Preventative Maintenance and Timing of Applications

Kelly Smith, P.E. - Consultant
David Peshkin, P.E. - Consultant
Dr. Walaa S. Mogawer, P.E. - PI
Alexander Austerman, P.E.

Prepared for
The New England Transportation Consortium
June 12, 2017

NETCR101 **NETC 06-4**

ACKNOWLEDGEMENTS

The following are the members of the Technical Committee that developed the scope of work for the project and provided technical oversight throughout the course of the research:

Paul Petsching, Rhode Island Department of Transportation, Chairperson
Mark Brum, Massachusetts Department of Transportation
Bryan Lee, Connecticut Department of Transportation
Deirdre Nash, New Hampshire Department of Transportation
Derek J. Nener-Plante, Maine Department of Transportation
Mike Fowler, Vermont Agency of Transportation

Technical Report Documentation Page

1. Report No. NETCR101	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Preventive Maintenance and Timing of Applications		5. Report Date June 12, 2017
		6. Performing Organization Code N/A
7. Author(s) Kelly Smith, P.E.- Consultant David Peshkin, P.E. - Consultant Professor Walaa S. Mogawer, P.E. – Principal Investigator (PI) Alexendar Austerman, P.E.		8. Performing Organization Report No. NETCR100
9. Performing Organization Name and Address Applied Pavement Technology, Inc. 115 W. Main Street, Suite 400 Urbana, Illinois 61801 And Department of Civil and Environmental Engineering University of Massachusetts Dartmouth 285 Old Westport Road North Dartmouth, MA 02747		10 Work Unit No. (TRAIS) N/A N/A
		11. Contract or Grant No. N/A
12. Sponsoring Agency Name and Address New England Transportation Consortium c/o Transportation Research Center University of Vermont 210 Colchester Avenue Burlington, VT 05405		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code NETC 06-4 A study conducted in cooperation with the U.S. DOT
15 Supplementary Notes N/A		

16. Abstract

The main objective of this study was to develop a pavement preventive maintenance implementation manual for agencies within the New England states. The development of the manual required:

- Identifying components of a pavement preventive maintenance program.
- Evaluating techniques that have been successfully used to cost-effectively extend pavement life.
- Identifying and quantifying factors that influence the success of preventive maintenance.
- Validating treatment parameters using Accelerated Pavement Testing.
- Developing example applications of optimal timing for applying preventive maintenance treatments.

Information for developing the manual was obtained through a comprehensive literature search and a detailed survey of the New England state highway agency (SHA) pavement practices. Pavement performance and other data on past preservation projects were obtained from a few of these agencies and used for the optimal timing examples.

17. Key Words Thin Lift, Surface Treatment, Polymer Modified Asphalt	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 99	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F

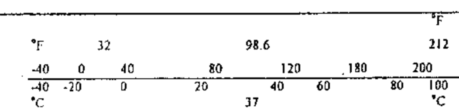


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Background

The application of pavement preventive maintenance (PPM) practices to maintain roadway networks is a somewhat recent development for public transportation agencies. Many agencies have had a long history of practicing a “worst-first” approach to managing their pavements; that is, they prioritized their budgets and operations to fix the worst roads in their pavement network first. Little was spent on roads in good condition and few challenged the wisdom of the worst-first strategy.

Over the past two decades that approach has changed; perhaps slowly at first but fairly rapidly since the mid-2000s. Explanations for this trend include decreased funding levels available to manage roadway networks, declining network pavement conditions (suggesting that “worst-first” doesn’t work), and a better understanding of preventive maintenance and its impact on pavement performance. The widespread use of pavement management systems (PMS’s) has helped by providing data that can be used to demonstrate that a proactive approach to managing pavements is more cost-effective than the worst-first approach.

There is a growing interest in the New England states in the ability to use timely PPM practices to reduce life-cycle expenditures, to extend roadway service life, and to improve roadway safety. To address this interest, a study was initiated by the New England Transportation Consortium (NETC Project 06-4) to examine preventive maintenance treatments and the timing of their application to improve pavement performance and reduce the life-cycle costs of managing a pavement network. The following objectives were identified for this project:

- Identify components of a pavement preventive maintenance program.
- Evaluate techniques that have been successfully used to cost-effectively extend pavement life.
- Identify and quantify factors that influence the success of preventive maintenance.
- Validate treatment parameters using Accelerated Pavement Testing.
- Determine the approximate cost of preventive maintenance techniques.
- Develop a pavement preventive maintenance implementation manual for agencies within the New England states.

A comprehensive data collection and analysis effort—including a literature review, a survey of New England state highway agencies (SHAs), and laboratory testing—was undertaken to accomplish these objectives. The main product of the study, the guidelines for preventive maintenance in the New England states, is presented in the remainder of this document.

Pavement Preventive Maintenance Overview and Definitions

A number of terms apply to the application of preventive maintenance treatments and strategies. These include various categories of maintenance, preventive maintenance, and pavement preservation.

The term "maintenance" itself can be sub-divided into several categories depending on the condition of the pavement and the timing of the activity. The following definitions are from a 2005 Federal Highway Administration (FHWA) memo (Geiger 2005)[1]:

- Catastrophic Maintenance: Work activities taken to restore a facility to a minimum level of service following a catastrophic event, such as a concrete pavement blow-up, road washout, avalanche, or rockslide.
- Corrective Maintenance: Work activities to correct a deficiency or deficiencies that negatively impact the safe, efficient operations of the roadway and the future integrity of the pavement section. Corrective maintenance is generally reactive, and restores an acceptable level of service but does not extend pavement life. Examples of corrective maintenance include patching, spall repair, and edge drop-off restoration.
- Routine Maintenance: Work that is planned and performed on a regular basis to maintain and preserve the condition of the highway system, such as ditch cleaning, crack filling, and minor patching. Depending on the condition of the pavement and the nature of the distress, routine maintenance may also be classified as preventive maintenance.
- Preventive Maintenance: A planned strategy of applying cost-effective treatments to a roadway system and its appurtenances to preserve the condition of the system, slow future deterioration, and maintain or improve surface characteristics (without significantly increasing the roadway's structural capacity).
- Pavement Preservation: Defined by the FHWA in the same memo as "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." This is essentially the same language incorporated into Section 1507 of Public Law 112-141, "Moving Ahead for Progress in the 21st Century" Act (MAP-21).

Table 1 from that memo shows the inter-relationship between various types of maintenance and pavement preservation. From this table, it can be inferred that preventive maintenance is a key component of pavement preservation, as are certain routine maintenance and minor rehabilitation activities. A common and differentiating characteristic of these activities from other maintenance activities is that they slow down pavement deterioration and restore desirable pavement surface characteristics without addressing the load-carrying capacity of the pavement.

Figure 1 is a commonly used graphical representation of when in the life of a pavement these various activities occur. A key takeaway from this figure should be that preventive maintenance is applied to pavements in good condition. Pavement age may also be a consideration, in that candidate pavements are generally newer rather than older, but pavement condition should be given primary consideration.

[1] Note that FHWA's Associate Administrator for Infrastructure, Butch Waidelich, issued a memo titled *Guidance on Highway Preservation and Maintenance,* dated February 25, 2016, that supersedes previously issued FHWA guidance on this topic, including the 2005 Geiger memo. The impacts of this new memo have yet to be resolved.

Table 1. Classification of pavement activities by purpose (adapted from Geiger 2005).

Type of Activity	Purpose of Activity				
	Increase Capacity	**Increase Strength**	**Slow Aging**	**Restore Surface Characteristics**	**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

Note: Yellow shaded activities are classified as "pavement preservation," with preventive maintenance (darker yellow) always following under pavement preservation and minor rehabilitation and routine maintenance (lighter yellow) sometimes doing so.

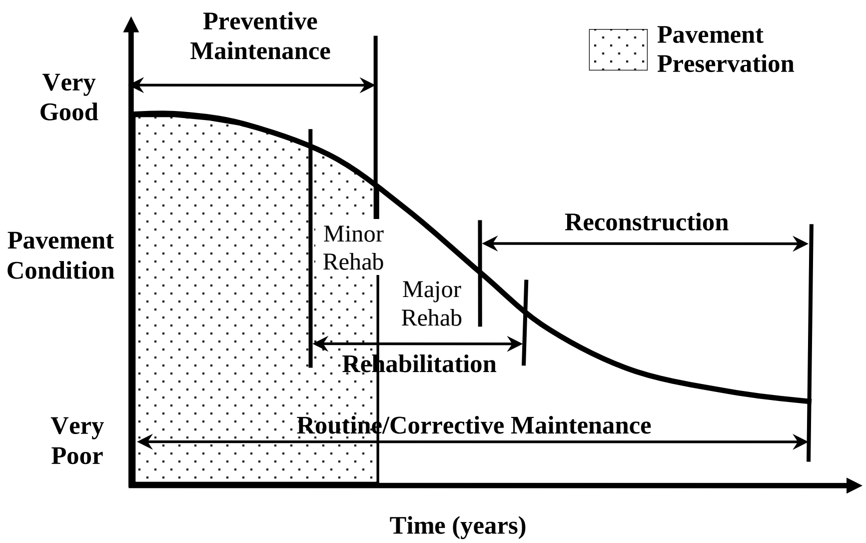


Figure 1. Relationship between pavement condition and the timing of varies categories of pavement treatments (Peshkin et al. 2011a).

Notwithstanding all of these described distinctions between the terms "preventive maintenance" and "pavement preservation," the two are often used interchangeably. The distinction is certainly subtle; the definitions above identify preventive maintenance as a strategy and pavement preservation as a program, but in practice both terms are being used to either describe treatments or programs and the distinction between them may be more of custom than substance.

Importance of Pavement Preventive Maintenance

The primary purpose of preventive maintenance is to keep good roads in good condition. When truly good candidate pavements receive preventive maintenance, agencies are able to manage their roadway networks in a cost-effective manner. Sound preventive maintenance practices are also linked to the following benefits (FHWA 2006; Peshkin et al. 2004, Smith et al. 2015):

- Extend pavement life.
- Delay the need for more costly rehabilitation or reconstruction.
- Reduce the life-cycle cost of managing pavements.
- Increase safety, especially when surface characteristics are enhanced.
- Improve user satisfaction through smoother roads.
- Reduce construction-related delays.

Figure 2 graphically represents the performance-related benefits identified in this list.

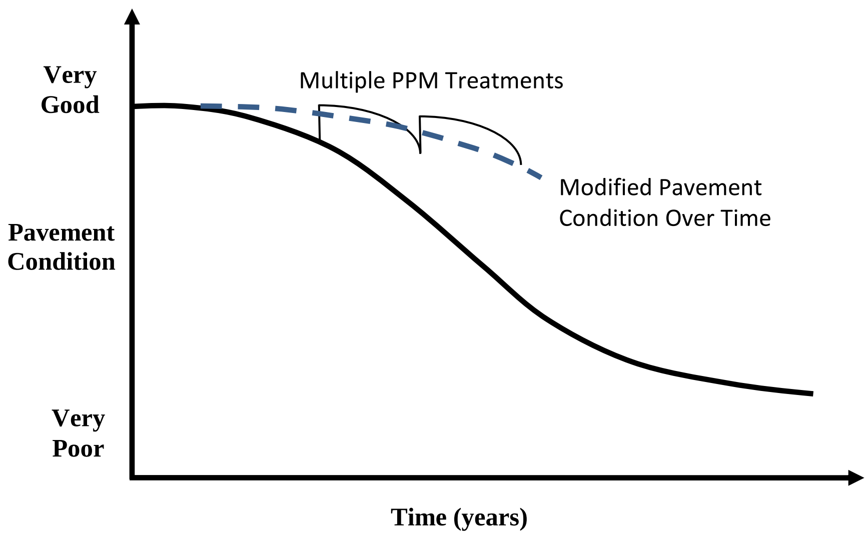


Figure 2. Pavement performance indicating the effects of preventive maintenance.

At the same time, there are factors that make the implementation of PPM strategies difficult. One such factor is that there is surprisingly little long-term data available to support or quantify the benefits of preventive maintenance. Also, given the range of factors affecting treatment performance, including climate (seasonal temperatures), pavement condition, construction quality, materials, traffic levels, and timing of application desired results are not always obtained. Thus for any geographical region, and for New England in particular, preventive maintenance guidance must be based on local conditions, available treatments, and timing considerations for the region.

Application of Pavement Preventive Maintenance in New England

A survey of the pavement practices of six New England SHAs—Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont—was a key part of this project. This detailed survey was developed and distributed to the agencies in 2015, and included an array of questions about agency practices and programs loosely organized into the following categories:

- Program size, maturity, and administration.
- Preventive maintenance treatment use.

- Project selection and treatment selection.
- Treatment performance.
- Materials and specifications.
- Work force.
- Program strengths and weaknesses.

The responses provided valuable insight on how PPM is being applied in the region, including the types of roads to which it is applied, their condition, and the common treatments in use. Although there is certainly great variability in the types of programs developed by these agencies, including the size of their programs, the treatments used, the availability and application of formal guidelines for project and treatment selection, and the availability of data to evaluate treatment performance and program effectiveness, the practices and experiences of each agency are invaluable to future program developments and upgrades, both at the state and local levels.

The results of the New England survey are featured throughout this report. For instance, Chapter 2 discusses the status and scope of agency programs, as well as their perceived strengths and weaknesses. Chapter 3 reports on the PPM treatment types being used and their specific applications (e.g., material modifications, placement thicknesses, types of roads on which they're applied). Chapters 4 and 5 tell of the factors and criteria being used to select PPM projects and treatments, and Chapter 5 describes the agencies' performance monitoring and modeling efforts for PPM treatments.

Organization of Report

In addition to this introductory chapter, this report contains the following chapters:

2. Pavement practices in New England
3. Pavement preventive maintenance toolkit.
4. Project selection.
5. Treatment selection.
6. Treatment timing.
7. Continuous improvement.

Purpose of the Pavement Preventive Maintenance Manual

It is envisioned that this report or manual will serve as a starting point for those New England agencies not already practicing pavement preventive maintenance, or as a tool to assist those who have already incorporated preventive maintenance into their programs to upgrade their practices.

2. PAVEMENT DESIGN, PERFORMANCE, AND MANAGEMENT IN NEW ENGLAND

This chapter summarizes the types of pavements typically used in the New England region, the types of deficiencies commonly observed in New England pavements, and the practices used to assess pavement condition and monitor pavement performance. It also discusses the New England SHA's use of pavement management data for selecting PPM projects and treatments, and the barriers or challenges associated with integrating the preventive maintenance and pavement management programs. The information presented is based on participant responses to a survey of their pavement preservation practices, as well as published documentation related to those agencies.

Pavement Types and Designs

The vast majority of the roads in New England are asphalt-surfaced. At least one state in the region has no concrete-surfaced roads, and most of the states that had concrete roads at one time have since overlaid them with HMA. Because very few pavements have been constructed in recent years with portland cement concrete (PCC) and because most of the older concrete pavements have been covered up with asphalt, it is understandable that there is far more use of PPM treatments on asphalt and composite pavements.

New asphalt pavements in New England mostly consist of an HMA surface and intermediate layer, a crushed stone or gravel base layer, an optional gravel subbase layer, and an improved subgrade. Cross-sectional thicknesses for these pavements, as well as HMA overlays placed on existing asphalt and concrete pavements, vary according to facility type, traffic levels, and subgrade soil characteristics.

Pavement Deterioration Mechanisms/Modes

Many factors affect the performance of highway pavements. These include the type and volume of traffic applied to the pavement, the environmental conditions to which the pavement is exposed, pavement design and construction practices, and pavement age. The collective interaction of these factors determine the rate and nature of pavement deterioration. If the pavement structure is insufficiently thick for the expected traffic loadings or if the paving materials are not designed or produced properly, then structural problems like fatigue cracking and rutting may develop prematurely. Likewise, if the asphalt materials are not properly designed for temperature and moisture conditions, then shrinkage cracking can develop prematurely, thereby exposing the pavement accelerated environmental deterioration.

New England's extreme variability in weather, unique topography and soils, and varying traffic conditions result in different pavement deterioration mechanisms and modes. A 2011 survey of New England SHAs revealed that the major distresses of concern in asphalt-surfaced pavements are as follows (Daniel et al. 2011):

- Alligator cracking—Bottom-up fatigue cracking caused by repeated and/or heavy loading on relatively thin or weak HMA layers or weak aggregate base layers.
- Longitudinal wheelpath cracking—Top-down fatigue cracking caused by wheel loads applied to an aged HMA surface or shearing of the HMA surface by radial tires with high-contact pressures.

- Longitudinal non-wheelpath cracking—Non-load-associated cracks occurring outside of the wheelpaths. These cracks are often the result of reflection cracks from the edges of an underlying old pavement or inadequate compaction at the edges of longitudinal paving lanes.
- Transverse thermal cracking—Low-temperature cracking due to extreme cold temperatures and thermal fatigue cracking due to daily temperature cycling.
- Rutting—Longitudinal depression of the wheelpaths, typically due to the consolidation or movement of material in the HMA layer, the base, and/or the subgrade.
- Ride quality—A function of the initial as-constructed longitudinal profile and the development of distresses (e.g., rutting, fatigue cracking, thermal cracking, depressions, swells, corrugations) over time.

As discussed later in this manual, PPM treatments are capable of addressing several of these distresses to a large degree, but may only have a small impact on the others.

Pavement Performance Monitoring

Pavements represent significant, long-term transportation investments that are vital to the socio-economics of modern-day society. While not as long-lasting as structures, such as bridges and buildings, the life-cycle of a pavement can often exceed 50 years with the application of maintenance and rehabilitation treatments at selected times over that period.

Because the funding for pavement maintenance and rehabilitation is often well below what is needed to keep them in good condition, it is important that every pavement application—whether new construction, pavement rehabilitation, or preventive maintenance—be administered in the most cost-effective manner possible to make the best use of limited dollars. In addition to maintaining a reliable and robust database of historical pavement treatment costs, a key to this objective involves accurately measuring and recording the performance of those treatments over time. The combination of costs and performance can be used to identify cost-effective treatments on future projects.

Pavement management is an established practice in state transportation agencies and is the principal tool used to (1) improve the condition of the pavement network and (2) maximize the performance of the network while keeping costs to a minimum. It has been defined as "a systematic process of planning, designing, constructing, operating, and maintaining pavements in a cost-effective manner; it combines solid engineering principles with sound business practices and economic theory to facilitate a more organized and logical approach to decision-making" (Zhang et al. 2003).

A PMS is a vital tool in the practice of pavement management. A PMS is composed of operational packages, including methods, procedures, data, software, policies, decisions, and so on, that link and enable the carrying out of all the activities involved in pavement management (Zhang et al. 2003). The typical data stored in a PMS includes inventory, traffic loadings, pavement structure and history, past and current conditions (as defined by distress, smoothness, friction, and other collected measurements), and often projected conditions. Although no two agencies use pavement management data in exactly the same manner, the over-arching goal of maximizing conditions with the available funding is the same.

Pavement management practices in the six New England states are very similar to each other, and are generally comparable to rest of the U.S. states. As summarized in table 2, information from the literature and the New England survey indicate that all six states conduct network-level pavement condition surveys using automated or semi-automated data collection vehicles. Distress and profile data are largely collected on annual or biennial cycles, depending on the route type. The collected data are then analyzed manually or automatically to quantify distress, rutting, and smoothness on specified intervals. All of the states use the Deighton dTIMS pavement management software for storing and querying the data, and most have developed and use pavement performance models for programming purposes.

New England PPM Programs

As PPM programs have developed and grown over the years, their value to the overall pavements program has become more recognized and accepted. Not only are most agencies including PPM treatments in their 5- or 10-year transportation plan, some are now evaluating ways in which to include them in the pavement design process. In fact, the recently published NCHRP Report 810 (*Consideration of Preservation in Pavement Design and Analysis Procedures*) presents information on the effects of preservation on pavement performance and service life, and describes different approaches for considering these effects in pavement design and analysis procedures (APTech 2015a).

The differences in New England PPM programs extend to variations in their size, nature, and fit within the organizational. All respondents of the New England survey agreed with the statement that they have in place a preventive maintenance program with guidelines or policies and dedicated funding, but with some significant variability in the formality of their programs and the available funding. Three of the agencies stated that their programs were well established and the other three classified theirs as being in the early stages. The three most important goals of their programs are: cost savings, improved pavement conditions, and better use of strategies and techniques.

The survey responses indicate that there is no standard regarding which agency department manages preventive maintenance. Depending on the agency, it may be housed in Maintenance, Pavement Management, Construction, Engineering, Design, Materials, or Project Development.

The survey responses also indicate that PPM program annual funding ranged from $18,700,000 to $86,000,000, but these numbers were not matched to the size of the roadway networks or to pavement conditions. The average program size was $48,540,000. Variability is further reflected in the number of PPM projects constructed annually, which ranged from 4 to 69 and averaged 27. The annual number of treated miles reported as lane miles were 250 and 417, and reported as centerline miles were 25, 100, 194, and "varies." If 1 centerline-mi is the equivalent of 2 lane-mi, then 261 lane-mi are treated on average each year. The approximate miles of roadway that each agency is responsible for are summarized in table 3.

