymer-modified asphalt emulsions for chip seals, slurry seals, and microsurfacing.

- As new methods to measure performance that are not subjective become available MN/DOT will evaluate them and implement them.

Question 21

For RURAL high-traffic-volume roadways, which treatments do you use to address the following pavement performance issues. Please check all that apply.

Tables C.23 and C.24 present the agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Table C.23. Summary of Preventive Maintenance Treatments Used to Address RURAL HMA Pavement Performance Issues

HMA-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Percent Responses									
	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress	Number of Responses
Crack fill	0	0	0	10	0	0	74	61	19	31
Crack seal	3	3	3	5	3	0	84	65	19	37
Cape seal	100	100	33	33	33	0	100	100	0	3
Fog seal	67	83	0	0	0	0	22	6	0	18
Scrub seal	67	67	0	0	0	0	67	33	0	3
Slurry seal	65	82	0	24	24	0	59	18	0	17
Rejuvenators	38	75	12	0	0	0	12	12	0	8
Single-course microsurfacing	57	71	29	31	57	11	77	37	6	35
Multiple-course microsurfacing	53	70	30	37	53	13	67	70	17	30
Single-course chip seal	42	70	24	9	52	0	79	42	3	33
Multiple-course chip seal	45	59	18	14	45	0	59	68	9	22
Chip seals with polymer-modified asphalt binder	42	65	15	8	58	0	77	50	8	26
Ultra-thin bonded wearing course (e.g., NovaChip)	50	71	29	46	83	25	88	50	8	24
Thin HMA overlay (<40 mm [<1.5 in.])	66	59	41	76	44	29	85	71	20	41
Cold milling and HMA overlay (<40 mm [<1.5 in.])	68	55	43	82	39	20	73	80	41	44
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	53	63	37	63	58	21	84	47	11	19
Hot in-place HMA recycling (<50 mm [<1.95 in.])	50	38	25	62	38	12	62	62	38	16
Cold-in-place recycling (<100 mm [<4.0 in.])	24	29	19	43	19	10	43	71	67	21
Profile milling (diamond grinding)	0	0	6	94	62	6	38	19	0	16
Ultra-thin whitetopping	20	13	13	60	20	7	40	60	60	15
Drainage preservation	0	0	0	17	0	0	33	83	83	6
Other (see below)	50	0	100	50	50	0	0	50	50	2

Other Treatments (Table C.23):

- 1.5 in. HMA mill and fill.
- Crack fill and crack seal. Prevent water intrusion; ultra-thin whitetopping (major rehabilitation).
- Shot blast or water blast.

Table C.24. Summary of Preventive Maintenance Treatments Used to Address RURAL PCC Pavement Performance Issues

PCC-Surfaced Pavement Treatments for RURAL High-Traffic-Volume Roadways	Percent Responses									No. of Responses
	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress	
Concrete joint resealing	5	0	0	27	0	14	91	36	9	22
Concrete crack sealing	0	0	0	14	0	11	96	46	4	28
Diamond grinding	3	0	0	82	58	37	24	32	5	38
Diamond grooving	0	0	0	56	94	25	12	12	6	16
Partial-depth concrete pavement patching	3	0	0	35	0	6	53	79	38	34
Full-depth concrete pavement patching	0	0	0	34	2	5	22	73	80	41
Dowel bar retrofit (load-transfer restoration)	0	0	0	55	3	6	24	42	36	33
Thin PCC overlays	0	0	0	45	18	9	36	64	64	11
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	8	0	0	69	54	15	23	23	0	13
Thin HMA overlay (<40 mm [<1.5 in.])	5	5	5	58	37	26	37	42	11	19
Drainage preservation	0	0	0	0	0	0	50	75	100	4
Other (see below)	0	0	0	0	0	0	0	0	0	0

Other Treatments (Table C.24):

- Crack fill, crack seal, and drainage preservation. Prevent water intrusion; thin PCC overlays (major rehabilitation).

Question 22

For URBAN high-traffic-volume roadways, which treatments do you use to address the following pavement performance issues. Please check all that apply.

Tables C.25 and C.26 present the agency responses and include summary statistics associated with the answers. Individual agency comments associated with this question are also included.

Question 23

Does your agency consider user costs in the treatment selection process for preventive maintenance applications? (Check the one answer that is most representative.)

Based on 56 responses, the following percentages of "Yes" and "No" were observed:

- Yes: 21%
- No: 79%

Question 23 (continued)

If "Yes," are user costs quantified numerically in your treatment selection process?