Only one agency, Connecticut, has formalized their PPM practices to the extent that they are readily available to others. Those practices are given in their 2011 "Pavement Preservation Manual," which is viewable online at http://www.ct.gov/dot/cwp/view.asp?a=1400&q=489424.

Table 2. Summary of New England pavement management practices.

Item	**SHA**					
	Connecticut	**Maine**	**Massachusetts**	**New Hampshire**	**Rhode Island**	**Vermont**
Network-Level Condition Survey Method/Equipment	State-Owned Automated System	State-owned Automated System	State-owned Automated System	State-owned Automated System	Vendor-supplied Automated System	Vendor-supplied Automated System
Survey Frequency	▪ All routes—100% coverage annually	▪ Interstate routes—100% coverage annually ▪ Non-interstate routes—50% coverage annually	▪ Interstate and limited-access routes—100% coverage annually ▪ Other state-owned roads—50% coverage annually	▪ Yr 1—Interstates, Turnpikes, numbered routes ▪ Yr 2—Interstates, Turnpikes, non-numbered routes	▪ State-numbered highways, principal arterials, and NHS routes—100% coverage annually	▪ NHS routes—100% coverage annually ▪ Non-NHS routes—50% coverage annually
Distress Data Collected	▪ Edge crack ▪ Long WP crack ▪ Long Non-WP crack ▪ Trans crack	▪ Alligator crack ▪ Long crack ▪ Trans crack	▪ Alligator crack ▪ Long crack ▪ Raveling ▪ Trans crack	▪ Trans crack ▪ WP fatigue crack ▪ Non-WP crack	▪ Alligator crack ▪ Bleeding ▪ Block crack ▪ Edge crack ▪ Long crack ▪ Patching ▪ Trans crack	▪ Environmental crack ▪ Structural crack
Other Data Collected	▪ Long profile (IRI ▪ Trans profile (rut depth)	▪ Long profile (IRI ▪ Trans profile (rut depth)	▪ Long profile (IRI ▪ Trans profile (rut depth)	▪ Long profile (IRI ▪ Trans profile (rut depth, cross-slope)	▪ Long profile (IRI ▪ Trans profile (rut depth)	▪ Long profile (IRI ▪ Trans profile (rut depth)
PMS System	Deighton dTIMS Pvt Mgt Software	Deighton dTIMS Pvt Mgt Software	Deighton dTIMS Pvt Mgt Software	Deighton dTIMS Pvt Mgt Software	Deighton dTIMS Pvt Mgt Software	Deighton dTIMS Pvt Mgt Software
Pavement Performance Modeling	Performance models for 106 pavement families based on: ▪ IRI ▪ Max Rut Depth ▪ Structural Cracking ▪ Environmental Cracking	Performance models for 8 to 10 treatments	Performance models based on: ▪ Cracking Index ▪ Rutting Index ▪ Ride Index ▪ Composite PSI Index	Performance models for 6 treatment families: ▪ Crack seals ▪ PPM ▪ Functional overlays ▪ Structural overlays ▪ Reclamation ▪ Rubblization	Performance models for preservation and other treatments based on: ▪ Individual distress scores ▪ Composite condition score	

Table 3. New England SHA roadway network responsibilities.

Agency	Roadway Network Size
Connecticut	3,750 centerline-mi / 9,900 lane-mi
Maine	8,900
Massachusetts	9,500 lane-mi
New Hampshire	4,559 centerline-mi
Rhode Island	1,100 centerline-mi
Vermont	3,200 centerline-mi

Connecticut's guidelines discuss pavement preservation at both the network and project levels, cover the project and treatment selection process, and provide decision tools for selecting among a good variety of PPM treatments. They include information on pavement evaluation and provide a detailed example in which the guidelines are applied. A separate document, available at the same website, address project selection for crack sealing and/or filling.

Toward the conclusion of the survey, each agency was asked to identify up to three strengths and weaknesses of their programs. Because of the differences among the agencies, such as the age and "maturity" associated with their preventive maintenance practices, there was significant variability in the responses. These are summarized by agency in table 4.

Table 4. Summary of reported strengths and weaknesses of New England PPM programs.

Agency	Strengths	Weaknesses
Connecticut	▪ Good treatments ▪ PMS ▪ Contracting mechanism	▪ Lack of data on early onset of distresses ▪ No program for minor treatments on secondary roads ▪ Lack of performance data
Maine	▪ Cost savings ▪ Improved pavement conditions ▪ Reduced maintenance needs	▪ Scope creep (poor project selection) ▪ No dedicated funding ▪ Insufficient funding
Massachusetts	▪ Improved conditions	▪ Treatment life ▪ Poor timing
New Hampshire	▪ Part of resurfacing program for 10 years ▪ Department-wide support ▪ Agency-wide commitment to asset management	▪ Project selection not data-driven ▪ Historical resurfacing data needed ▪ PPM performance models needed
Rhode Island	▪ Delayed need for rehabilitation ▪ Improved performance (e.g., reduced spring potholes)	▪ Challenge from hot-mix industry ▪ Better coordination needed between Materials, Design, and Pavement Management
Vermont	▪ Over 5-year commitment to some level of PPM program	▪ PPM program is usually first one cut by management when budgets are reduced

One notable observation from table 4 is that agencies appear to have a level of comfort with the treatments they are using. Several report experiencing the types of benefits one expects to see from successful preventive maintenance programs, which is also encouraging. A shared weakness is the lack of performance data and of decision support based on objective data. There are also weaknesses in project selection, treatment selection, and challenges to the continual funding for preventive maintenance.

Integration of PPM and Pavement Management

PPM programs rely on proper treatment selection and timing of the treatment to be successful. As discussed later in this manual, the expected performance of a pavement both before and after a PPM treatment is placed are major factors in determining which treatment to use for a particular project and when best to apply it.

The most valuable resource for estimating pavement performance is the condition data collected and stored in an agency's PMS. As they relate to preventive maintenance, these data are very important in determining (1) whether a project is a suitable candidate for PPM, (2) which treatments are feasible for a project, and (3) which treatment is most ideal in terms of cost effectiveness and other considerations (Smith et al. 2014). Performance indicators, such as overall condition indexes/ratings, smoothness indexes, and key distress measures, can be used to establish the PPM window that defines when preventive maintenance should be considered for a project. Likewise, these same performance indicators can be used to set trigger and threshold levels for individual treatments that govern when they should be considered. Historical, time-series condition data can be used to develop pavement performance models, which can then be used to select the preferred PPM treatment based on expected performance and cost effectiveness.

Results of the New England survey indicate that five of the six agencies link the selection of preventive maintenance projects to their pavement management program. In one agency, PPM and pavement management are fully integrated, in three other agencies they are partially integrated, and in a fifth agency integration is in the planning stage. Connecticut's guidelines, previously introduced, are an indication of how integration between preventive maintenance practices and pavement management could be formalized.

3. PPM TREATMENT TOOLKIT

There is a broad range of PPM treatments that can be used on pavements. Each treatment has unique capabilities and functions that enable them to extend the life of the pavement through the following means (Peshkin et al. 2011b):

- Prevent or delay the occurrence of new distresses.
- Slow the development of existing distresses.
- Restore the integrity and serviceability of the pavement.
- Improve the surface characteristics of the pavement.

This chapter briefly discusses the types of PPM treatments available for use and that can be included in a highway agency's treatment toolkit. It also provides a summary of the treatments currently being used by the New England SHAs. The information is presented in terms of treatments that are applicable for asphalt and composite pavements and those that are applicable for concrete pavements. As an added resource, Appendix A contains technical profiles for each treatment type, including a description and design illustration of the treatment, and the pavement deficiencies addressed by the treatment.

PPM Treatment Types and Categories

PPM treatments are largely defined by their purpose, timing, and application characteristics. The effectiveness of a treatment is maximized when the pavement conditions are most suitable for being addressed by that treatment. Treatment application characteristics include the following:

- Refinishing the existing pavement surface.
- Directly placing a new surface on the existing pavement surface.
- Partially removing the existing surface and placing a new surface.
- Global or blanket application versus localized or spot application.
- Type of treatment material(s) used.

Based on these application characteristics, as well as the purpose and timing, PPM treatments can be grouped into the following categories:

- Retexturing/Reprofiling—Revitalization of the surface texture to improve friction or other pavement-tire interactions. Removal of a small portion of the existing pavement surface to restore profile or improve surface drainage or ride quality.
- Permanent Repairs—Patching localized distressed areas or installing dowel bars across joints to restore the integrity or load transfer efficiency of PCC pavement slabs.
- Crack/Joint Treatment—Sealing or filling of cracks or joints to prevent the infiltration of water and incompressible materials, or to reinforce the pavement cracks or joints.
- Asphalt Seals—Global application of an asphaltic material to restore or rejuvenate the binder properties of an existing asphalt surface.
- Asphalt-Aggregate Seals—Global application of an asphalt-aggregate mixture to seal and protect the existing pavement surface, restore its profile, or improve its surface characteristics.
- HMA Overlays—Global application of a thin HMA layer to seal and protect the existing pavement surface, restore its profile, or improve its surface characteristics.

- Mill-and-HMA Overlays—Removal of a portion of the existing asphalt pavement surface followed by placement of a thin HMA overlay, in order to eliminate surface distress, seal and protect the existing pavement, restore profile, or improve surface characteristics.
- Recycling—Reuse of a portion of the existing asphalt pavement through in-place processing with material additives followed by placement as a new pavement layer, in order to eliminate surface distress, restore profile, or improve surface characteristics.
- PCC Overlays—Global application of a thin PCC layer to eliminate surface distress, restore profile, or improve surface characteristics.
- Mill-and-PCC Overlays—Removal of a portion of the existing pavement surface followed by placement of a thin PCC overlay, in order to eliminate surface distress, restore profile, or improve surface characteristics.

Table 5 lists the various PPM treatment categories, the types of treatments that comprise those categories, and the types of pavements for which the treatments are suitable. Because of the wide range of materials and procedures available and the numerous possibilities for pavement removal depths and material layer thicknesses, there are many conceivable treatment options. Occasionally, two or more treatments may be combined, resulting in additional treatments. In addition, PPM treatments may be accompanied by a variety of preparatory activities, such as surface or base patching, leveling or shim course application (i.e., in wheelpaths, depressions, or other localized areas), bump grinding, and slab stabilization or jacking.

Table 5. PPM treatment types by treatment category and recipient pavement type.

Treatment Category	Asphalt and Composite Pavement Treatment Types	Concrete Pavement Treatment Types
Reprofiling/Retexturing	Standard Cold Milling, Profile Milling[1]	Diamond Grinding, Diamond Grooving
Permanent Repairs	—	Partial-Depth Repair, Full-Depth Repair[2], Dowel Bar Retrofit
Crack/Joint Treatment	Crack Filling, Crack Sealing	Crack Sealing, Joint Resealing
Asphalt Seals	Rejuvenator Seal, Fog Seal	—
Asphalt-Aggregate Seals	Sand Seal, Scrub Seal, Slurry Seal, Micro Surfacing, Chip Seal[3]	—
HMA Overlays	Ultrathin and Thin HMA Overlay[4], Ultrathin Bonded Wearing Course (UBWC)[5]	Ultrathin and Thin HMA Overlay[4], UBWC[5]
Mill-and-HMA Overlays	Mill-and-Thin HMA Overlay or Inlay[6]	—
Recycling	Cold In-Place Recycling (CIR), Hot In-Place Recycling (HIR)	—
PCC Overlays	Ultrathin PCC Overlay[7]	Ultrathin PCC Overlay
Mill-and-PCC Overlays	Mill-and-Ultrathin PCC Overlay or Inlay[6]	Ultrathin PCC Overlay

[1] Includes fine-tooth milling (aka, precision milling) and micro-milling (aka, carbide grinding).
[2] Includes slab replacement.
[3] Also referred to as seal coat or bituminous surface treatment.
[4] Ultrathin HMA overlay is typically 0.5 to 0.75 in thick. Thin HMA overlay is typically 0.875 to 1.5 in thick.
[5] Formerly known as the proprietary product NovaChip®.
[6] An inlay is an overlay that maintains the same pavement elevation (i.e., milling depth equals overlay thickness).
[7] Also referred to as ultrathin whitetopping, which is typically placed 3 to 4 in thick and bonded to existing pavement (Delatte 2014).

Asphalt and Composite Pavement Treatments

PPM treatments for asphalt and composite pavements are primarily used to seal or protect the existing pavement, treat or eliminate surface distresses (cracking, raveling, and wheelpath rutting), and correct or restore key surface characteristics (smoothness and friction). In general, localized treatments like crack sealing (figure 3 left) and global treatments like fog seals and slurry seals (figure 3 right), are most appropriate for pavements in good to very good condition. More substantial global treatments like chip seals (figure 4 left), as well as thin HMA overlays (figure 4 right) are most appropriate for pavements in fair to good condition. Treatments that involve the elimination of distress through surface removal and replacement, such as mill-and-thin HMA overlay (figure 5 left) and HIR (figure 5 right), are most appropriate for pavements in fair condition.

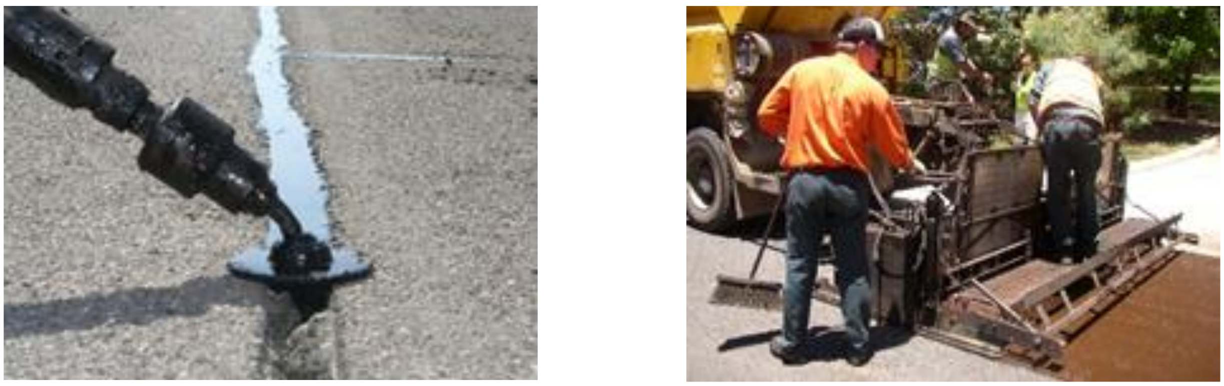


Figure 3. Crack sealing (left) and slurry seal application (right).

Figure 4. Chip seal application (left) (Crawford & Luce 2007) and thin HMA overlay placement (right) (courtesy of Suit-Kote Corporation).

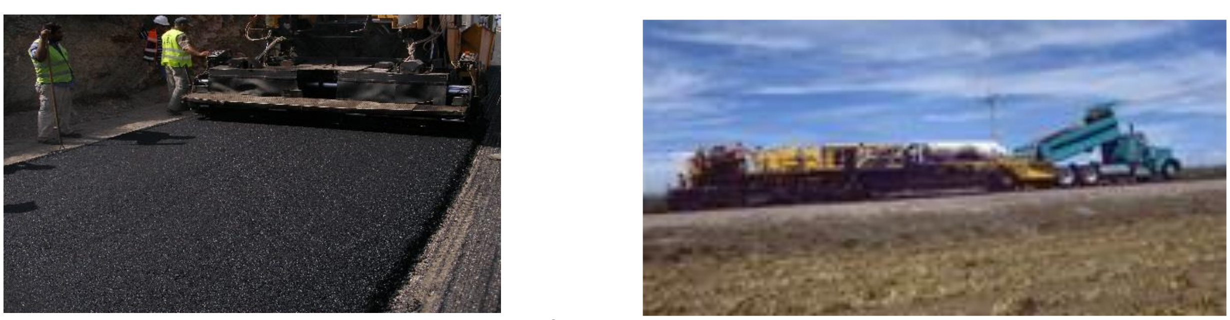


Figure 5. Mill-and-thin HMA overlay (left) and hot in-place recycling (right) (FHWA 1997).

Specific PPM Treatment Options

Table 6 provides an expanded list of PPM treatment options for asphalt and composite pavements. It shows the variations that are possible with each treatment type in terms of application features and materials used. It also lists other PPM treatments and preparatory activities that can be used in conjunction with the treatment.

New England PPM Treatments

Table 7 summarizes the use of PPM treatments for asphalt and composite pavements in New England, based on the survey responses of the six participating SHAs. The information is broken down by usage on high-, moderate-, and low-traffic-volume roads located in rural and urban areas. As can be seen, treatments most commonly used are crack sealing, micro surfacing, thin HMA overlays, UBWC (aka, paver-placed surface treatment [PPST]), and mill-and-thin HMA overlays. On low-volume roads, chip seals are also commonly used. (Note: Although standard cold milling and profile milling are used by about half the agencies, it is believed that these treatments are normally used in conjunction with an overlay rather than as a stand-alone treatment). Specific applications of the common treatment types include the following:

- Crack Sealing
  - Configurations—Simple flush-fill (no reservoir); reservoir and overband; simple overband; reservoir and recess.
  - Materials—Hot-applied rubberized asphalt (ASTM D6690/AASHTO M324) with or without fibers; hot-applied polymerized asphalt with fibers; cold- or hot-applied asphalt with polymer, rubber, or fiber modifiers.
- Micro Surfacing
  - Application—Double course at 0.375 to 0.5 in thick (total).
  - Materials—Slow-set emulsion with polymer and Type 2 aggregate gradation; slow-, medium-, rapid-, or quick-set emulsion with polymer or rubber modifiers and dense-graded aggregate; CSS-1h emulsion with 100% aggregate passing 0.375-in sieve.
- Chip Seals
  - Application—Single-course at 0.375 in thick; single- or double-course at unspecified thickness; single-course at 0.5 in thick; single-course at 0.375 to 0.5 in thick.
  - Materials—Crumb-rubber-modified asphalt with 0.375-in maximum size aggregate; rubber-modified asphalt with uniformly graded aggregate; hot-applied rubber-modified with 0.5-in maximum size aggregate.
- Thin HMA Overlays / Mill-and-Thin HMA Overlays
  - Thin Overlay Application—1-in single-lift HMA; 1.25-in single-lift HMA (with rut-filling shim course); 1.25- to 1.5-in single-lift HMA.
  - Mill-and-Thin Overlay Application—1.25-in milling depth and 1.25-in single-lift HMA; 1.75-in milling depth and 1.75-in double-lift HMA (shim course plus surface course); 1.5-in milling depth and 1.5-in single-lift HMA; 0.5-in milling depth and 1-in single-lift HMA.
  - Materials—Polymer-modified HMA with 0.25-in maximum size aggregate; polymer-modified with 0.375-in maximum size aggregate; neat HMA with 0.5-in maximum size aggregate; rubber-modified HMA with gap-graded 0.5-in maximum size aggregate; neat HMA with 0.375-in maximum size aggregate; polymer-modified HMA with gap-graded 0.375-in maximum size aggregate.

Table 6. Specific PPM treatment options for asphalt and composite pavements.

Treatment Category	Treatment Type	Work Done to Existing Pavement	Materials Application	Materials Selection	Accompanying Treatments
Reprofiling/ Retexturing	Standard Cold Milling	Shallow pavement surface removal via standard cold milling to eliminate surface distress and/or restore transverse and longitudinal profile (e.g., rut removal, increase smoothness).	—	—	▪ Patching, as needed. ▪ Asphalt-aggregate seals. ▪ HMA or PCC overlays. ▪ HIR or CIR.
	Profile Milling	Shallow pavement surface removal via fine-tooth milling or micro-milling to improve surface texture (for safety, smoothness, and/or noise) and/or restore transverse and longitudinal profile.	—	—	▪ Patching, as needed. ▪ Asphalt-aggregate seals. ▪ HMA or PCC overlays. ▪ HIR or CIR.
Crack/Joint Treatment	Crack Filling	Crack cleaning and drying.	Limited filler design configurations.	Various cold-applied or hot-applied asphalt fillers with/without polymer or rubber modifiers.	▪ Patching, as needed. ▪ Asphalt-aggregate seals. ▪ HMA overlays.
	Crack Sealing	Crack routing or sawing and crack cleaning and drying to provide good-quality sealant reservoir.	Various sealant design configurations.	Various hot-applied asphalt sealants with/without polymer or rubber modifiers.	▪ Patching, as needed. ▪ Asphalt-aggregate seals. ▪ HMA overlays.
Asphalt Seals	Rejuvenator Seals	Surface sweeping.	<u>Single Application</u> 0.06 to 0.1 gal/yd^2 (0.011 to 0.02 in thick).	Various diluted rejuvenating emulsions (typically engineered cationic emulsions) with/ without polymer-modifiers.	▪ Can be used in a fog seal, sand seal, or scrub seal.
	Fog Seals	Surface sweeping.	<u>Single Application</u> 0.05 to 0.1 gal/yd^2 (0.009 to 0.02 in thick).	Various diluted asphalt emulsions (typically slow-set).	—
Asphalt-Aggregate Seals	Sand Seals	Surface sweeping.	<u>Single Application</u> 0.125 to 0.35 in thick.	Various asphalt emulsions (typically rapid-set) topped with fine aggregate.	▪ Can include rejuvenators.
	Scrub Seals	Surface sweeping.	<u>Single Application</u> 0.125 to 0.35 in thick. <u>Multiple Application</u> 0.375 to 1.5 in thick.	Various asphalt emulsions (typically rapid set) with/without polymer-or rubber-modifiers, topped and scrubbed with fine aggregate.	▪ Can include rejuvenators.
	Slurry Seals	Surface sweeping.	<u>Single Application</u> 0.125 to 0.375 in thick.	Various asphalt emulsions (typically slow-set or quick-set) with/without polymer modifiers, mixed with different sized aggregate, as follows: • Type I—Fine gradation (0.125-in max size), typically used on low traffic roads. • Type II—Moderate gradation (0.25-in max size), typically used on moderate traffic roads. • Type III—Coarse gradation (0.375-in max aggregate size), typically used on high traffic roads.	▪ Patching and crack filling, as needed. ▪ Type I aggregate slurries are sometimes used as a preparatory treatment for an asphalt-aggregate seal or an HMA overlay. ▪ When used on top of a chip seal, treatment is referred to as a cape seal.