Based on 13 responses, the following percentages of "Yes" and "No" were observed:

- Yes: 38%
- No: 62%

If "No," does your agency have plans to begin considering [or incorporating] user costs in the treatment selection process?

Based on 52 responses, the following percentages of "Yes" and "No" were observed:

- Yes: 23%
- No: 77%

Individual comments included:

- Not specifically, but we are starting to use FHWA's *RealCost* software, which can incorporate user costs.
- We have attending classes detailing the processes.
- To evaluate cost-effectiveness of treatments.
- Actually, our plans are to indirectly incorporate user costs through the development and implementation of more comprehensive performance requirements.
- It is currently included, whether it be formally or informally.
- We will not spend limited funds on low-volume roads. We track ADT and spend the funds we have on the routes that tend to get the most traffic.
- We are considering the development of life-cycle costs, including user costs, for preservation projects in order to promote the use of alternate bidding.
- We already do.
- Asset management has been developed and implemented.
- Used in the consideration of lane closure times.
- I have heard that we are looking into it but have no direct knowledge.

Table C.25. Summary of Preventive Maintenance Treatments Used to Address URBAN HMA Pavement Performance Issues

HMA-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Percent Responses									Number of Responses
	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress	
Crack fill	0	0	0	6	0	3	81	56	12	32
Crack seal	0	0	0	8	0	5	86	62	16	37
Cape seal	100	100	0	0	0	0	67	67	0	3
Fog seal	56	81	0	0	0	0	19	6	0	16
Scrub seal	60	60	0	0	0	0	60	20	0	5
Slurry seal	67	87	7	7	20	0	80	20	0	15
Rejuvenators	33	83	0	0	0	0	0	17	0	6
Single-course microsurfacing	67	60	27	33	50	7	83	40	0	30
Multiple-course microsurfacing	69	65	35	46	50	8	73	73	15	26
Single-course chip seal	33	53	0	0	67	0	80	47	0	15
Multiple-course chip seal	38	54	0	0	46	0	62	69	15	13
Chip seals with polymer-modified asphalt binder	47	60	7	7	53	0	93	67	13	15
Ultra-thin bonded wearing course (e.g., NovaChip)	50	64	36	55	73	32	86	41	9	22
Thin HMA overlay (<40 mm [<1.5 in.])	65	57	45	72	40	25	90	65	20	40
Cold milling and HMA overlay (<40 mm [<1.5 in.])	74	53	50	76	37	24	76	79	42	38
Ultra-thin HMA overlay (<20 mm [<0.75 in.])	62	69	44	62	62	31	94	38	12	16
Hot in-place HMA recycling (<50 mm [<1.95 in.])	50	42	33	50	42	17	67	50	50	12
Cold-in-place recycling (<100 mm [<4.0 in.])	20	13	20	40	20	13	47	93	60	15
Profile milling (diamond grinding)	0	0	6	94	59	12	18	24	0	17
Ultra-thin whitetopping	21	14	14	50	21	14	36	64	43	14
Drainage preservation	0	0	0	0	0	0	25	75	75	4
O ther (see below)	50	0	100	50	0	0	0	50	50	2

Other Treatments (Table C.25):

- Crack fill and crack seal. Prevent water intrusion; ultra-thin whitetopping (major rehabilitation).
- Shot blast or water blast.

Table C.26. Summary of Preventive Maintenance Treatments Used to Address URBAN PCC Pavement Performance Issues

PCC-Surfaced Pavement Treatments for URBAN High-Traffic-Volume Roadways	Percent Responses									Number of Responses
	Raveling	Oxidation	Bleeding	Smoothness/ Ride Quality	Friction	Noise	Light Surface Distress	Moderate Surface Distress	Heavy Surface Distress	
Concrete joint resealing	4	0	0	29	0	17	88	46	4	24
Concrete crack sealing	0	0	0	20	0	12	88	52	8	25
Diamond grinding	3	0	0	84	65	41	19	24	5	37
Diamond grooving	0	0	0	56	75	31	19	25	6	16
Partial-depth concrete pavement patching	6	0	0	42	0	3	55	79	36	33
Full-depth concrete pavement patching	2	0	0	42	2	5	35	75	72	40
Dowel bar retrofit (load-transfer restoration)	0	0	0	69	3	7	31	55	41	29
Thin PCC overlays	0	0	0	64	9	0	45	55	36	11
Ultra-thin bonded wearing course (e.g., HMA < 25 mm [1 in.])	7	0	0	64	57	36	64	50	14	14
Thin HMA overlay (<40 mm [<1.5 in.])	0	0	0	72	44	33	61	72	11	18
Drainage preservation	0	0	0	0	0	0	25	75	75	4
Other (see below)	0	0	0	0	0	0	0	0	0	0

Other Treatments (Table C.26):

- Concrete joint resealing, concrete crack sealing, and drainage preservation—prevent water intrusion; thin PCC overlays (major rehabilitation).