Table 6. Specific PPM treatment options for asphalt and composite pavements (continued).

Treatment Category	Treatment Type	Work Done to Existing Pavement	Materials Application	Materials Selection	Accompanying Treatments
Asphalt-Aggregate Seals	Micro Surfacing	Surface sweeping.	<u>Single Application</u> 0.25 to 0.375 in thick. <u>Double Application</u> 0.375 to 0.75 in thick. <u>Rut Fill Application</u> 0.25 to 1.5 in thick.	Various polymer-modified asphalt emulsions (typically cationic slow-set or quick-set) mixed with different sized aggregate, as follows: • Type II—Moderate gradation (0.25-in max size), typically used as surface course for low to moderate traffic roads and as scratch/leveling courses. • Type III—Coarse gradation (0.375-in max size), typically used as surface course for high traffic roads, or as rut-filling and scratch/leveling courses.	▪ Patching and crack filling, as needed. ▪ When used on top of a chip seal, treatment is referred to as a cape seal.
	Chip Seals (and variant designs)	Surface sweeping.	<u>Single Application</u> 0.375 to 0.5 in thick. <u>Double Application</u> 0.75 to 1.0 in thick. <u>Triple Application</u> 1.0 to 1.5 in thick.	Various asphalt emulsions (standard or high-float rapid-set or medium-set) with/without polymer modifiers, or hot asphalt cements topped with one-sized aggregate (0.375- to 0.625-in max size). Also, precoated aggregate chips (typically using hot asphalt cement, but emulsion also an option).	▪ Patching and crack filling, as needed. ▪ Can include fog seal placed on surface for holding chips in place or sand seal placed on surface for "locking" chips together. ▪ Other variant designs include: ➢ Cape Seal—Slurry seal on chip seal. ➢ Racked-in-Seal—Choke stone on chip seal. ➢ Sandwich Seal—Chip seal sandwiched between a larger aggregate layer (bottom) and smaller aggregate layer (top). ➢ Inverted Seal—Double application chip seal, with bottom seal using smaller aggregate and top seal using larger aggregate. ➢ Cape Seal—Slurry seal or micro surfacing on chip seal. ➢ Geotextile-Reinforced Seal—Single-course chip seal on geotextile embedded in tack coat.
HMA Overlays	Ultrathin HMA Overlay	Surface sweeping. Tack coat application.	<u>Single-Lift Application</u> 0.5 to 0.75 in thick.	Various binder grades (PG or other), with/without polymer or rubber modifiers. Various HMA mix types (dense-graded, open-graded) and sizes/gradations (typically 0.1875- to 0.25-in max size for dense-graded and 0.375-in max size for open-graded). Various aggregate types (polish resistant, reclaimed asphalt pavement [RAP] blend).	▪ Patching and crack filling, as needed. ▪ Milling not typically used full-width, but can be used at edges or other locations to allow the overlay to match adjacent curb and gutter or pavement.
	Thin HMA Overlay and Mill-and-Thin HMA Overlay/Inlay	Surface sweeping. Tack coat application.	<u>Single-Lift Application</u> 0.875 to 1.5 in thick. <u>Double-Lift Application</u> 1.0 to 1.5 in thick.	Various binder grades (PG or other), with/without polymer or rubber modifiers. Various HMA mix types (dense-graded, open-graded, gap-graded/SMA) and sizes/gradations (typically 0.25- to 0.5-in max size for dense-graded and 0.375- to 0.5-in max size for open-graded and gap-graded). Various aggregate types (polish resistant, RAP blend).	▪ Patching and crack filling, as needed. ▪ Milling up to 1.5 in deep for distress removal, profile improvement, and/or enhanced bonding of overlay.

Table 6. Specific PPM treatment options for asphalt and composite pavements (continued).

Treatment Category	Treatment Type	Work Done to Existing Pavement	Materials Application	Materials Selection	Accompanying Treatments
HMA Overlays	UBWC	Surface sweeping. Tack coat application.	<u>Single-Lift Application</u> 0.375 to 0.75 in thick.	Polymer-modified emulsion membrane. Various binder grades (PG or other) with polymer modifier. Various gap-graded HMA sizes/gradations, as follows: • Type A—Fine (0.25-in max size) • Type B—Moderate (0.375-in max size) • Type C—Coarse (0.5-in max size)	▪ Patching and crack filling, as needed. ▪ Milling not typically used full-width, but can be used at edges or other locations to allow the overlay to match adjacent curb and gutter or pavement.
Recycling	HIR Type I (Surface Recycling)	Surface sweeping. Removal of flammable crack sealant.	<u>Single Application</u> 0.5 to 1.5 in deep/thick.	Various asphalt emulsion rejuvenators to improve scarified RAP-mix layer.	▪ Patching, as needed. ▪ Can be surfaced with an asphalt-aggregate seal or HMA overlay (i.e., the second pass in double-pass surface recycling operation).
	HIR Type II (Remixing)	Surface sweeping.	<u>Single-Stage Application</u> 1 to 2 in deep/thick. <u>Multi-Stage Application</u> 1.5 to 3 in deep/thick (0.5 to 1.5 in per layer).	Various asphalt emulsion rejuvenators, virgin aggregate, and/or HMA, as needed, to improve recycled RAP-mix layer.	▪ Deep patching, as needed. ▪ Can be surfaced with an asphalt-aggregate seal or HMA overlay.
	HIR Type III (Repaving)	Surface sweeping.	<u>Single-Pass Application</u> 0.5 to 1.5 in deep/thick recycled layer and 0.5 to 1.5 in thick integral overlay. <u>Multi-Pass Application</u> 1 to 2 in deep/thick recycled layer (0.5 to 1 in per layer) and 1 to 2 in thick integral overlay.	Various asphalt emulsion rejuvenators, virgin aggregate, and/or HMA, as needed, to improve recycled RAP-mix layer. Various binder grades (PG or other) with/ without polymer or rubber modifiers for integral overlay. Various HMA mix types (dense-graded, open-graded, gap-graded/SMA) and sizes/gradations (typically 0.25- to 0.5-in max size for dense-graded and 0.375- to 0.5-in max size for open-graded and gap-graded) for integral overlay.	▪ Deep patching, as needed.
	CIR	Surface sweeping.	<u>Single Application</u> 2 to 4 in deep/thick.	Various asphalt emulsions (typically standard and high-float slow- or medium-set) with/ without polymer modifiers. Virgin aggregate, as needed, to improve RAP mix.	▪ Deep patching, as needed. ▪ Can be surfaced with an asphalt-aggregate seal or HMA overlay.
PCC Overlays	Thin PCC Overlay/Inlay and Mill-and-Thin PCC Overlay/Inlay	Surface sweeping.	<u>Single Application</u> 2 to 4 in thick.	Type I or II Portland cement mixes, with or without polyolefin or polypropylene fibers (fibrous mixes typically required for thinner application [2 to 3 in]).	▪ Patching, as needed. ▪ Milling up to 1.5 in deep for distress removal, profile improvement, and/or enhanced bonding of overlay.

Table 7. Asphalt and composite pavement treatments used by New England SHAs.

Treatment Category	Treatment Type	Number of New England SHAs Reporting Use					
		High Volume Interstate/ Expressway		Moderate Volume Arterials and Collectors		Low Volume Collectors and Local Roads	
		Rural	Urban	Rural	Urban	Rural	Urban
Reprofiling/ Retexturing	Standard Cold Milling	3	3	3	3	3	3
	Profile Milling	3	4	2	2	2	2
Crack/Joint Treatment	Crack Filling	2	2	1	1	2	2
	Crack Sealing	6	6	6	6	4	3
Asphalt Seals	Fog Seal			1		2	1
	Rejuvenator Seal						
Asphalt-Aggregate Seals	Slurry Seal						
	Sand Seal						
	Scrub Seal						
	Micro Surfacing	3	3	3	3	1	1
	Chip Seal			1		3	1
	Inverted Seal			1		1	
HMA Overlays	Ultrathin HMA Overlay	1	1	2	2	1	1
	Thin HMA Overlay	4	2	4	3	2	2
	UBWC	5	5	5	4	1	1
Mill-and-HMA Overlays	Mill-and-Ultrathin HMA Overlay/Inlay	2	2	2	2		
	Mill-and-Thin HMA Overlay/Inlay	3	3	4	4	3	3
Asphalt Recycling	CIR	1		1	1	1	1
	HIR Type I (Surface Recycling)	1	1	2	1	1	1
	HIR Type II (Remixing)	1	1	1	1		
	HIR Type III (Repaving)	1	1	1	1		
PCC Overlays	Ultrathin PCC Overlay						
Mill-and-PCC Overlays	Mill-and-Ultrathin PCC Overlay/Inlay						

- UBWC
  - Application—Single course at 0.5, 0.625, or 0.75 in.
  - Materials—Neat, polymer-modified, or rubber-modified HMA with 0.5-in maximum size aggregate; neat or polymer-modified HMA with 0.0.375-in maximum size aggregate; neat HMA with gap-graded 0.375-in maximum size aggregate.

Finally, specific treatments touted as success stories in the New England survey include UBWC (four agencies), asphalt rubber chip seals (two agencies), and thin HMA overlay using a gap-graded rubber-modified mix.

Concrete Pavement Treatments

PPM treatments for concrete pavements are typically used to seal the existing pavement, restore the structural integrity and functional behavior of the PCC slabs, and correct or restore key surface characteristics (smoothness and friction). Treatments include various concrete pavement restoration (CPR) activities and thin overlays that when applied to a pavement in fair to very good condition can effectively extend the life of that pavement.

Generally speaking, PPM treatments for PCC are targeted for pavements requiring little or no repair. Localized treatments like joint resealing (figure 6 left) and dowel bar retrofitting (figure 6 right) are best done before the joints show significant deterioration and faulting. Partial- and full-depth repairs (figure 7 left) are appropriate when the distressed areas within a project are few and intermittent. Diamond grinding (figure 7 right), which is often performed in conjunction with some of the above treatments, is most appropriate when faulting and/or roughness levels have become noticeable to users. Finally, thin HMA overlays and ultrathin PCC overlays are most suitable for pavements in fair to good condition.

Specific PPM Treatment Options

Table 8 provides an expanded list of PPM treatment options for concrete pavements. It shows the variations that are possible with each treatment type in terms of application features and materials used. It also lists other PPM treatments and preparatory activities that can be used in conjunction with the treatment.

Figure 6. Joint resealing (left) and dowel bar retrofit (right) (Smith et al. 2014).

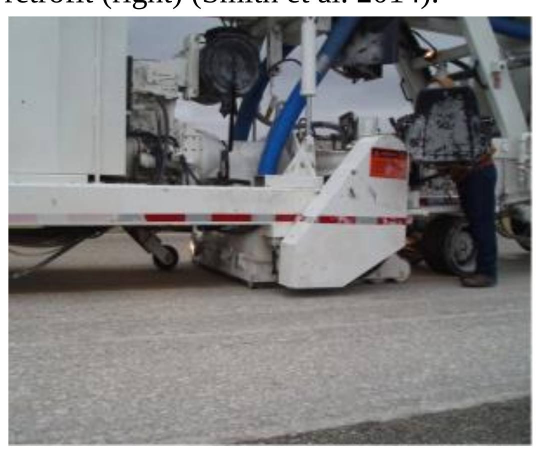


Figure 7. Partial-depth repair (left) and diamond grinding (right) (Smith et al. 2014).

Table 8. Specific PPM treatment options for concrete pavements.

Treatment Category	Treatment Type	Work Done to Existing Pavement	Materials Application	Materials Selection	Accompanying Treatments
Reprofiling/ Retexturing	Diamond Grinding	Shallow pavement surface removal and retexturing to restore profile (for smoothness) and improve surface texture (for safety and/or noise).	—	—	▪ Joint resealing, crack sealing. ▪ Partial-depth repairs, full-depth repairs. ▪ Dowel bar retrofit.
	Diamond Grooving	Shallow pavement surface removal and retexturing to improve surface texture (for safety and/or noise)	—	—	▪ Joint resealing, crack sealing. ▪ Partial-depth repairs, full-depth repairs.
Crack/Joint Treatment	Joint Resealing	Joint seal removal, joint sawing, and joint cleaning and drying to provide good-quality sealant reservoir.	Various sealant design configurations.	Various sealant backer rod types. Various hot-applied asphalt sealants with/ without polymer or rubber modifiers, cold-applied elastomeric sealants (1-part silicones or 2-part polysulfides or polyurethanes), and cold-applied preformed compression seals.	▪ Crack sealing. ▪ Partial-depth repairs, full-depth repairs. ▪ Dowel bar retrofit. ▪ Diamond grinding, diamond grooving.
	Crack Sealing	Crack routing or sawing and crack cleaning and drying to provide good-quality sealant reservoir.			▪ Joint resealing. ▪ Partial-depth and full-depth repairs. ▪ Dowel bar retrofit. ▪ Diamond grinding, diamond grooving.
Permanent Repairs	Partial-Depth Repair	Partial-depth PCC removal via jack hammer or milling, and repair area cleaning.	Patching to dimensions of repair area.	Various conventional and modified cementitious materials, polymeric materials, and bituminous materials.	▪ Joint resealing, crack sealing. ▪ Diamond grinding. ▪ Full-depth repair, dowel bar retrofit
	Full-Depth Repair (incl. Slab Replacement	Full-depth PCC removal near crack or joint, or full-depth PCC slab removal.	Patching to dimensions of repair area.	Various conventional and modified cementitious cast-in-place materials, or precast PCC slabs	▪ Joint resealing, crack sealing. ▪ Diamond grinding. ▪ Partial-depth repair, dowel bar retrofit
	Dowel Bar Retrofit	Slot creation and cleaning across joints and/or cracks having poor load transfer.	Dowel bar placement Patching material placement.	Epoxy-coated dowel bars of various diameters and lengths. Various conventional and modified cementitious materials, and epoxy resins.	▪ Joint resealing, crack sealing. ▪ Diamond grinding. ▪ Partial-depth repair, full-depth repair
HMA Overlays	Thin HMA Overlay/Inlay	Surface sweeping. Tack coat application.	<u>Single-Lift Application</u> 0.875 to 1.5 in thick. <u>Double-Lift Application</u> 1.0 to 1.5 in thick.	Various binder grades (PG or other), with/without polymer or rubber modifiers. Various HMA mix types (dense-graded, open-graded, gap-graded/SMA) and sizes/gradations (typically 0.25- to 0.5-in max size for dense-graded and 0.375- to 0.5-in max size for open-graded and gap-graded). Various aggregate types (polish resistant, RAP blend).	▪ Patching and crack filling, as needed. ▪ Milling up to 1.5 in deep for distress removal, profile improvement, and/or enhanced bonding of overlay.
	UBWC	Surface sweeping. Tack coat application.	<u>Single-Lift Application</u> 0.375 to 0.75 in thick.	Polymer-modified emulsion membrane. Various binder grades (PG or other) with polymer modifier. Various gap-graded HMA sizes/gradations, as follows: • Type A—Fine (0.25-in max size) • Type B—Moderate (0.375-in max size) • Type C—Coarse (0.5-in max size)	▪ Patching and crack filling, as needed. ▪ Milling not typically used full-width, but can be used at edges or other locations to allow the overlay to match adjacent curb and gutter or pavement.
PCC Overlays	Thin PCC Overlay	Surface sweeping.	<u>Single Application</u> 2 to 4 in thick.	Type I or II Portland cement mixes, with or without polyolefin or polypropylene fibers (fibrous mixes typically required for thinner application [2 to 3 in]).	▪ Patching, as needed.

New England PPM Treatments

Table 9 summarizes the use of PPM treatments for concrete pavements in New England, based on the survey responses of the six participating SHAs. Again, the information is broken down by usage on high-, moderate-, and low-traffic-volume roads located in rural and urban areas. Noting that the amount of concrete pavement in New England is very low, the most commonly used treatments are joint resealing and partial-depth repair. Specific applications of these treatment types include the following:

- Joint Resealing
  - Configurations—Reservoir and flush-fill; simple flush-fill (no reservoir).
  - Materials—Hot-applied rubberized asphalt (ASTM D6690 / AASHTO M324); cold- or hot-applied asphalt with polymer, rubber, or fiber modifiers.
- Partial-Depth Repair
  - Application—Joint and interior slab spall repairs.
  - Materials—Non-gypsum-based products; polymeric products; PCC.

Table 9. Concrete pavement treatments used by New England SHAs.

Treatment Category	Treatment Type	Number of New England SHAs Reporting Use					
		High Volume Interstate/ Expressway		Moderate Volume Arterials and Collectors		Low Volume Collectors and Local Roads	
		Rural	Urban	Rural	Urban	Rural	Urban
Reprofiling/ Retexturing	Diamond Grinding	1	1	1	1		
	Diamond Grooving						
Crack/Joint Treatment	Crack Sealing						
	Joint Resealing	1	2	1	2		
Permanent Repairs	Partial-Depth Repair	1	2	1	2		
	Full-Depth Repair			1	1		
	Dowel Bar Retrofit						
HMA Overlays	Ultrathin HMA Overlays						
	Thin HMA Overlays						
	UBWC						
PCC Overlays	Ultrathin PCC Overlay						

Testing and Implementation

PPM has been popularly coined as "the Right Treatment on the Right Road at the Right Time." Since its inception, highway agencies and industry alike have sought to improve treatment materials or develop new ones that can more effectively and economically extend a pavement's life. For instance, the conventional emulsified asphalt chip seal has seen major advancements in the binder (polymer-modified, rubber-modified, and hot asphalt cement), aggregate (durability, gradation, pre-coating), and application methods (design variation, multiple course). Likewise, the traditional thin HMA overlay is now produced with polymer-or rubber-modified binder and gap-graded or open-graded aggregate, and may also be placed as a warm-mix asphalt (WMA).

Testing and implementation of new and improved materials and techniques is vital to the success of any PPM program. The combination of laboratory and field testing helps identify and confirm the material properties needed to achieve a certain level of performance in the field. They also help to establish the test procedures and specifications that can be used on formal projects to ensure treatment success. Implementation entails the application of a prospective treatment in a controlled field environment, followed by routine performance monitoring to assess its feasibility and effectiveness as a PPM treatment. The ideal implementation makes use of a statistical experimental design, whereby multiple test sections are constructed with the prospective treatment and, for comparison sakes, either the conventional treatment or no treatment.

New England agencies have been quite active in the testing and implementation of PPM treatments. For instance, as part of the Strategic Highway Research Program 2 (SHRP2) R26 Implementation Assistance Program, three New England agencies have constructed projects involving PPM treatments placed on high-traffic-volume roads. The performance of these projects, which are listed and described in table 10, are currently being monitored and evaluated (FHWA 2014).

Table 10. SHRP2 R26 PPM projects implemented by New England agencies.

Agency and Treatment	**Project Location and Year**	**Treatment Description**
MassDOT UBWC	US 3, Burlington to Tyngsborough (2015)	▪ UBWC Conventional Binder Technology: 0.625-in UBWC Type C unmodified asphalt binder (PG 64-28, 0.5-in max size). ▪ UBWC New Binder Technology: 0.625-in UBWC Type C polymer-modified asphalt binder (PG 64V-28, 0.5-in max size). ▪ UBWC Recycled Binder Technology: 0.625-in UBWC Type C crumb rubber-modified asphalt binder (ASTM D6114, 0.5-in max size).
MaineDOT Thin HMA Overlay and HIR-and-Thin HMA Overlay	US 202, Sanford/Lebanon (2014)	▪ Thin HMA Overlay: 0.75-in HMA overlay (and shim) using fine-graded Superpave Mix with PG 64-28 binder and 15% RAP. ▪ HIR-and-Thin HMA Overlay: 2-in Type II HIR (remixing) and 1-in HMA overlay using fine-graded Superpave Mix with PG 64-28 binder and 15% RAP.
RIDOT Crack Seal, Chip Seal, Mill-and-Stress Absorbing Membrane Interlayer (SAMI) Seal, and Mill-and-Thin HMA Overlay	I-95 Hopkinton/Richmond (2014)	▪ Crack Seal: Rubber/polymer- modified asphalt with fibers, placed with 2.5-in wide overband.
	SR 102 Exeter (2014)	▪ Chip Seal: 0.5-in single-course asphalt rubber chip seal (ARCS) containing 20% rubber and 0.375-in precoated aggregate chips.
	SR 3 West Greenwich (2014)	▪ Mill-and-SAMI Seal: 1.5-in deep milling, followed by 0.375-in ARCS containing 20% rubber and 0.375-in precoated aggregate chips, followed by 1-in PPST (i.e., UBWC).
	SR 114 East Providence (2014)	▪ Mill-and-Thin HMA Overlay: 1-in deep milling followed by 1-in PPST.

4. PROJECT SELECTION

Introduction

This chapter discusses the factors affecting PPM project selection and presents a rational procedure for determining which pavements are legitimate candidates for a PPM treatment. The information presented is based on the best practices identified in the literature and on the results of the New England survey.

As indicated in table 11, the study survey found that engineering judgment is part of everyone's process, and this likely supplements other guidelines such as decision support tools and treatment cycles. The survey also revealed that five of the six states link the selection of PPM activities to the condition information contained in the PMS.

Table 11. New England SHA methods for PPM project selection.

Question: Which methods best describe your agency's approach to determining if a pavement should receive a PPM treatment?	**Number of Respondents**
Engineering Judgment	6
Use of a Decision Matrix/Tree Based on Existing Pavement Condition	5
Benefit/Cost Analysis	2
In-House Guidelines	2
Use of a Decision Matrix/Tree Based on Existing Pavement Age or Remaining Service Life	1
Preset Schedule of Times	1
Use of Feasibility Matrix that Considers Multiple Engineering and Economic Factors	1

Factors Affecting Project Selection

Several factors affect the selection of pavements for possible preservation activities (Peshkin et al. 2011). These factors primarily relate to the type, age, and condition of the existing pavement. However, other factors, such as the traffic characteristics of the road, the facility type and setting, and climate, can also impact the determination. Table 12 describes the factors that are most relevant, based on the results of the literature review and the New England survey.

In considering pavement condition as a factor in project selection, it is important to emphasize that PPM primarily addresses functional distresses by:

- Preventing and delaying the occurrence of new distresses, and slowing the development of existing distresses.
- Restoring the structural integrity and functionality of the pavement, and improving the pavement's surface characteristics (PSCs).

Rehabilitation, on the other hand, primarily addresses structural distresses by increasing the strength and load-carrying capacity of the pavement. Although rehabilitation can also address all functional deficiencies, its use becomes cost-prohibitive as the amount and severity level of structural distress approaches zero.

Table 12. Key factors affecting PPM project selection.

Factor	Description
Pavement Type, Age, and Condition	▪ The key to cost effectively extending pavement life through PPM is proper timing. If PPM is applied too soon, money is spent on roads that do not require treatment and will not provide sufficient benefit to justify the costs. If it is applied too late, the road may be deteriorated to the point that the treatment is ineffective or does not add sufficient life to justify the cost. Thus, proper timing represents a "window of opportunity" in terms of the age and condition of the pavement at the expected time of PPM treatment application. ▪ Considerable amounts of structural distress (e.g., fatigue cracking, potholes, subgrade- or base-related distortions, and deteriorated joint-reflection cracking) or materials-related distress (e.g., asphalt stripping, concrete alkali-aggregate distress) are strong indicators that PPM is not appropriate. Also, high deflections observed from falling weight deflectometer (FWD) testing is a sure sign that PPM is not appropriate. However, a few, isolated instances of these issues can often be properly addressed prior to applying a PPM treatment. ▪ PPM is generally appropriate for restoring smoothness on moderately rough roads and for increasing friction and texture to improve skid, hydroplaning, splash/spray, and noise issues. ▪ Because concrete pavements generally deteriorate more slowly than asphalt pavements, the window of opportunity for PPM on concrete pavements occurs somewhat later than with asphalt pavements.
Traffic Characteristics	▪ Higher traffic volumes result in higher numbers of loadings to the pavement and increased wear. Consequently, the performance of PPM treatments (especially thin ones) can be negatively affected. ▪ Higher volumes of commercial vehicles (and buses) and more heavily loaded commercial vehicles (and buses) also result in increased pavement damage and reduced treatment performance. ▪ Reduced treatment performance may make PPM too risky to use.
Facility Type and Traffic Environment	▪ The levels of traffic and intensity/magnitude of traffic loadings increases as the highway system class (secondary ⇨ primary ⇨ Interstate) and highway functional class (local ⇨ minor collector ⇨ major collector ⇨ minor arterial ⇨ principal arterial) increases, and as the traffic environment/setting changes from rural to urban. ▪ Again, the performance of PPM treatments can be significantly reduced with increased traffic, possibly making PPM too risky to use.
Climate	▪ More severe climates often have (a) prolonged periods of freezing which can lead to more severe thermal cracking or (b) increased freeze-thaw cycles which can lead to increased deterioration of the pavement structure. As a result, the performance of PPM treatments on pavements in these climates can be significantly reduced. ▪ More severe climates also often experience more snow and ice events. These lead to more use of snow plows and deicing chemicals, which can damage PPM treatments and reduce their performance. ▪ Reduced treatment performance may make PPM too risky to use.
Broader Project Needs	▪ If a project is programmed for rehabilitation, capacity improvements, or non-pavement safety upgrades, then PPM will most likely not be an option. ▪ The performance of PPM treatments is highly dependent on pavement drainage and foundation characteristics. If the existing pavement exhibits poor drainage characteristics, such as a bathtub design, shallow ditches, clogged edge drains, or poor cross slopes, then a rehabilitation treatment that fully addresses the specific drainage issues should be used instead of PPM. Similarly, if expansive soils are predominant throughout the project and significant frost heaving has been observed, then alternatives to PPM should be sought.

Selection Process

The first step in implementing PPM is identifying which sections of road are good candidates for a PPM treatment. This scoping activity entails compiling relevant information (e.g., pavement type and structure, age, overall condition) on the sections in the network, flagging those with good potential for preventive maintenance, conducting preliminary field reviews of the sections as needed, and finalizing the list of candidates so they can be evaluated further for treatment selection.

The agency's PMS database should have most of the information needed to determine which pavement sections might be candidates for one or more types of PPM treatments, based on the factors discussed previously. Data from other agency systems may need to be extracted and merged with the PMS data prior to conducting this screening activity.

Most PMS database systems have excellent querying capabilities, by which specified search criteria (pavement type, age, condition, traffic, etc.) can be entered and used to identify suitable sections. In addition, most spreadsheet-based programs have filtering and sorting functions that can facilitate the identification process. If available, pavement videos obtained from fairly recent (6 months or less) automated condition surveys can be viewed to aid the identification process.

Suitable sections are typically those that are comparatively new, have little to no structural- and materials-related distress, and have low to moderate levels of environmental distress and/or moderate to high levels of smoothness. The SHRP2 R26 *Guidelines for the Preservation of High-Traffic-Volume Roadways* recommends that asphalt and composite pavements be no more than 10 to 12 years in age at the time of PPM treatment and that the 0-to-100 scale pavement condition index (PCI) be between 60 and 95 (Peshkin et al. 2011). For concrete pavements, a maximum age of 12 to 15 years and a PCI between 65 and 90 are recommended.

Although age and overall condition criteria can be sufficient in identifying potential sections, consideration should be given to using supplemental condition parameters and criteria. For instance, criteria for items like smoothness, friction, and key structural distresses can be set and used to ensure that the correct approach (PPM or rehabilitation) is taken. General guidance relating to various pavement surface characteristics is available in the SHRP2 R26 *Guidelines* and is summarized in table 13.

Similar guidance regarding pavement structural adequacy is provided in the AASHTO *Mechanistic-Empirical Pavement Design Guide Manual of Practice* and is summarized in table 14. As this table shows, separate criteria for different facility types and traffic environments can be established and used, as appropriate. Other condition parameters that could be used to qualify or disqualify pavement sections are potholes, structural or mix-instable rutting, distortions caused by base/subgrade issues, shattered slabs, and blowups at joints/cracks.

While few US agencies conduct network-level FWD testing, the data collected from this type of activity can also be useful in identifying PPM projects. The deflection measurements obtained with FWD equipment can provide an indication of the stiffness or structural capacity of the pavement, which in turn can indicate if PPM treatments are appropriate for use or not. In recent years, continuous deflection measurement devices, such as the Rolling Weight Deflectometer (RWD) and the Traffic Speed Deflectometer (TSD), have been a focus of investigation, particularly as high-speed tools for screening projects for PPM or rehabilitation.

Table 13. Suitability of PPM corresponding to pavement surface characteristics (adapted from Peshkin et al. 2011).

Surface Characteristic	Adequate (PPM not warranted)	Inadequate: Addressable through PPM	Inadequate: Addressable through Rehabilitation
Smoothness, in/mi	IRI ≤ 100	100 ≤ IRI ≤ 150	IRI > 150
Friction	$FN_{40S} \geq 32$	FN40S < 32	
Pavement-Tire Noise, dBA	OBSI ≤ 106	OBSI > 106	

IRI: International Roughness Index.
FN40S: Friction number at 40 mi/hr using smooth test tire.
OBSI: On-board sound intensity.

Table 14. Suitability of PPM corresponding to load-related distresses (AASHTO 2015).

Pavement Type	Distress Type	Highway Classification	Current Distress Level Regarded as: Adequate/Good	Marginal/Fair[a]	Inadequate/Poor[b]
Flexible and Composite	Alligator/Fatigue Cracking, % of total lane area	Interstate/Freeway	<5	5 to 20	>20
		Primary	<10	10 to 45	>45
		Secondary	<10	10 to 45	>45
	Longitudinal WP Cracking, ft/mi	Interstate/Freeway	<265	265 to 1,060	>1,060
		Primary	<530	530 to 2,650	>2,650
		Secondary	<530	530 to 2,650	>2,650
	Joint Reflection Cracking, % of total lane area	Interstate/Freeway	<5	5 to 20	>20
		Primary	<10	10 to 45	>45
		Secondary	<10	10 to 45	>45
	Transverse Cracking Length, ft/mi	Interstate/Freeway	<500	500 to 800	>800
		Primary	<800	800 to 1,000	>1,000
		Secondary	<800	800 to 1,000	>1,000
	Rutting (mean depth), in	Interstate/Freeway	<0.25	0.25 to 0.45	>0.45
		Primary	<0.35	0.35 to 0.6	>0.6
		Secondary	<0.4	0.4 to 0.8	>0.8
	Shoving, % of wheelpath area	Interstate/Freeway	None	1 to 10	>10
		Primary	<10	10 to 20	>20
		Secondary	<20	20 to 50	>50
Rigid (JPCP)	Deteriorated Cracked Slabs (medium- and high-severity transverse and longitudinal cracks and corner breaks), % slabs	Interstate/Freeway	<5	5 to 10	>10
		Primary	<8	8 to 15	>15
		Secondary	<10	10 to 20	>20
	Transverse Joint/Crack Faulting (mean), in	Interstate/Freeway	<0.1	0.1 to 0.15	>0.15
		Primary	<0.125	0.12 to 0.20	>0.20
		Secondary	<0.15	0.15 to 0.30	>0.30

[a] In need of maintenance or minor repair/rehabilitation.
[b] In need of major rehabilitation.
JPCP: Jointed plain concrete pavement.
Note: Although not indicated in the *Manual of Practice*, it is suspected that the cracking and shoving distresses refer to medium- and high-severity levels.

The New England survey results document that suitable pavement sections are generally identified as described above. Table 15 shows that most of the states consider existing pavement condition and at least half consider pavement age in determining if a section qualifies for preventive maintenance. In some agencies, an overall condition indicator is used, while in others, key distress data are considered as part of the project selection process.

Table 15. Factors used by New England SHAs to identify candidate sections for PPM.

Agency	Factors Considered in Section Identification
1	Age (6 to 12 years) is a trigger and distress criteria are used as a support.
2	Age (9 to 15 years) and overall condition from the PMS are a first cut. Field evaluation performed to (a) identify/verify distress types and (b) determine deterioration mechanisms/drivers, provides the basis for a second cut.
3	Age (5 to 15 years) and overall condition are used. Current and historical condition data are critical to determining the appropriateness of PPM.
4	Engineering judgment and in-house guidelines (no decision matrix/tree) are used. Condition is considered, but not officially supported by data. Timing of the planning of a treatment before the pavement falls below the good condition is also a consideration.
5	Engineering judgment and a decision matrix (as a guide) are used.

Input from area maintenance engineers can also be helpful in identifying potential PPM sections. Not only will these individuals be able to identify additional suitable sections from regularly riding over their roads, they might have particular insights about a road that would warrant removing it from the list generated from the PMS query. For example, they may know of recurring drainage or frost-heave problems that were not identified in the network-level surveys, and that need to be treated through rehabilitation.

In some cases, there may be a need to verify or update the available pavement section data, or to supplement it with other relevant information (e.g., causes of pavement distress, project/site constraints, non-pavement issues). This can be done through a field review of the sections of interest. The field review can be either cursory (i.e., windshield survey to rate the overall condition and identify predominant distresses) or detailed (i.e., a PCI survey that uses manual, semi-automated, or automated procedures), depending on the resources available and the goals of the data collection effort. A cursory survey is quicker, less expensive, and is often sufficient to provide the information needed for project selection. A detailed survey, on the other hand, provides a more accurate and full account of existing distresses and their mechanisms, which can aid both the project and treatment selection process. Appendixes B and C provide resource material for conducting field reviews—Appendix B containing pavement condition and distress photos, and Appendix C containing detailed condition survey forms for both asphalt/composite pavements and concrete pavements.

To complete the scoping process, a final list of candidate projects should be developed that incorporates the results of the PMS queries, the maintenance engineer solicitations, and the field reviews. In most cases, the identified pavement sections will be autonomous and sufficiently long to be considered a project. However, there will be instances where it is appropriate to combine adjacent identified sections into one overall project.

5. TREATMENT SELECTION

Introduction

Each project identified as a candidate for PPM requires further evaluation to determine the most appropriate PPM treatment. This entails examining the detailed conditions of the existing pavement and the characteristics of the project against the performance capabilities and application limitations of each treatment. It also involves analyzing the cost effectiveness of alternative treatments and assessing how well each treatment satisfies a combination of economic, engineering, and other factors.

This chapter provides guidance in selecting a PPM treatment for a candidate project. It discusses the factors affecting treatment selection and provides a four-step procedure for identifying feasible treatments, evaluating their cost-effectiveness, and assessing their overall merit for a project. It also presents an example application of the treatment selection process.

As with PPM project selection, the information presented is based on the best practices identified in the literature and the results of the New England survey. In addition to showing that five of the six New England states link the selection of PPM activities to their PMS, this survey indicated that many different condition parameters with specified trigger and threshold values are used to identify PPM treatments for consideration. The reported parameters are listed in table 16. The survey also indicated that five states use different trigger and threshold values for different facility types (e.g., high-volume interstates, moderate-volume arterials), whereas only two use different values corresponding to traffic environment/setting (e.g., urban, rural).

Factors Affecting Treatment Selection

With the exception of broader project needs, all of the project selection factors discussed previously are factors in the selection of a PPM treatment. In addition, the performance capabilities and limitations of the treatments and the conditions in which they are suitable for placement and use must be fully considered.

As figure 8 shows, the treatment selection process involves evaluating the characteristics of all the treatments in the agency's toolbox against the various needs and constraints of the selected pavement project. The treatment that can best satisfy all the requirements and do so in the most cost-effective manner, is the preferred treatment for the project.

Selection Process

The recommended four-step procedure for treatment selection is presented in the sections below. Typically, the agency's toolbox of treatments will include a variety of individual treatments (e.g., crack sealing, chip seal) capable of addressing one or more pavement deficiencies, as well as a combination of treatments (e.g., milling and thin HMA overlay, crack sealing and micro surfacing) capable of addressing a combination of deficiencies. Identifying which treatments are suitable remedies for the existing pavement conditions is the recommended starting point in treatment selection.

The four-step procedure may be simplified slightly by immediately eliminating treatments based on key technical factors other than pavement condition. For instance, the Connecticut DOT screens some treatments according to problems that could be encountered with their construction

Table 16. Pavement condition and distress parameters used by New England SHAs to select PPM treatments.

Question: If your agency uses a treatment decision matrix/tree based on existing pavement condition, what specific condition parameters are included?	**Number of Respondents**	**Question: For those condition parameters specified, have trigger and threshold values been set that define the "window of opportunity" for when individual treatments can be used?**
Overall Condition Parameters		
Pavement Condition Index (PCI) (0-to-100 scale)	1	Yes
Pavement Serviceability Rating (PSR) (1-to-9 scale)	1	Yes
Pavement Condition Rating (PCR)	1	Yes
Present Serviceability Index (PSI) (0-to-5 scale)	1	Yes
Pavement Structural Health Index (PSHI)	1	Yes
IRI	2	Yes
Indexes for Individual Distresses	4	Yes
Asphalt Pavement Distress Parameters		
Block Cracking	2	Yes
Bleeding/Flushing	1	Yes
Fatigue Cracking	3	Yes
Joint Reflection Cracking	2	Yes
Longitudinal Non-Wheelpath Cracking	3	Yes
Patch Deterioration and Potholes	2	Yes
Raveling/Weathering	3	Yes
Rutting	4	Yes
Transverse Thermal Cracking	3	Yes

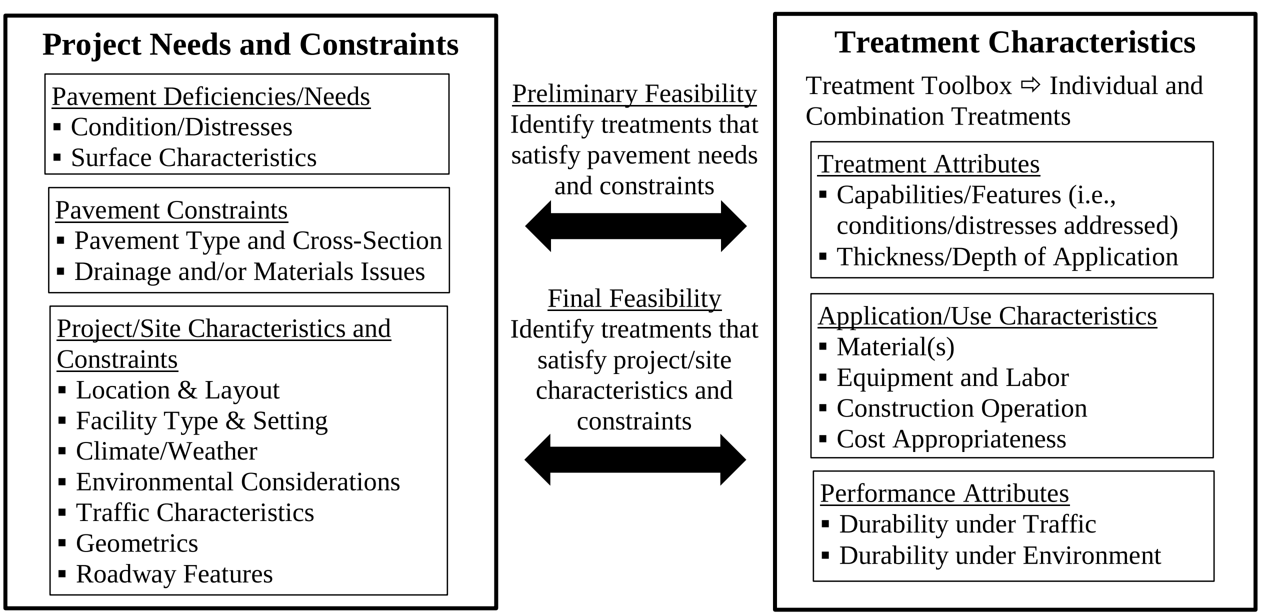


Figure 8. Summary of factors to be considered in treatment selection process.

(e.g., milling on a pavement with a thin asphalt-bound layer, placing a treatment where tight vertical constraints exist) or with its use (e.g., kick-up of aggregate from a chip seal under higher volume/speed traffic) (ConnDOT 2011). The agency also considers treatment cost, filtering out particularly expensive treatments where the roadway priority is low.

Treatment durability under challenging traffic and climatic conditions could also be used to filter treatments at the outset. For instance, some treatments may fail prematurely if the weather conditions during application are not exceptionally good. Likewise, some treatments may be prone to serious damage due to extreme traffic and weather conditions or the use of snowplows and deicing chemicals.

Step 1—Preliminary Identification of Feasible Treatments

The most crucial aspect of PPM treatment selection is the proper assessment of pavement conditions, as determined from PMS data, field reviews, and other data sources. Ideally, the condition information should include both current and historical data on the following:

- Overall condition.
- Type, severity, and amount/extent of individual distresses.
- Pertinent surface characteristics, such as smoothness, friction, texture, and noise.