Question 24

There are a number of reasons why agencies may not be performing pavement preservation on high-traffic-volume roadways. Please prioritize the additional guidance that you feel is needed for the successful implementation of preservation strategies on high-traffic-volume roadways.

Table C.27 presents the agency responses and includes summary statistics associated with the answers.

Table C.27. Summary of Additional Guidance Needed for the Successful Implementation of Pavement Preservation Strategies on High-Traffic-Volume Roadways

	No Guidance Needed %	Some Guidance Needed %	Significant Guidance Needed %	Number of Respondents
Other agency experience with treatment	17	61	22	54
Experienced contractor availability list	34	45	21	53
Availability of suitable materials	38	45	17	53
Typical traffic control requirements	57	40	4	53
Typical closure time information	52	42	6	52
Durability/expected treatment life	11	33	56	54
Typical noise associated with treatment	45	47	8	53
Treatment production rates	34	38	8	53
Time needed before trafficking	31	48	21	52
Typical treatment costs by region	19	57	25	53
Applicable traffic volumes	24	35	41	54
Appropriate climatic regions for treatments	25	36	40	53

APPENDIX D

Other Pavement Preservation Treatments

A few other types of preservation treatments were identified and examined as part of the literature review. These included polymer-modified asphalt concrete (PMAC) overlays, epoxy asphalt, high-performance cementitious materials (HPCM), high-friction surface (HFS), undersealing, cross stitching, ultra-thin epoxied laminates, and shot abrading. These treatments fall under one of the following categories: (a) lengthy existence but limited overall use, (b) lengthy existence but use limited to one or two agencies, (c) international use with recent trials in the United States, or (d) new/innovative with recent trials in the United States. Known details regarding each of these treatments are provided below.

- Polymer-modified asphalt concrete (PMAC; also known as Smoothseal) is a thin surfacing material composed of polymer-modified asphalt cement and fine-graded aggregate mixed in a conventional HMA plant and placed using a conventional asphalt paving machine. It is primarily used in Ohio as a PM treatment capable of retarding raveling and oxidation, reducing the intrusion of water, improving surface friction, and removing minor surface irregularities. It is reportedly suitable for all levels of traffic and is available in two mixture forms. Type A PMAC is used for low-speed (<45 mph) urban applications and is typically placed 0.625 in. thick. Type B PMAC is placed between 0.75 and 1.25 in. thick and is intended for high-speed (≥45 mph) applications.
- Epoxy asphalt is a product made with aggregate and a modified binder that can be applied in thin layers on existing pavement. It has been used worldwide as a bridge deck surface, but is relatively untested on a large scale on roadways because of its high material cost and special construction considerations. However, laboratory testing has shown it to be stiffer than conventional asphalt pavement, giving better load distribution. Additionally, it is resistant to rutting, low-temperature cracking, surface abrasion, and fatigue cracking. It is less susceptible to water damage than conventional asphalt pavement. Aggregates must be carefully selected for compatibility, and mixing time and temperature must be closely monitored. These special construction considerations can be overcome through experience with the material. The initial cost of epoxy asphalt is estimated to be two to three times higher than conventional asphalt, but the treatment is expected to have a longer life span.
- HPCM is a new treatment method where a thin layer of high-performance, fiber-reinforced mortar is placed on the existing pavement, and then hard aggregate particles are embedded in the mortar, similar to a chip seal. The strength of the bond between the HPCM and the underlying asphalt concrete is critical, but laboratory tests have shown that a strong bond is possible if the asphalt is thoroughly cleaned prior to applying the HPCM. Small cracks are inevitable as shrinkage occurs, but the fibers minimize the width of crack opening. Because this method is new, work still needs to be completed to make it viable on a large scale. HPCM is estimated to cost two to three times more than a conventional asphalt treatment.
- HFS treatments have been widely used in Great Britain. It is relatively new in the United States, but several test projects have proved effective. The treatment consists of a layer of resins and polymers mixed with a binder and topped with small, hard aggregate. One common HFS treatment feature is the use of an epoxy resin and bauxite aggregate. The construction process can be completed during a single shift or an overnight closure, as the epoxy-resin cures in about 3 hours. It is recommended that cracks be sealed before placing the HFS treatment and, as with a chip seal, the surface should be swept to remove excess stones before opening to traffic. HFS treatments are designed to improve surface friction at problem sections such as tight curves and steep grades especially at intersection approaches and on and off ramps. HFS treatments can be applied over surface distortions such as rutting or faulting, but will not address those problems.