Each PPM treatment has unique capabilities and functions that allow it to impact the functional or structural performance of an existing pavement structure. The impacts may be in the form of preventing, delaying, or slowing pavement distresses through waterproofing, protection, and rejuvenation, or in the form of restoring/improving the integrity and functionality of the pavement through thin-layer resurfacing and localized repair.

Tables 17 and 18 summarize the primary capabilities and functions of the various PPM treatments presented earlier (APTech 2015b). The degree to which pavement performance is enhanced by a particular treatment depends largely upon:

- Design and quality of construction of the pavement and treatment.
- Type, severity, and amount of distresses at the time of treatment application.
- Traffic levels and climatic conditions to which the treated pavement is subjected.
- Ability of the treatment to address the pavement needs.
- Pavement condition parameters used to measure and track performance.

The information provided in tables 17 and 18 can be used to help link treatments with specific pavement conditions. Trigger and threshold values should be established for each treatment for the agency's overall condition parameter and for the individual distress types and surface characteristics measured and reported by the agency. These values will define the conditions for which the treatment is appropriate for use, and they can be incorporated into a decision matrix or decision tree that can be applied manually or as a programming algorithm in a PMS.

As table 16 indicates, the New England states currently have triggers and thresholds for overall condition, as well as for IRI and various distress types. While all PPM treatments are best applied when the pavement is in Fair to Good condition, it is generally the case that thicker more extensive treatments are more appropriate for pavements in Fair condition (or in transition from

Table 17. Primary capabilities and functions of PPM treatments for flexible and composite pavements (adapted from APTech 2015b).

	Prevention/Delay		Restoration/Improvement			
Treatment Type	**Seal/Waterproof Pavement for Improved Pavement Structural Response Properties**	**Rejuvenate Surface for Improved Pavement Surface Response Properties**	**Reduce/ Eliminate/Stabilize Surface Defects for Improved Functionality and Structural Integrity[1]**	**Improve/Restore Profile[2] for Increased Smoothness, Improved Surface Drainage, Reduced Hydroplaning Potential**	**Improve Texture for Increased Friction, Reduced Splash/Spray, Reduced Hydroplaning Potential**	**Improve Texture for Reduced Pavement-Tire Noise**
Cold Milling			✓	✓		
Profile Milling				✓	✓	
Crack Filling	✓		✓			
Crack Sealing	✓		✓			
Fog Seal	✓	✓				
Rejuvenator Seal		✓				
Scrub Seal	✓	✓			✓	
Slurry Seal	✓	✓			✓	
Micro Surfacing	✓	✓		✓	✓	
Sand Seal	✓	✓			✓	
Chip Seal (and variants)	✓		✓	✓ (minor)	✓	
Thin HMA Overlay						
Dense-Graded	✓		✓	✓	✓	✓
Open-Graded					✓	
Gap-Graded				✓	✓	✓
Ultra-thin HMA Overlay	✓		✓	✓	✓	✓
UBWC	✓		✓	✓	✓	✓
Mill and Thin HMA Overlay	✓		✓	✓	✓	✓
Hot In-place Recycling						
Surface Recycling		✓	✓	✓		
Remixing		✓	✓	✓		
Repaving			✓	✓	✓	
Cold In-place Recycling and Thin HMA Overlay		✓	✓	✓		
Ultra-thin PCC Overlay			✓	✓	✓	
Drainage Maintenance	✓[3]					

1 Surface defects include weathering/raveling, bleeding, polishing, surface cracks, and so on.
2 Including reducing/eliminating stable ruts.
3 Improves drainability of pavement system.

Table 18. Primary capabilities and functions of PPM treatments for rigid pavements (adapted from APTech 2015b).

	Prevention/Delay		Restoration/Improvement		
Treatment Type	**Seal/Waterproof Pavement for Improved Pavement Structural Response Properties**	**Prevent Intrusion of Incompressibles for Improved Joint Performance**	**Improve Texture for Increased Friction, Reduced Splash/Spray, Reduced Hydroplaning Potential**	**Improve/Restore Profile[1] for Increased Smoothness, Improved Surface Drainage, Reduced Hydroplaning Potential**	**Improve Texture for Reduced Pavement-Tire Noise**
Crack Sealing	✓	✓			
Joint Resealing	✓	✓			
Diamond Grinding			✓	✓	✓
Diamond Grooving			✓		
Partial-Depth Repair	✓	✓		✓	
Full-Depth Repair	✓	✓		✓[2]	
Dowel Bar Retrofit				✓	
UBWC	✓	✓	✓	✓	✓
Thin HMA Overlay	✓	✓	✓	✓	✓
Drainage Maintenance	✓[3]			✓	

[1] Including removing/controlling faulting.
[2] In conjunction with diamond grinding.
[3] Improves drainability of pavement system.

Good to Fair), while thinner, simpler treatments are better suited for pavements in Good condition (or in transition from Excellent to Good). This is illustrated in tables 19 and 20, which list the PCI windows of opportunity for different treatments, as given in the SHRP2 R26 *Guidelines* (Peshkin et al. 2011). Depending on the overall condition parameter used, appropriate trigger and threshold values should be set for each treatment to enable the initial assessment of feasibility.

Detailed pavement condition data provide the main basis for determining which PPM treatments are most suitable for a project. Although one can get a general idea of which treatments are appropriate by evaluating distress and surface characteristics data against treatment capabilities and functions (tables 17 and 18), a more coordinated approach is needed that considers all deficiencies and their levels of progression.

Two different approaches for identifying treatments that can address existing pavement conditions are decision-support matrices and trees. Both approaches rely on a set of rules and criteria to identify treatments; the former uses a tabular structure and the latter a flow-chart, graphical approach (Peshkin et al. 2011). The rules and criteria should be based on an agency's own understanding (from past experience or historical performance data) of the ability of individual treatments to fix or mitigate specific distresses, and to improve key surface characteristics.

Table 19. Overall pavement condition windows of opportunity for selected PPM treatments applied to flexible and composite pavements (Peshkin et al. 2011).

<table>
<tr><th>Treatment</th><th>PCI Window of Opportunity</th><th>PCI Rating Scale</th></tr>
<tr><td>Profile Milling</td><td>80 to 90</td><td rowspan="19"><table><tr><td>PCI Rating</td><td>Description</td></tr><tr><td>86 to 100</td><td>Excellent</td></tr><tr><td>71 to 85</td><td>Good</td></tr><tr><td>56 to 70</td><td>Fair</td></tr><tr><td>41 to 55</td><td>Poor</td></tr><tr><td>26 to 40</td><td>Very Poor</td></tr><tr><td>11 to 25</td><td>Serious</td></tr><tr><td>0 to 10</td><td>Failed</td></tr></table></td></tr>
<tr><td>Crack Fill</td><td>75 to 90</td></tr>
<tr><td>Crack Seal</td><td>80 to 95</td></tr>
<tr><td>Slurry Seal (Type III)</td><td>70 to 85</td></tr>
<tr><td>Micro Surfacing-Single</td><td>70 to 85</td></tr>
<tr><td>Micro Surfacing-Double</td><td>70 to 85</td></tr>
<tr><td>Chip Seal-Single, Conventional</td><td>70 to 85</td></tr>
<tr><td>Chip Seal-Single, Polymer-modified</td><td>70 to 85</td></tr>
<tr><td>Chip Seal-Double, Conventional</td><td>70 to 85</td></tr>
<tr><td>Chip Seal-Double, Polymer-modified</td><td>70 to 85</td></tr>
<tr><td>UBWC</td><td>65 to 85</td></tr>
<tr><td>Ultra-Thin HMA Overlay</td><td>65 to 85</td></tr>
<tr><td>Thin HMA Overlay</td><td>60 to 80</td></tr>
<tr><td>Cold Milling and Thin HMA Overlay</td><td>60 to 75</td></tr>
<tr><td>HIR I-Surface Recycle and HMA Overlay</td><td>70 to 85</td></tr>
<tr><td>HIR II-Remixing and HMA Overlay</td><td>60 to 75</td></tr>
<tr><td>HIR III-Repaving</td><td>60 to 75</td></tr>
<tr><td>CIR and HMA Overlay</td><td>60 to 75</td></tr>
<tr><td>Ultra-Thin PCC Overlay</td><td>60 to 80</td></tr>
</table>

Table 20. Overall pavement condition windows of opportunity for selected PPM treatments applied to rigid pavements (Peshkin et al. 2011).

<table>
<tr><th>Treatment</th><th>PCI Window of Opportunity</th><th>PCI Rating Scale</th></tr>
<tr><td>Joint Resealing</td><td>75 to 90</td><td rowspan="9"><table><tr><td>PCI Rating</td><td>Description</td></tr><tr><td>86 to 100</td><td>Excellent</td></tr><tr><td>71 to 85</td><td>Good</td></tr><tr><td>56 to 70</td><td>Fair</td></tr><tr><td>41 to 55</td><td>Poor</td></tr><tr><td>26 to 40</td><td>Very Poor</td></tr><tr><td>11 to 25</td><td>Serious</td></tr><tr><td>0 to 10</td><td>Failed</td></tr></table></td></tr>
<tr><td>Crack Sealing</td><td>70 to 90</td></tr>
<tr><td>Diamond Grinding</td><td>70 to 90</td></tr>
<tr><td>Diamond Grooving</td><td>70 to 90</td></tr>
<tr><td>Partial-Depth Repair</td><td>65 to 85</td></tr>
<tr><td>Full-Depth Repair</td><td>65 to 85</td></tr>
<tr><td>Dowel Bar Retrofit</td><td>65 to 85</td></tr>
<tr><td>Ultra-Thin Bonded Wearing Course</td><td>70 to 90</td></tr>
<tr><td>Thin HMA Overlay</td><td>70 to 90</td></tr>
</table>

The effort involved in developing a decision-support methodology can range from simple and quick to complex and time-consuming, depending on the desired level of analysis. As table 21 shows, a detailed analysis uses individual distress types and intensities (i.e., severity level and extent) to determine which treatments are feasible, whereas an intermediate analysis uses individual distress indexes and a simplified analysis uses combined distress indexes.

Each analysis level requires consistent and explicit distress severity criteria to govern treatment selection. For the detailed analysis level, criteria must be established that define each extent category for each distress type, as illustrated in table 22. Although three categories of extent are common with most distress types, criteria development can be simplified by reducing the extent categories from three to two. The SHRP2 R26 *Guidelines* provide treatment suitability recommendations for a variety of distress types and severity levels, with the assumption that "each distress exists in significant quantities to warrant considering a preservation treatment" (Peshkin et al. 2011). A partial illustration is given in table 23.

For the intermediate analysis level, the combination of severity and extent of a particular distress type are accounted for and reflected in an index for that distress. The index value is determined by subtracting preset deduct points for each severity-extent combination from a base value of the index representing perfect condition (e.g., PCI of 100), as illustrated in table 24. The deduct points can be assigned using either an expert opinion approach or an engineering/mathematical approach.

For the simplified analysis level, individual distress indexes are combined into a broader index representing a particular mode of deterioration. Examples of this are an environmental cracking index that covers climate-related cracks or a structural cracking index that covers load-related cracking. The combined distress index can be computed as either a function of the individual indexes or by using a deduct points approach that includes the distress types being combined.

Table 21. Levels of analysis for flexible and composite pavements.

Impact Type	Distress Type	Probable Cause(s)	Defect Typically Begins in	*Detailed*: Severity Level and Extent									*Intermediate*	*Simplified*	
				Low Severity			Medium Severity			High Severity			Individual Distress Indexes	Combined Distress Indexes	Combined Distress Indexes
				Low	Moderate	High	Low	Moderate	High	Low	Moderate	High			
Functional	Bleeding/Flushing	materials, climate, design	HMA											Surface Distress	Surface Distress
	Raveling and Weathering	climate, materials, moisture[1]	HMA												
	Polishing	materials, traffic	HMA												
	Water bleeding/pumping	moisture[1]													
	Bumps and Sags	moisture[1], climate	subgrade												Deformation Distress
	Depressions/Settlements	moisture[1], load, climate, construction	subgrade												
	Block Cracking	climate, materials	HMA											Env. Cracking	Cracking Distress
	Longitudinal Non-WP Cracking (cold-joint, random)	construction, climate	HMA												
	Transverse Thermal Cracking	climate, materials	HMA												
Structural	Alligator Cracking	load, moisture[1], design	HMA											Structural Cracking	
	Longitudinal WP Cracking	load, moisture[1], design	HMA												
	Joint Reflection Cracking	load, climate	HMA												
	Edge Cracking	load, design	HMA												
	Slippage Cracking	load, materials, moisture[1]	HMA												
	Corrugations/Washboarding	load, materials, moisture[1]	HMA, base												Deformation Distress
	Heaves/Swells	moisture[1], climate, materials	base, subgrade												
	Patches/patch deterioration	traffic, load, climate, materials, moisture[1]	HMA, base, subgrade											Structural Distress	
	Potholes	load, moisture[1], climate, material	HMA, base, subgrade												
	Shoving	load, materials	HMA												
	Rutting[2] - structural - mix/instability	traffic, load, materials, moisture[1]	HMA, base, subgrade												
	Rutting[2] - abrasion/wear - stable (densification)	traffic, load	HMA												

[1] Excess moisture, possibly exacerbated by poor drainage.
[2] Knowing the cause of rutting is crucial to determining the type(s) of treatments that are suitable.

Table 22. Extent category descriptions and example criteria.

	3 Extent Categories			2 Extent Categories	
Category	**Low**	**Moderate**	**High**	**Minor**	**Significant**
General Description	No or isolated/limited occurrence	Occasional to frequent occurrence	Widespread to full occurrence	No or small quantity	Substantial quantity
Example 1 Criteria	< 5% of surface area with X-severity raveling	≥ 5% and < 50% of surface area with X-severity raveling	≥ 50% of surface area with X-severity raveling	< 15% of surface area with X-severity raveling	≥ 15% of surface area with X-severity raveling
Example 2 Criteria	< 20 X-severity transverse cracks per mile (or average crack spacing > 264 ft)	≥ 20 and < 100 X-severity transverse cracks per mile (or average crack spacing ≤ 264 ft and > 52 ft)	≥ 100 X-severity transverse cracks per mile (or average crack spacing ≤ 52 ft)	< 25 X-severity transverse cracks per mile (or average crack spacing > 211 ft)	≥ 25 X-severity transverse cracks per mile (or average crack spacing ≤ 211 ft)

Note: X-severity denotes a specific distress severity level (e.g., low, medium, high).

Table 23. Partial illustration of SHRP2 R26 preliminary feasibility matrix.

Preservation Treatment	**Distress Types and Severity Levels (L=Low Severity, M=Medium Severity, H=High Severity)**									
	Surface Distress			**Cracking Distress**				**Deformation Distress**		
	Ravel/ Weather	**Bleed/ Flush**	**Polish**	**Fatigue/ Long WP**	**Block**	**Trans Thermal**	**Long/ Edge**	**Wear/ Stable Rutting**	**Bumps/ Sags**	**Patches**
	L/M/H	**—**	**—**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**	**L/M/H**
Crack Seal				✖✖✖	⦿○✖	●⦿○	○✖✖			
Micro Surfacing-Single Course	⦿●⦿	✖	⦿	⦿○✖	●⦿○	⦿○✖	⦿○✖	⦿○✖	○✖✖	⦿○✖
Chip Seal-Single										
Conventional binder	⦿●⦿	○	●	⦿✖✖	●⦿○	●⦿○	⦿⦿○	⦿○✖	○○✖	⦿⦿○
Polymer-modified binder	○⦿⦿	✖	●	⦿○✖	●⦿⦿	●⦿⦿	⦿○✖	⦿○✖	○○✖	⦿⦿○
Thin HMA overlay	⦿●⦿	○	●	●⦿○	●●⦿	⦿●⦿	⦿⦿●	⦿●⦿	●⦿○	●●⦿
HIR										
Surf Recycle	○⦿●	○	○	⦿⦿○	●⦿○	○⦿●	⦿⦿○	⦿●⦿	⦿⦿○	⦿⦿○
Remixing	✖○○	○	⦿	⦿●⦿	⦿●⦿	⦿●⦿	⦿●⦿	⦿●●	○⦿●	○⦿⦿
Repaving	✖○○	○	⦿	⦿●⦿	⦿●⦿	⦿●⦿	⦿●⦿	⦿●●	○⦿●	○⦿⦿

● Highly Recommended ⦿ Generally Recommended ○ Provisionally Recommended ✖ Not Recommended

Table 24. Illustration of deduct points for combinations of distress severity level and extent.

Transverse Cracking Deducts					
Severity Level	**Extent (ft/mi)**				
	0-100	**101-250**	**251-500**	**501-1,000**	**>1,000**
Low	0	3	10	15	20
Medium	0	7	15	25	35
High	0	10	20	35	50

The results of the New England survey indicate most of the agencies use the intermediate analysis approach, and about half use the simplified analysis approach. Common distress indexes include longitudinal cracking, transverse cracking, alligator cracking, and distortion/rutting. Common combined indexes include structural cracking, environmental cracking, and overall cracking. An example of one agency's (Rhode Island) treatment selection matrix using 0-to-100 scale distress indexes and a 0-to-100 scale roughness index is shown in table 25. Although this chart includes the selection criteria for all types of treatments (including reconstruction), it can be seen that the criteria for Rhode Island's PPM treatments vary for each distress type.

As previously mentioned, the results of the New England survey indicate that five states use different trigger and threshold values for different facility types, while two use different values corresponding to traffic environments. Because of the effect of traffic intensity on treatment performance and because of maintenance priority (higher type facilities kept to a higher level), consideration should be given to assigning different trigger and threshold values for different roadway traffic conditions. This is illustrated in Rhode Island's treatment selection matrix in table 25. The appropriateness of setting different levels should be verified in the field.

Although the current condition data can be used to identify feasible treatments, it is important to consider when the PPM action is expected or scheduled to occur (Peshkin et al. 2011a). If there is a significant gap (say, greater than 1 year) between the time the latest condition data were collected and the time the activity will take place, then it is recommended that projected condition data (based on historical trends) be used in the feasibility assessment, as illustrated in figure 9. Depending on the time gap and the historical trends, this could greatly affect the treatments identified as suitable.

A final consideration in preliminary treatment selection is treatment customization. The pavement conditions may be such that it is best to combine two or more treatment types into one, or to supplement a particular treatment with one or more preparatory activities. As discussed in chapter 3, flexible pavement treatments like crack filling and milling are frequently used with asphalt-aggregate seals and HMA overlays, while rigid pavement treatments like joint resealing and crack sealing are used with partial- and full-depth repairs and diamond grinding. Preparatory activities, such as surface or base patching, leveling course application, bump grinding, and slab stabilization or jacking, are usually appropriate if the PPM treatment is unable to address certain isolated distresses.

Table 25. Rhode Island's distress index-based treatment selection matrix (modified from Lima 2015).