They are designed to be extremely durable and withstand heavy braking and snow plows while maintaining their surface friction characteristics. A similar treatment uses an epoxy-resin and a specially designed hard aggregate to create a rigid spongelike texture that holds anti-icing treatments near the surface to release more as needed. This creates a high-friction surface that resists ice and snow and requires less frequent treatment.

- A fiber-reinforced seal (FRS) is a sprayed-on surface treatment consisting of a layer of glass fiber strands sandwiched between two coats of a polymer-modified asphalt emulsion (Austroads 2005). The system includes a layer of fine aggregate that is spread and rolled on top. The proprietary treatment was originally developed in Britain and has been used extensively throughout that and other European countries for treating cracked and aged HMA pavements covering a range of applications (parking lots to major roadway and airport pavements).
- Undersealing is the pressure insertion of a flowable material beneath a PCC slab to fill voids between the slab and base, thereby reducing deflections and, consequently, deflection-related distresses such as pumping or faulting. This treatment performs best if applied before faulting starts to develop. Given the higher cost of the treatment, undersealing has not received extensive use. When used, the treatment is most often performed at areas where pumping and loss of support occur, such as beneath transverse joints and deteriorated cracks. The voids filled by this technique are generally less than 0.12 in. thick.
- Cross stitching is a longitudinal crack and joint repair technique that consists of grouting tie bars in holes drilled across nonworking longitudinal cracks or joints at an angle to the pavement surface. Cross stitching prevents horizontal and vertical crack and joint movements. Use of this treatment is growing because cross stitching has proven effective at strengthening longitudinal cracks, preventing slab migration, mitigating the omission of tie bars from longitudinal contraction joints, tying separating roadway lanes or shoulders, and tying together faulted center-lane joints. The treatment is not appropriate for slabs that have multiple cracks or are considered shattered (broken into more than four or five pieces). When the treatment is properly applied, it is expected to last approximately 15 years.
- Ultra-thin (0.12 to 0.25 in. [3.0 to 6.0 mm]) epoxied laminates (i.e., Italgrip System proprietary treatment) have been used for concrete roads for surface texture restoration primarily in Europe, but with some success in the United States. The Italgrip method, which uses an epoxy for binding a 0.01-in. (0.25-mm) hard, synthetic stone to the road surface, has been used in Italy for the past 15 years.

  Benefits/strengths reportedly associated with the Italgrip system include good anti-skid microtexture properties, good macro-texture for water removal and reduced hydroplaning, early opening time to traffic under summer conditions, fast application rate, reduced pavement-tire noise, and elimination of bridge clearance and curb-and-gutter problems due to thin layer. Reported weaknesses/disadvantages include high initial cost and durability that is sensitive to the combination of low initial temperatures and early traffic application.
- Shot abrading was originally developed in 1979–1980 as a way of preparing concrete surfaces before applying bonded concrete overlays but has been more recently used for restoring friction on PCC highways. The process uses a machine (called a Skidabrader) that hurls steel abrasive materials at the road surface to increase the texture of concrete surfaces. This method has been used on many high-profile concrete road texture restoration projects in the United States, including the shuttle runway for NASA, major airport runways, tunnels, Interstates, and the Lake Pontchartrain Bridge in Louisiana.

  Benefits and strengths of the shot-abrading method include increased macro-texture levels for friction restoration, relatively high production rate, and relatively low cost. Reported concerns/weaknesses include microtexture wear if the coarse aggregate is susceptible to polishing, increased noise if larger aggregates are exposed, and limited ability to restore ride quality.

Related SHRP 2 Research

Modular Pavement Technology (R05)

Composite Pavement Systems (R21)

Using Existing Pavement in Place and Achieving Long Life (R23)

Guidelines for the Preservation of High-Traffic-Volume Roadways (R26)