		Treatment Type																				
		Crack Seal			Chip Seal			PPEST			SAMI			Mill & Overlay			Level & Overlay			Slurry		
	PSHI Score	NHS		Non NHS	NHS		Non NHS	NHS		Non NHS	NHS		Non NHS	NHS		Non NHS	NHS		Non NHS	NHS		Non NHS
		Interstate Freeway	PA		Interstate Freeway	PA		Interstate Freeway	PA		Interstate Freeway	PA		Interstate Freeway	PA		Interstate Freeway	PA		Interstate Freeway	PA	
IRI	100 80 60 40 20 0	≥ 80	≥ 65	≥ 65	n/a	n/a	≥ 65	n/a	≥ 60 and < 80	< 70	n/a	≥ 40 and < 80	< 70	< 90	≥ 40 and < 80	< 70	n/a	≥ 40 and < 80	< 70	n/a	n/a	n/a
Alligator Cracking	100 80 60 40 20 0	n/a	≥ 95	≥ 95	n/a	n/a	≥ 70 and < 90	n/a	≥ 80	≥ 70	n/a	≥ 70	≥ 55 and < 80	n/a	≥ 80	≥ 65 and < 90	n/a	≥ 80	≥ 65 and < 90	n/a	n/a	n/a
Longitudinal Cracking	100 80 60 40 20 0	≥ 70 and < 90	≥ 60 and < 90	≥ 60 and < 90	n/a	n/a	≥ 50 and < 70	n/a	≥ 60 and < 80	≥ 50	n/a	< 50	< 40	< 80	< 60	< 50	n/a	< 60	< 50	n/a	n/a	n/a
Transverse Cracking	100 80 60 40 20 0	≥ 70 and < 90	≥ 60 and < 90	≥ 60 and < 90	n/a	n/a	≥ 50 and < 70	n/a	≥ 60 and < 80	≥ 50	n/a	< 50	< 40	< 80	< 60	< 50	n/a	< 60	< 50	n/a	n/a	n/a
Block Cracking	100 80 60 40 20 0	n/a	or < 100	or < 100	n/a	n/a	or ≥ 50 and < 70	n/a	or ≥ 70 and < 90	or ≥ 50 and < 75	n/a	or < 50	or < 50	or < 75	or < 50	or < 50	n/a	or < 50	or < 50	n/a	n/a	n/a
Rutting	100 80 60 40 20 0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

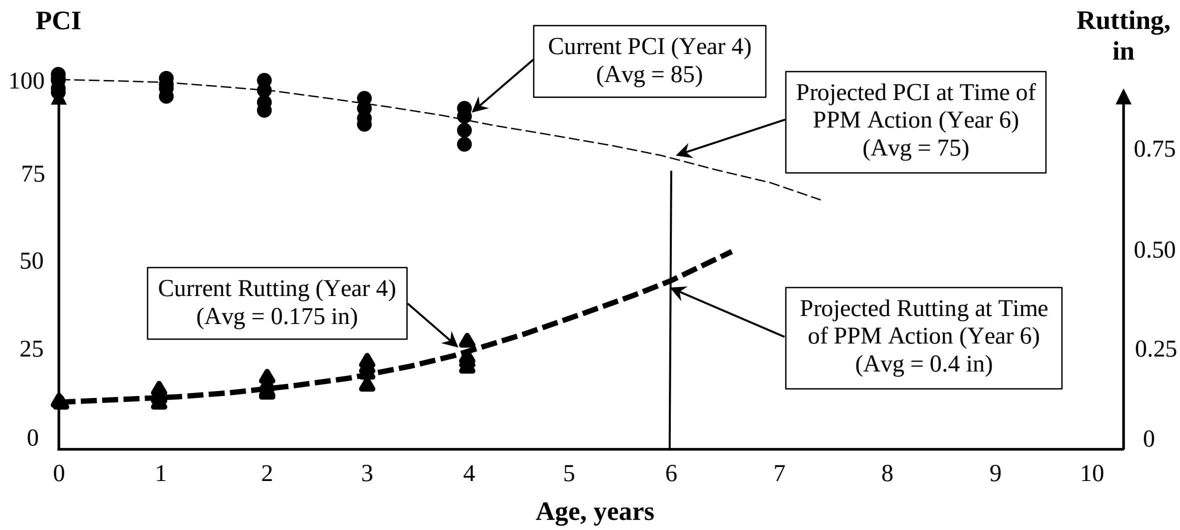


Figure 9. Projected condition data for treatment feasibility assessment.

Step 2—Final Identification of Feasible Treatments

Once a preliminary list of feasible PPM treatments has been developed, further evaluation is needed to determine which of the treatments satisfy the needs and constraints of the project/site (Peshkin et al. 2011a). As illustrated in table 26, there are many different factors that can affect the application or use of treatments and the expected performance of treatments. These factors can be grouped according to traffic characteristics; facility type and setting; project location, layout, and design features; road geometrics; climate/weather considerations; and environmental and sustainability considerations.

The goal of this step is to narrow the list of feasible treatments created in Step 1 by identifying specific attributes of the project that would preclude using a particular treatment. Although some agencies consider these types of factors concurrently with pavement condition, a separate assessment is less likely to confound the selection process and more likely to provide pinpointed reasons to eliminate a particular treatment.

The SHRP2 R26 *Guidelines* include example feasibility matrixes that incorporate several key factors, and a partial illustration of it is provided in table 27. Some level of judgment with respect to removing a treatment from consideration, is required with this type of application. For instance, the number of instances of “not recommended” or “provisionally recommended” is not specified, nor are acceptable or unacceptable criteria for treatment application cost given. New England agencies are encouraged to develop and implement a process that minimizes the subjectivity of keeping or removing treatments from consideration.

Table 26. Project and site factors affecting the application or use of treatments and the performance of treatments.

Project/Site Characteristics	Treatment Application/Use: Materials, Equipment, & Labor	Treatment Application/Use: Construction Operation	Treatment Performance
Traffic Characteristics			
Volume and Composition (i.e., current and projected ADT and percent trucks)	Cost appropriateness of treatment	Time-to-opening Safety impacts	Durability under traffic loadings and frequencies (both immediately after opening to traffic and long term)
Speed			
Loading Intensity/Magnitude			
Bicyclists/Pedestrians	Safety and comfort impacts of treatment		
Facility Type and Setting			
Functional Class or Highway System	Cost appropriateness of treatment	Traffic control and safety impacts associated with interchanges, intersections, and access drives	Durability under traffic maneuvers (starting, stopping, turning maneuvers associated with interchanges, intersections, and access drives)
Setting (Rural, Urban)			
Maintenance of Traffic Requirements / Work Zone Duration Restrictions	Material setting and curing times affecting time-to-opening	Speed of construction affecting completion, time-to-opening	
Project Location, Layout, and Design Features			
Location	Availability of local quality materials Availability of local qualified contractors Need for specialized equipment, materials	Mobilization requirements	Performance impacts associated with construction quality
Layout (right-of-way, land use)	Stockpiling/storage of material options	Staging and equipment parking options	
Design Features (structures, drainage facilities, traffic control devices)		Vertical constraints (e.g., overpasses, curb/gutter, manholes, pavement striping/markings, detector loops)	
Road Geometrics			
Horizontal Alignment		Safety impacts created by horizontal and vertical curves Treatment application impacts created by grades, superelevations, and lane/shoulder configurations	
Vertical Profile			
Lateral Cross-Section			
Climate/Weather Considerations			
Direct Impacts	Minimum temperatures for material use	Treatment application impacts created by crack/joint openings and presence of moisture in pavement	Performance under climatic conditions (e.g., temperature and precipitation ranges, freeze-thaw cycles)
Indirect Impacts			Durability under snowplows and deicing chemicals
Highway User and Surrounding Community Issues			
Safety	Crash-prone roadway		
Traffic Noise	Noise-sensitive environment		
Environmental & Sustainability Considerations			
Material Conservation	Recycling/reuse of existing material		
Energy Consumption	New material production Added equipment use		
CO2 Emissions and Air Quality			

Table 27. Partial illustration of SHRP2 R26 final feasibility matrix.

	Treatment Durability								Work Zone Duration Restrictions			
	Rural Roads				Urban Roads							
		Climatic Zone				Climatic Zone						
Preservation Treatment	ADT> 5.000	Deep-Freeze	Moderate-Freeze	Non-Freeze	ADT> 10.000	Deep-Freeze	Moderate-Freeze	Non-Freeze	Overnight or Single-Shift	Weekend	Longer	Cost
Crack Seal	●	●	●	●	●	●	●	●	●			$
Slurry Seal (Type III)	○	×	⦿	⦿	○	×	⦿	⦿	●			$$
Micro Surfacing-Double Course	⦿	⦿	●	⦿	⦿	⦿	●	⦿	●			$$/$$$
UBWC	⦿	⦿	●	⦿	⦿	⦿	●	⦿	●			$$$
Milling and Thin HMA Overlay	●	●	●	⦿	●	●	●	●	●			$$$
CIR and HMA Overlay	⦿	⦿	⦿	○	⦿	⦿	⦿	⦿	●			$$$
Ultra-Thin Whitetopping	○	○	○	○	○	○	⦿	○	×	○	⦿	$$$$

● Highly Recommended ⦿ Generally Recommended ○ Provisionally Recommended × Not Recommended
Cost: $ (lowest relative cost) ↔ $$$$ (highest relative cost)

Step 3—Cost Effectiveness Analysis

If two or more treatments are identified as final candidates for a PPM project, then a fair and direct comparison of those treatments must be made in order select the preferred treatment. Step 3 involves developing the information for one part of this comparison—treatment cost effectiveness values.

The SHRP2 *Guidelines* describes and illustrates two different approaches to determining treatment cost effectiveness—the Equivalent Annual Cost (EAC) method and the Benefit-Cost Ratio (BCR) method. The EAC method involves a simple calculation of the treatment unit cost divided by the expected treatment performance. The treatment unit cost is the estimated in-place cost of the treatment, commonly expressed in a unit area (e.g. square yard) or lane-mile basis. The expected performance is represented as the extension in service life of the existing pavement due to the application of the treatment. The treatment alternative with the lowest EAC is the most cost effective.

The BCR method is more complicated and requires calculating both the benefit and the cost of using a particular treatment. The benefit is quantified by computing the area under the long-term pavement performance curve, as defined by the deterioration trends of the original pavement, the PPM-treated pavement, and one or more rehabilitations. The cost is determined using life-cycle cost analysis (LCCA) techniques, whereby the cost of the original pavement is added to the discounted costs of the future PPM treatment and future rehabilitations to yield a net present value (NPV). The BCR can then be computed by dividing the benefit by the NPV. The treatment with the highest BCR is the most cost effective.

A key aspect of Step 3 is reliable, up-to-date performance estimates for the alternative PPM-treated pavements (for the BCR method, reliable performance estimates of the original pavement and rehabilitated pavement are also needed). PMS databases provide the best source for modeling pavement performance and developing service life estimates (Smith et al. 2014). The historical condition data in these systems can be used to construct a variety of performance curves for unique pavement families and for different PPM treatments applied to those pavement families. If insufficient historical condition data exist, then estimates may be derived from an analysis of treatment application cycles or by expert opinion.

The New England survey responses suggest that data-driven performance estimates for PPM treatments are not widespread. As table 28 shows, half the agencies reported that they regularly track the performance of PPM projects, while the other three said they do not. The frequency of monitoring varies between annually and biennially, with higher type facilities like interstates typically surveyed more frequently.

Half of the agencies analyze the performance data for developing estimates of treatment life, pavement life extension, and/or treatment cost effectiveness. The performance modeling is primarily based on an overall condition or distress indicator, and the treatments most often evaluated for performance include UBWC, micro surfacing, chip seal, and mill-and-thin HMA overlay.

Step 4—Selection of the Preferred Treatment

Although treatment cost effectiveness analysis can provide a good indication of which treatment is best for a high-traffic-road project, it is but one part of the overall decision-making process. Other factors, such as available budgets, network priorities, environmental practices and constraints, and agency and highway user preferences must also be considered.

A list of some of the critical factors that are appropriate for inclusion in the final selection process is provided below, grouped according to different attributes (Smith et al. 2014). The selection of the preferred treatment should properly be one of professional engineering practice and judgment, based on the consideration and evaluation of all factors applicable to the project.

Economic Attributes

- Initial cost.
- Cost-effectiveness (EAC, BCR).
- Agency cost.
- User cost.

Construction/Materials Attributes

- Availability of qualified (and properly equipped) contractors.
- Availability of quality materials.
- Conservation of materials and energy.
- Weather limitations.

Customer Satisfaction Attributes

- Traffic disruption.
- Safety issues (e.g., friction, splash/spray, reflectivity/visibility).
- Ride quality.
- Noise issues.

Table 28. Performance monitoring and modeling efforts of New England SHAs.

Questions	Responses
Does your agency currently track the performance of regularly constructed PM treatments (i.e., treatments not specially placed as part of a planned field trial or test site)?	Yes–3 No–3[a]
If you answered "Yes" to the above question, how is the performance tracked?	Network-level surveys only–1 Network- and project-level surveys–2
If you answered "Yes" to the above question, how frequent is the performance monitoring (i.e., how frequent are performance data collected and reported)	Annual–1 Combination Annual and Biennial–2 Other–1[b]
Has your agency analyzed or modeled PM treatment data?	Yes–3 No–3
If you answered "Yes" to the above question, what types of estimates were sought from the analyses/modeling?	Treatment life–2 Pavement life extension–2 Treatment cost effectiveness–2
If you answered "Yes" to the above question, was the analyses/modeling done at the network level or project level?	Network level–1 Project level–1
If you answered "Yes" to the above question, what pavement condition parameters were used in assessing treatment life or pavement life extension?	Overall condition rating–1 Overall distress rating–1 Overall ride quality rating–1 Individual distress rating–1
What PM treatment types have been evaluated for performance by your agency?	Crack seal–1 Micro Surfacing–2 Chip seal–2 Cape seal–1 UBWC–3 Thin HMA overlay–1 Mill and thin HMA overlay–2 Ultrathin PCC overlay–1

[a] One agency indicated they have test sites that are monitored.
[b] One agency manually monitors performance of their preservation treatments twice annually.

Agency Policy/Preference Attributes

- Continuity of adjacent pavements.
- Continuity of adjacent lanes.
- Local preference.

A useful mechanism to systematically and rationally evaluate the different factors and identify the preferred strategy is a treatment decision matrix (Peshkin et al. 2011). In a treatment decision matrix, various selection factors are identified for consideration and each factor is assigned a weighting. The weightings are then multiplied by rating scores given to each treatment, based on how well the treatment satisfies each of the selection factors. The weighted scores of each treatment are then summed and compared with the weighted scores of the other treatments. The one with the highest score is recognized as the preferred treatment. Illustrative examples of the decision matrix approach can be found in both the SHRP2 R26 *Guidelines* (Peshkin et al. 2011a) and the National Cooperative Highway Research Program (NCHRP) *Guide for Pavement Type Selection* (Hallin et al. 2011).

Example Illustration of Preliminary Identification of Treatments

The project featured in this example consists of a rural, 2-lane state highway with an ADT of 10,200 vehicles/day and 3 percent commercial trucks. The project terrain is mildly rolling and there are no significant horizontal curves. The posted speed limit for this 2.6-mi long project is 55 mph.

The existing pavement structure was originally constructed in 1995 as a flexible pavement. In 2010, it was resurfaced with a structural HMA overlay. The pavement cross-section now consists of 6.0 in of HMA on top of 8 in of full-depth reclamation (FDR) base and a lime-stabilized subgrade.

Pavement condition has been monitored annually since construction using an automated data collection vehicle. The collected distress data have been converted into 0-to-100 scale distress indexes, along with the collected IRI data. The historical scores for the project are listed in table 29. Since the project is not expected to occur for at least 1 year, the historical data have been used to project the scores 1 year into the future. Pavement friction throughout the project is adequate.

Table 29. Summary of pavement condition data.

Condition Indicator	0-to-100 Scale Condition Index Score					
	2011	2012	2013	2014	2015	2016 (projected)
PSHI	98	96	93	90	87	84
IRI	100	98	91	87	82	78
Alligator Cracking	100	100	100	95	91	87
Longitudinal Cracking	100	100	96	84	77	70
Transverse Cracking	100	98	91	85	78	74
Block Cracking	100	100	100	100	96	90
Rutting	100	100	98	95	93	90

The agency's treatment toolkit consists of crack sealing, slurry seal, rubberized asphalt chip seal, paver-placed elastomeric surface treatment (PPEST), and SAMI seal. The selection criteria for these treatments are listed in table 30. Based on the projected scores and the treatment selection criteria, two treatments are appropriate for use—slurry seal and rubberized asphalt chip seal. The overall pavement condition is slightly lower than what is acceptable for crack sealing, and yet has not deteriorated to the point where PPEST and SAMI Seal are feasible options.

Table 30. PPM treatment selection criteria for Non-NHS routes.

Condition Indicator	Treatment				
	Crack Sealing	Slurry Seal	Rubberized Asphalt Chip Seal	PPEST	SAMI Seal
PSHI	>85	80-90	75-85	65-80	70-80
IRI	>65	>75	>65	<70	<70
Alligator Cracking	>90	>85	70-90	>70	55-80
Longitudinal Cracking	60-90	60-90	50-75	>50	<70
Transverse Cracking	60-90	60-90	50-75	>50	<70
Block Cracking	<100	60-90	50-90	50-75	<50
Rutting	>90	>90	70-90	>70	55-80

6. TREATMENT TIMING

PPM treatments are most effective when applied to relatively young pavements that are in good condition. If applied too early or too late in a pavement's life, the benefit provided by the treatment will be less than the cost of applying it, thereby negating the value of its use. However, if applied at some point between these two times, the benefit outweighs the cost. As discussed previously and illustrated in figure 10, this range represents the window of opportunity for the treatment.

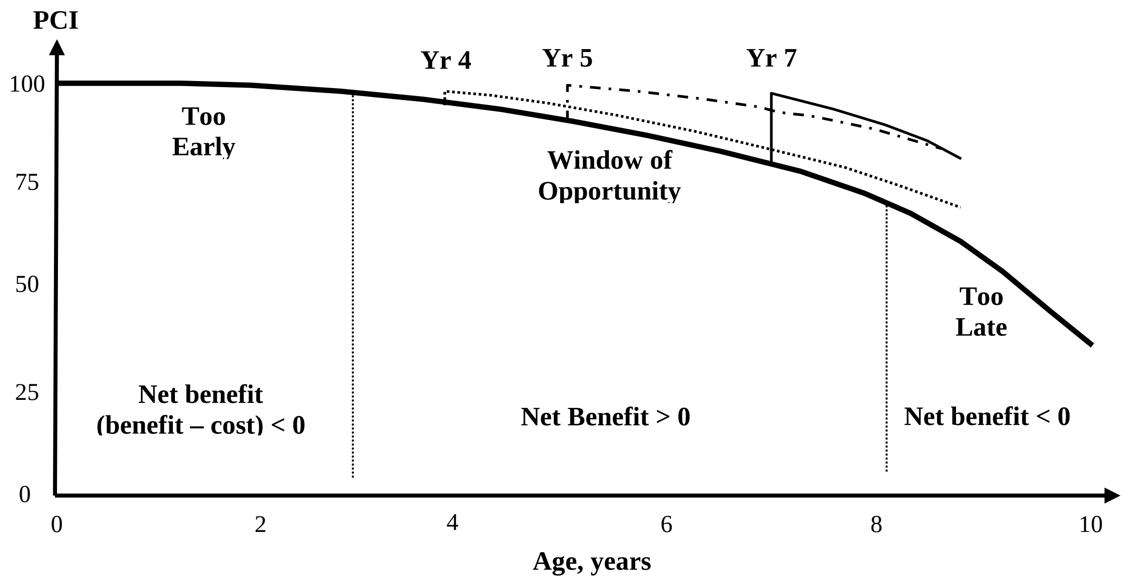


Figure 10. PPM treatment window of opportunity.

There are several different methodologies in use for the selection of PPM treatment application timing. Simple strategies include conducting PPM on a pre-determined schedule, applying it at after a specific time since last application, and basing application on a PMS process (Peshkin et al. 2004). Another approach is to incorporate PPM treatments into the pavement design process and then apply the treatments at the scheduled times following construction of the designed pavement. A fourth approach examines benefit and cost data in detail using one or more pavement performance indicators. This approach, which was developed under NCHRP Project 14-14, is described in NCHRP Report 523, *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (Peshkin et al. 2004). It is also the basis for the specialized spreadsheet tool (*OPTime*) that was developed for calculating optimum timing.

The objective of NCHRP Project 14-14 was to develop a methodology for determining the optimal timing for the application of PPM treatments to help agencies to obtain the greatest increase in performance at the least cost. In reference to figure 10, this entails evaluating the performance trends of the treated pavement when the treatment is applied at different ages and corresponding condition levels. Since the pavement deficiencies and the treatment's ability to address those deficiencies change with age, the performance trends of the treated pavement will vary. The goal is to identify where within the window of opportunity is the net benefit the maximum.

This chapter discusses the issue of treatment timing, which can be performed either during the treatment selection process or once a treatment has been selected. The chapter includes a brief overview of the *OPTime* program and the optimal timing process, and it discusses the data requirements for evaluating treatment timing. Also included are two example applications of the process using data provided by a New England agency.

Overview of *OPTime* Program and Optimal Timing Process

The *OPTime* tool is a Visual Basic Application (VBA)-driven Microsoft® Excel workbook that includes a simple analysis method for choosing the most effective treatment timing based on user-chosen timing scenarios (Peshkin et al. 2004). The scenarios are based on performance and cost data for a specific treatment applied at different pavement ages. The analysis considers only a one-time application of the treatment; multiple sequential applications of the treatment are not possible.

The user-selected scenarios are analyzed using two parallel methods—Detailed and Simple. In the Detailed analysis, actual or estimated field performance data (both prior to and after treatment application) are obtained so that the relationship between expected pavement condition and age can be determined through a statistical analysis. In this case, the statistical analysis is based on selecting a regression equation and entering known regression coefficients, or by fitting a regression equation to the known treatment performance data.

If actual performance data are unknown, unavailable, or there is a concern with the statistical analysis, the Simple analysis can be used. With the Simple analysis, a generic performance model equation is provided and the user can customize the equation to reflect agency observations about performance or examine hypothetical "what if" scenarios in the absence of actual data. The customization allows for specifying a starting pavement condition level and a future condition level through which the performance curve must pass.

Within *OPTime*, PPM treatment effectiveness is based on pavement condition, time of treatment application, and cost. Costs are compiled as an equivalent uniform annual cost (EUAC) and may include all costs associated with treatment application, rehabilitation at the end of useful life for the applied preventive treatment, work zone-related user delay, and routine maintenance (Peshkin et al. 2004). A BCR value is computed to determine the most cost-effective treatment timing scenario. The most cost-effective treatment is defined as the treatment that results in the highest increase in one or more condition indicators at the lowest cost.

Pavement condition can be defined in accordance with commonly accepted measures, such as PCI, IRI, PSI, or any custom-defined performance measure. The benefit of a PPM treatment is calculated as the difference in the area beneath the performance curve due to the treatment application and that of the "do nothing" alternative (see figure 11).

OPTime is currently capable of analyzing a number of pre-selected PPM treatments and also allows the inclusion of user-specified treatments. The standard set of treatment options are listed in table 31.

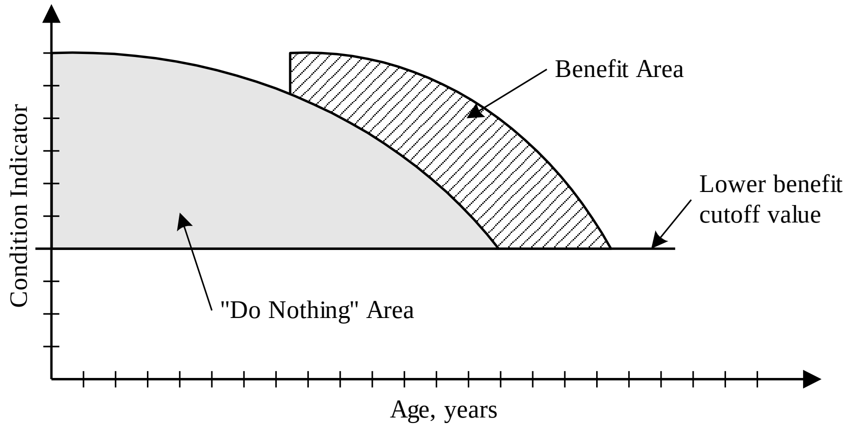


Figure 11. Illustration of the do-nothing and benefit areas (Peshkin et al. 2004).

Table 31. PPM treatments included in *OPTime* (Peshkin et al. 2004).

HMA-Surfaced Pavements	**PCC-Surfaced Pavements**
Crack filling/sealing	Crack sealing
Fog seal	Joint resealing
Slurry seal	Diamond grinding
Scrub seal	
Micro surfacing	
Chip seal	
Thin overlay	
Ultrathin friction course	

The step-by-step process for computing PPM treatment benefit and cost within *OPTime* is as follows (Peshkin et al. 2004):

1. **Analysis setup**. Select PPM treatment and timing. Selected treatments should result in measurable benefits in pavement condition.
2. **Select condition indicators and benefit cutoff values**. One or more condition indicators are selected that will be tracked/predicted over time. Benefit cutoff values are assigned as boundary conditions (i.e., upper and lower limits of the pavement performance curve) for condition indicators with a decreasing relationship (PCI, friction) and those with an increasing relationship (i.e., rutting, IRI) (see figure 12).
3. **Compute the do-nothing case area**. Determine the area bound by the do-nothing performance curve.
4. **Compute the expected service life of the do-nothing case**. The expected service life of the do-nothing case serves as a baseline for determining life extension and is the earliest age a condition indicator (i.e., IRI, rutting, friction) reaches the benefit cutoff value.
5. **Compute the expected service life of the post-treatment case**. The expected service life of the post-treatment case is the earliest age a condition indicator reaches its benefit cutoff value.

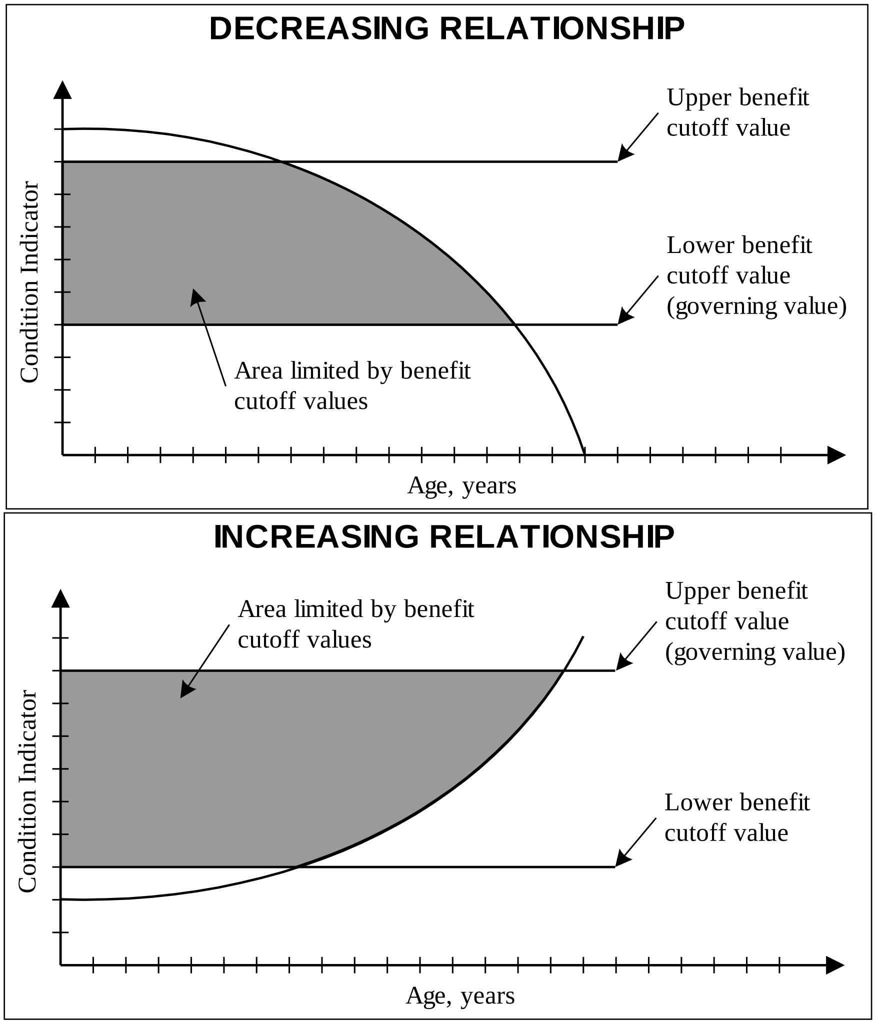


Figure 12. Illustration of upper and lower benefit cutoff values (Peshkin et al. 2004).

6. **Compute the post-treatment case area**. Determine the area bound by the post-treatment case performance curve.
7. **Compute the benefit of each individual condition indicator**. Determine the mathematical difference between the post-treatment area and the associated do-nothing area.
8. **Compute the overall benefit**. If multiple condition indicators are used in the analysis, benefit values are combined using weighting factors for determination of the overall treatment benefit.
9. **Compute the life-cycle cost**. Conduct a LCCA on each PPM application scenario.
10. **Determine the most cost-effective timing scenario**. Determine the most effective timing scenario based on the BCR.

Data Requirements

A summary of the data requirements for conducting an *OPTime* analysis is provided in table 32. The requirements are presented according to the ten steps listed above.

Table 32. Data requirements for *OPTime* analysis.

Step	Analysis Type: Simple	Analysis Type: Detailed
1. Analysis Setup	1. PPM treatment type(s). 2. PPM treatment application ages (timing scenarios).	
2. Selection of Condition Indicators and Benefit Cutoff Values	1. Overall condition or distress index, individual distress indexes, IRI, rut depth. 2. Ceiling/basement values (corresponding to high-end performance). 3. Threshold values (corresponding to treatment or pavement failure).	
3. Compute Do-Nothing Case Area	1. User customization of generic performance relationship of the untreated pavement (age-based model/equation for each selected condition indicator).	1. Data-driven performance relationship of the original untreated pavement (age-based model/equation for each selected condition indicator).
4. Compute Expected Service Life of Do-Nothing Case	—	—
5. Compute Expected Service Life of Post-Treatment Case	1. User customization of generic performance relationship of each selected PPM treatment when applied at selected ages (age-based model/equation for each selected condition indicator).	1. Data-driven performance relationship of each selected PPM treatment when applied at selected ages (age-based model/equation for each selected condition indicator).
6. Compute Post-Treatment Case Area	—	—
7. Compute Benefit Associated with Each Condition Indicator	—	—
8. Compute Overall Benefit	1. 0-to-100 scale weighting factors for each selected condition indicator.	
9. Compute Life-Cycle Cost	1. In-place agency cost (and user cost, if desired) of each selected PPM treatment. 2. In-place agency cost (and user cost, if desired) of routine maintenance activities and rehabilitation treatments. 3. LCCA discount rate.	
10. Determine Most Cost-Effective Timing Scenario	—	

The analysis of optimal timing using the Detailed method in *OPTime* can be performed using either project-level or network-level performance data. A project-level analysis uses time-series condition data collected on specially constructed PPM treatment test sections, as well as adjacent untreated control sections. All of the sections must include the same original pavement structure and similar levels of traffic. In addition, the PPM test sections must be comprised of one or more treatments applied at different times following construction of the original pavement (e.g., micro surfacing placed at Years 3, 5, and 7, thin HMA overlay placed at Years 5, 7, and 9).

A network-level analysis uses time-series condition data on several pavement management sections that have received a particular PPM treatment. The sections must be comparable in terms of pavement design, traffic levels, subgrade characteristics, and climate, among other things. In addition, like project-level analysis, they must include treatments applied at different times following construction of the original pavements.

A project-level analysis is best suited for new treatments or treatments being considered for inclusion in the agency's toolbox. Also, it is appropriate when considering expanding the applications of a toolbox treatment, such as use on a high-traffic-volume roadway. A network-level analysis is best suited for toolbox treatments with a history of significant use. The main reason for using this type of analysis is to develop improved and more reliable performance models for the treatments.

Example Illustrations

The New England survey asked if agencies had data available for two PPM projects that could be used to analyze the optimal timing of a particular treatment. The requirements for the projects were set forth as follows:

> *The projects should have been constructed within the last 5 to 10 years, and should involve the same treatment type placed on a similar pavement type located on a similar highway facility (i.e., same functional class, comparable traffic level) and in a similar climatic zone. The projects should differ in terms of the age or condition of the existing pavement at the time the PM treatments were applied (e.g., pre-treatment PCI of 90 for one project and pre-treatment PCI of 75 for the other project). The data required for the projects include pre-treatment and post-treatment performance data (at least 3 sets of time-series performance data for both pre- and post-treatment), pre-treatment pavement cross-section data, PM treatment data (materials/mix design, application thickness, construction cost, etc.), and project site characteristics (route, location, traffic speed and volume, climate).*

Three of the responding agencies identified and proposed projects for consideration. Data on some of these projects were provided by the agencies upon request. A comprehensive review of the data for these, as well as other projects that were previously proposed, indicated there were shortcomings with respect to the data needed to perform an *OPTime* analysis. Ultimately, the following two PPM projects from Connecticut were selected:

- CT Route 89 Chip Seal.
- CT Route 101 Mill-and-Thin HMA Overlay.

Additional time-series performance data and other data were requested and received from the Connecticut DOT. Descriptions of the projects, the analyses performed, and the results obtained are presented in the sections below.

Project 1—CT 89 Chip Seal

Project Overview

The CT 89 project is a two-lane highway located near Mansfield, east of Hartford. The road is a rural major collector with an ADT of 4,200 vehicles/day on its most heavily traveled segment. The section of road chosen for the optimal timing analysis is 3.25 mi long, extending from CT 195 to just past Juniper Lane. The pavement along this stretch was originally constructed as a medium-thickness flexible pavement. In 2000, it was resurfaced with 2 in of HMA. In 2011, a PPM treatment in the form of a single-course, rubberized asphalt chip seal was applied to the pavement.

Pavement Performance Data

Pavement condition on CT 89 has been monitored on an annual basis since 2000. The condition data (distresses, IRI) were collected using an automated data collection vehicle. Data collected prior to 2008 reside in the agency's maintenance management database and are summary data representing the entire 3.25-mi length. Data collected from 2008 to present day reside in the agency's PMS and are on 0.1-mi increments.

The pavement performance and other data for CT 89 were obtained and reviewed for *OPTime* application. The data set provided included both raw distress and IRI data, as well as 1-to-9 scale combined distress indexes (cracking, disintegration, distortion), ride index, and overall condition index (PSR). Because of the availability of good historical performance data, a Detailed analysis approach was used in the *OPTime* analysis.

Step 1—Analysis Setup

The PPM treatment type is a rubberized asphalt chip seal with 10 percent rubber. As noted above, this treatment was placed in 2011. Because this project was not an experimental project with multiple test sections representing different treatment application timings, a special approach was taken in order to establish timing scenarios. This involved sorting the 0.1-mi road increments according to their pre-PPM treatment PSR values from highest to lowest, and then grouping the increments into categories that would simulate different treatment timings. The categories established were as follows:

1. PSR > 5.65
2. 5.5 ≤ PSR ≤ 5.65
3. PSR < 5.5

Step 2—Selection of Condition Indicators and Benefit Cutoff Values

To simplify this example illustration, the PSR condition indicator was chosen for use. This indicator has a decreasing relationship, such that a new pavement typically begins with a value of 9 and then deteriorates to lower values over time.

The Connecticut DOT use various triggers and thresholds for its PPM and rehabilitation treatments. For PPM treatments, the PSR triggers primarily fall in the 4 to 6 range. For the *OPTime* analysis, a value of 4.5 was selected for the lower benefit cutoff and a value of 8.5 was selected for the upper benefit cutoff.

Step 3—Compute Do-Nothing Case Area

The data collected between 2000 (time of last major rehabilitation) and 2011 (time of PPM treatment application) were used to model the do-nothing performance curve. As shown in figure 13, the time-series performance data consist of summary data points (in orange) for 2000 through 2007 (ages 0 through 7 on the graph) and 0.1-mi increment data points (in blue) for 2008 through 2011 (ages 8 through 11 on the graph).

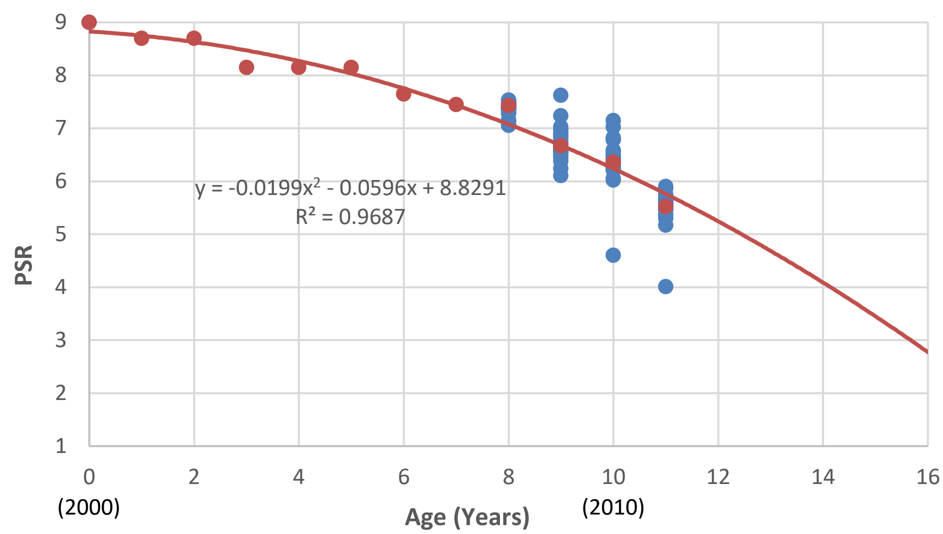


Figure 13. Do-nothing performance curve for CT 89.

A second-order polynomial curve was fit through the PSR data to yield the model for the do-nothing case. The yearly PSR averages (in orange) were used to develop the curve. The resulting model was entered into *OPTime*, which then computed the do-nothing condition area based on the model curve and the selected benefit cutoff values (see previous figure 11).

Step 4—Compute Expected Service Life of Do-Nothing Case

The baseline age for determining the extension of pavement life provided by the chip seal treatment is the age of the do-nothing curve when it reaches the benefit cutoff value of PSR=4.5. This age is approximately 13.5 years.

Step 5—Compute Expected Service Life of Post-Treatment Case

As discussed in Step 1, a special approach was taken to establish timing scenarios. The timing scenarios focused on pre-treatment PSR ranges that would simulate different timings. To convert the ranges to timings, the average PSR immediately before chip seal application was calculated for each timing category, and the age on the do-nothing curve corresponding to that average PSR value was identified. The pre-treatment PSR averages and resulting ages for the three timing categories were as follows:

Pre-Treatment PSR Category	Average Pre-Treatment PSR	Age of Application
PSR > 5.65	5.75	10
5.5 ≤ PSR ≤ 5.65	5.58	11
PSR < 5.5	5.42	12

Next, the post-treatment curves were plotted using the PSR values of each of the 0.1-mi increments comprising each timing category. A fixed-end power model was used to model the curves for each of the three categories. Figure 14 shows the chip-seal-treated pavement performance models for the three timing scenarios.

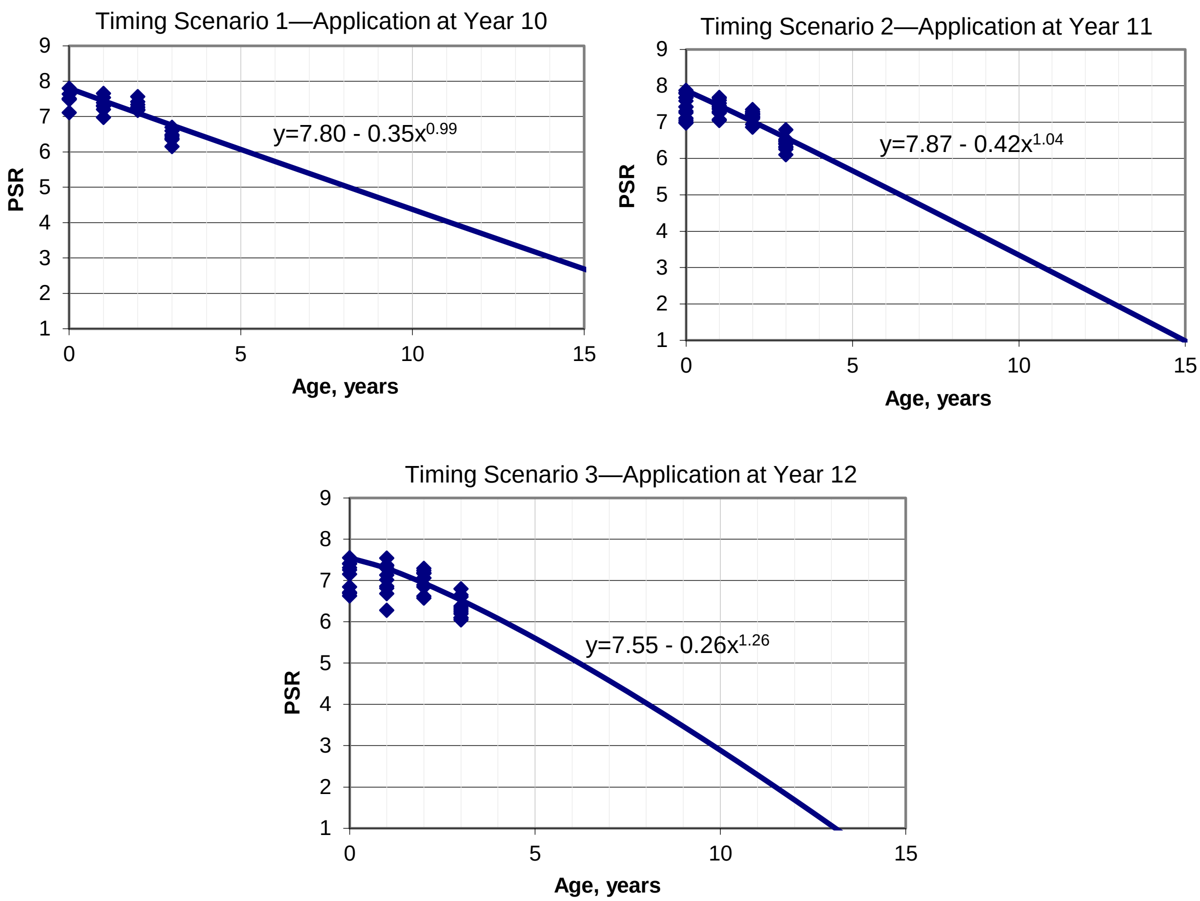


Figure 14. Post-treatment performance curves for the three chip seal timing scenarios.

Each post-treatment performance model and its timing was entered into *OPTime*. The extension of pavement life provided by the chip seal treatment at each timing was determined within the program by subtracting the age at which the post-treatment curve reached PSR=4.5 from the age at which the do-nothing curve reached the same lower benefit cutoff (13.5 years).

Step 6—Compute Post-Treatment Case Area

For each timing scenario, the area bounded by the post-treatment performance curve was computed by *OPTime*, as illustrated previously in figure 11.

Step 7—Compute Benefit Associated with Each Condition Indicator

For each timing scenario, the benefit associated with the PSR condition indicator was computed by *OPTime*.

Step 8—Compute Overall Benefit

Since only one condition indicator was used in the analysis, a benefit weighing factor of 100 was assigned to PSR.

Step 9—Compute Life-Cycle Cost

Only the PPM treatment application cost and a subsequent rehabilitation cost were included in this analysis; routine maintenance costs and user delay costs were not considered. Based on an estimated in-place treatment cost of $7.42/yd^2 provided by the DOT, a cost of $52,200/lane-mi was entered and used in *OPTime*. A cost of $500,000/lane-mi was used for the rehabilitation activity. A 4 percent discount rate was used to compute the life-cycle cost for each timing scenario.

Step 10—Determine Most Cost-Effective Timing Scenario

Table 33 summarizes the calculated benefits for each timing scenario. Because the analysis used only one condition indicator (PSR) with a benefit weighing factor of 100, the benefits for this indicator are the same as the total benefits. Table 34 summarizes the costs associated with each timing scenario. These include the present-worth treatment costs, rehabilitation costs, and total costs, as well as the EUAC. Finally, table 35 summarizes the effectiveness index and expected extension of life associated with each timing scenario. As can be seen, the timing scenario with the greatest effectiveness index for the rubberized chip seal treatment is the 10-year application. The estimated extension of life provided by this application is slightly greater than 6 years, resulting in a total expected service life of almost 20 years.

Table 33. Benefit summary for CT 89 chip seal.

	Benefit Weighting ⇨	**100**
Application Age, yrs	**Total Benefit**	**Composite Index (PSR)**
10	0.35	0.35
11	0.31	0.31
12	0.32	0.32

Table 34. Cost summary for CT 89 chip seal.

Application Age, yrs	**Treatment Cost, PW $**	**User Cost, PW $**	**Other Maint Cost, PW $**	**Rehab Cost, PW $**	**Total Present Worth, $**	**EUAC, $**
10	105,793	N/A	N/A	694,317	800,110	59,585
11	101,724	N/A	N/A	725,358	827,082	64,062
12	97,812	N/A	N/A	708,011	805,823	61,048

Table 35. Effectiveness summary for CT 89 chip seal.

Application Age, yrs	**Effectiveness Index**	**Total Benefit**	**EUAC, $**	**Expected Life, yrs**	**Expected Life Extension, yrs**
10	100.00	0.35	59,585	19.6	6.3
11	82.94	0.31	64,062	18.5	5.2
12	88.93	0.32	61,048	19.1	5.8

Project 2—CT Route 101 Mill-and-Thin HMA Overlay

Project Overview

The CT 101 project is a two-lane highway located near Killingly on the eastern edge of the state. The road is a rural minor arterial with an ADT of 8,100 vehicles/day on its most heavily traveled segment. The section of road chosen for the *OPTime* analysis is 4.3 mi long and extends from Valley Road in Killingly to the Connecticut–Rhode Island state line. The pavement on this stretch of CT 101 was originally constructed as a thick flexible pavement. In 2000, it was rehabilitated via milling and a structural HMA overlay. In 2011, it received a PPM treatment consisting of milling followed by a 2-in HMA (warm mix) overlay.

Pavement Performance Data

Like CT 89, the pavement condition on CT 101 has been monitored on an annual basis since the rehabilitation in 2000. The condition data collected prior to 2008 are summary data for the entire 4.3-mi section, whereas the data from 2008 forward are on 0.1-mi increments.

The pavement performance data obtained for analysis included both raw distress and IRI data, as well as 1-to-9 scale combined distress indexes (cracking, disintegration, distortion), ride index, and overall condition index (PSR). Again, because of the availability of good historical performance data, a Detailed analysis approach was used in the *OPTime* analysis.

Step 1—Analysis Setup

The PPM treatment type is a mill-and-thin HMA overlay placed in 2011. As with the CT 89 chip seal project, timing scenarios were established by sorting the 0.1-mi road increments according to their pre-PPM treatment PSR values from highest to lowest, and then grouping the increments into categories that would simulate different treatment timings. The categories established were as follows:

1. PSR > 6.0
2. 5.5 ≤ PSR ≤ 6.0
3. PSR < 5.5

Step 2—Selection of Condition Indicators and Benefit Cutoff Values

Like the CT 89 chip seal example, the PSR condition indicator was chosen for use, with benefit cutoff values of 4.5 and 8.5.

Step 3—Compute Do-Nothing Case Area

The do-nothing performance curve was modeled using the data collected between 2000 (time of last major rehabilitation) and 2010 (time of PPM treatment application). As shown in figure 15, the performance data consist of the 2000-2007 summary data points (in orange) (ages 0 through 7 on the graph) and the 2008-2010 0.1-mi increment data points (in blue) (ages 8 through 10 on the graph).

The model form used for the do-nothing performance curve was a second-order polynomial fitted through the yearly average PSR values. The resulting performance model was entered into *OPTime*, which then computed the do-nothing condition area, based on the model curve and the selected benefit cutoff values.

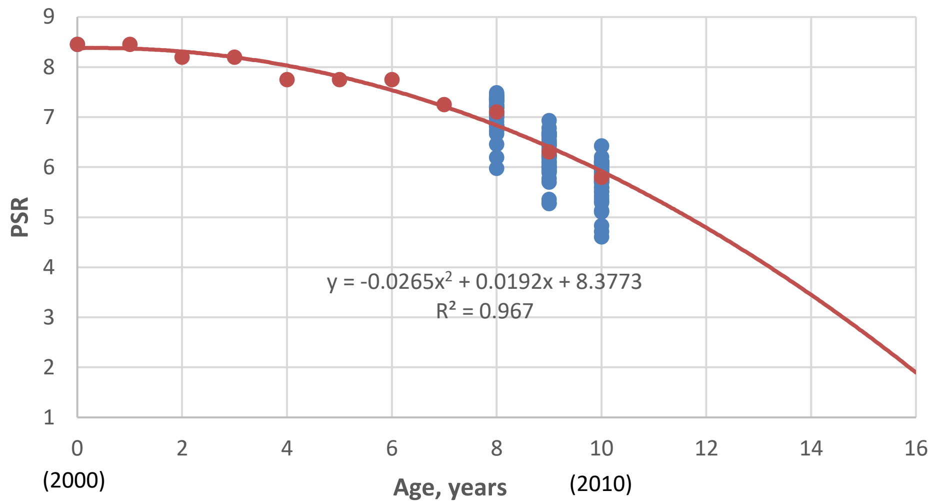


Figure 15. Do-nothing performance curve for CT 101.

Step 4—Compute Expected Service Life of Do-Nothing Case

The baseline age for determining the extension of pavement life provided by the mill-and-thin HMA overlay is the age of the do-nothing curve when it reaches the benefit cutoff value of PSR=4.5. This age is approximately 12.5 years.

Step 5—Compute Expected Service Life of Post-Treatment Case

To convert the pre-treatment PSR ranges to timings, the average PSR immediately before the PPM treatment application was calculated for each timing category, and the age on the do-nothing curve corresponding to that average PSR value was identified. The pre-treatment PSR averages and resulting ages for the three timing categories were as follows:

Pre-Treatment PSR Category	Average Pre-Treatment PSR	Age of Application
PSR > 6.0	6.10	9
5.5 ≤ PSR ≤ 6.0	5.76	10
PSR < 5.5	5.09	11

Next, the post-treatment curves were plotted using the PSR values of each of the 0.1-mi increments comprising each timing category. A fixed-end power model was used to model the curves for each of the three timing scenarios. The resulting models, which can be seen in figure 16, were entered into *OPTime*, along with their respective timings. The extension of pavement life provided by the mill-and-thin HMA overlay treatment at each timing was computed as described earlier for the CT 89 chip seal project.

Step 6—Compute Post-Treatment Case Area

For each timing scenario, the area bounded by the post-treatment performance curve was computed by *OPTime*, as illustrated previously in figure 11.

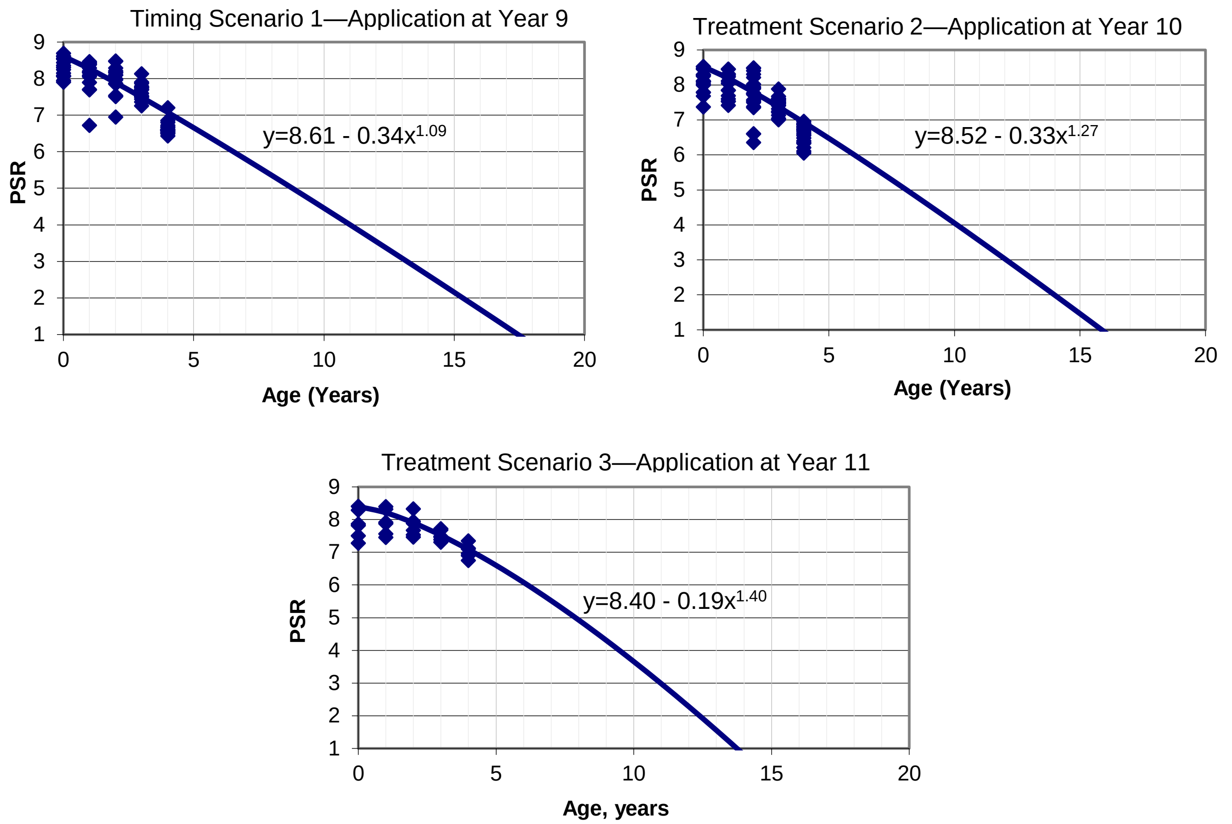


Figure 16. Post-treatment performance curves for the three mill-and-thin HMA overlay timing scenarios.

Step 7—Compute Benefit Associated with Each Condition Indicator

For each timing scenario, the benefit associated with the PSR condition indicator was computed by *OPTime*.

Step 8—Compute Overall Benefit

Since only one condition indicator was used in the analysis, a benefit weighing factor of 100 was assigned to PSR.

Step 9—Compute Life-Cycle Cost

Only the PPM treatment application cost and a subsequent rehabilitation cost were included in this analysis. Based on an estimated in-place treatment cost of \$16.03/yd^2 provided by the DOT, a cost of \$113,000/lane-mi was entered and used in *OPTime*. A cost of \$500,000/lane-mi was used for the rehabilitation activity. A discount rate of 4 percent was used to compute the life-cycle cost for each timing scenario.

Step 10—Determine Most Cost-Effective Timing Scenario

Table 36 summarizes the calculated benefits for each timing scenario. As with the CT 89 chip seal example, the benefits for the PSR condition indicator are the same as the total benefits since it receives the full (100 percent) weighting.

Table 37 summarizes the costs associated with each timing scenario. These include the present-worth treatment costs, rehabilitation costs, and total costs, as well as the EUAC.

Finally, table 38 summarizes the effectiveness index and expected extension of life associated with each timing scenario. This table shows that the timing scenario with the greatest effectiveness index for the mill-and-thin HMA overlay treatment is the 11-year application. The estimated extension of life provided by this application is slightly greater than 7 years, resulting in a total expected service life of almost 20 years.

Table 36. Benefit summary for CT 101 mill-and-thin HMA overlay.

	Benefit Weighting ⇨	**100**
Application Age, yrs	**Total Benefit**	**Composite Index (PSR)**
9	0.54	0.54
10	0.54	0.54
11	0.58	0.58

Table 37. Cost summary for CT 101 mill-and-thin HMA overlay.

Application Age, yrs	Treatment Cost, PW $	User Cost, PW $	Other Maint Cost, PW $	Rehab Cost, PW $	Total Present Worth, $	EUAC, $
9	79,392	N/A	N/A	238,211	317,603	24,264
10	76,339	N/A	N/A	236,341	312,680	23,718
11	73,403	N/A	N/A	230,944	304,346	22,623

Table 38. Effectiveness summary for CT 101 mill-and-thin HMA overlay.

Application Age, yrs	Effectiveness Index	Total Benefit	EUAC, $	Expected Life, yrs	Expected Life Extension, yrs
9	86.51	0.54	24,264	18.9	6.4
10	87.74	0.54	23,718	19.1	6.6
11	100.00	0.58	22,623	19.7	7.2

The use of the Detailed analysis in *OPTime* is very much dependent on having sufficient quality performance data over time. When measured consistently and over a long enough time, the data should clearly reflect the pavements' performance. For agencies without sufficient time-series data, with poor quality data, or which have experienced significant changes in data collection methodologies, it may be necessary to begin benefit-cost analyses using the "Simple" method, which is based primarily on expert opinion.

7. IMPLEMENTATION AND CONTINUOUS IMPROVEMENT

As noted previously, the PPM programs in New England are at different stages of development; half the agencies reported that their programs are well established, while the other half reported being in the early stages of development and implementation. This manual is intended to assist each state, as well as their local agencies, in achieving full implementation. It is also intended to provide insight on ways to continuously improve the PPM program to better address evolving highway pavement needs. These topics are discussed in the following sections.

Implementation

Full implementation of a successful PPM program requires a long-term commitment and financial support from management and a collective set of treatments proven to be cost effective at preserving the condition of the pavement network. In most instances, the latter is necessary before the former can be obtained. Thus, for agencies in the early stages of implementation, the focus has to be on demonstrating a higher net benefit (e.g., BCR, rate of return) for the preventive maintenance approach, as compared to a do-nothing/reconstruction approach or various rehabilitation approaches.

For agencies that have obtained dedicated funding for preventive maintenance, the focus is generally shifted toward (a) integrating the program with pavement management and (b) ensuring that proper techniques are being used to monitor performance, select projects, select treatments, and determine treatment timings. Once this is done and it is shown that at least one PPM treatment is more cost effective than reconstruction and rehabilitation strategies, then full implementation of the PPM program has occurred. At this point, the program can be expanded to include other cost effective treatments and can be improved in terms of processes, data, systems, and staff responsibilities.

The steps for full implementation can be summarized as follows:

1. Review this manual and develop a good understanding of the types of PPM treatments available, the pavement deficiencies addressed by the treatments, the processes for project and treatment selection, and the process for determining treatment timing.
2. Review agency objectives for PPM practices and set new objectives, if appropriate.
3. Identify predominant forms of distress encountered on agency pavements and identify the treatments able to address these distresses. These may be treatments already in use by the agency, treatments being successfully used by other agencies, or promising new treatments.
4. Expand treatment experience by continuing the regular use of existing treatments and trying new treatments on low-risk projects or as part of an experimental test section.
5. Establish condition data collection and analysis procedures for evaluating treatment performance, based on agency pavement monitoring practices and the guidance provided herein. This would include both network-level and project-level condition surveys, smoothness testing, friction testing, and other desired testing, as well as the condition indicators and cost factors to be used.
6. Identify acceptable windows of opportunity (i.e., triggers and thresholds) for each treatment, using the guidance provided herein.

7. Identify relevant project and site factors and establish criteria for performing a final assessment of treatment feasibility.
8. Develop procedures for evaluating treatment cost effectiveness and identifying the preferred treatment, using the guidance provided herein.
9. Apply Steps 5 through 8 for each treatment being evaluated.
10. Report on the progress of implementation and communicate the results in terms of the impact of PPM activities on network condition.

Continuous Improvement

Full program implementation does not mean there is no room for improvements to the process or to the inputs that drive the process. Thus, the work to administer the program on an annual basis and to make it more functional and effective over time is never done.

Because preventive maintenance is so closely tied to pavement management, the areas in which improvement can be sought and obtained are similar. These areas are best illustrated in terms of the life cycle of the pavement and the five phases that comprise the life cycle: (1) planning, (2) design, (3) construction, (4) in-service evaluation, and (5) maintenance and rehabilitation.

As figure 17 shows, the life-cycle process has to be monitored and assessed throughout all five phases by a variety of staff (Zhang et al. 2003). Although there are many years in the life of a pavement in which a rehabilitation or preventive maintenance treatment is not applied, pavement monitoring data are still needed at regular and somewhat frequent intervals in order for planners and programmers to identify future pavement needs and develop long-term pavement plans. For those years where it's determined that a treatment is required, the process of designing and constructing the treatment must take place, thereby activating staff in those areas.

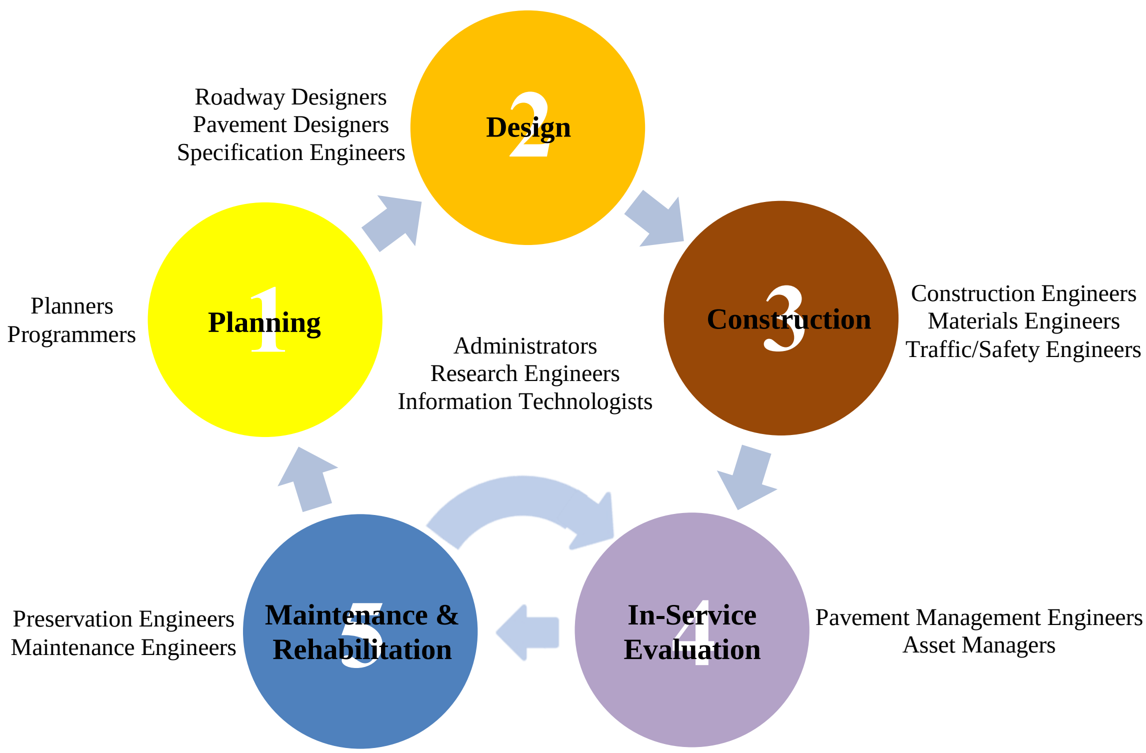


Figure 17. Five basic phases in the highway life cycle (modified from Zhang et al. 2003).

Finally, when considering the entire pavement network, many treatments are scheduled and applied on an annual basis. In this scenario, staff in all the areas contribute, including administrators who oversee each area and the entire program, researchers who identify new materials and technologies that can be used, and information technology (IT) staff who develop improved systems and programs for leveraging and analyzing data.

The following are some of the key inputs that agency staff from each area can provide to continuously improve the PPM program:

- **Planning**: Planners and programmers use information from the PMS, financial, and other systems to develop long-term improvement plans for the highway network. Various strategies and prioritization scenarios are examined under different budget scenarios to identify an optimal long-term plans. Often, the PPM treatment performance and cost data used in this process are general in nature, and thus do not adequately characterize the impacts of preventive maintenance on the system. More reliable and up-to-date performance and cost data, as well as more flexible budgeting tools, can provide a clearer picture of the opportunities for PPM.
- **Design**: Roadway and pavement designers use project-level pavement, traffic, cost, and other data to design and evaluate PPM and rehabilitation treatment alternatives and then select the best one for use. The details of the design, including placement locations and thicknesses, associated quantities, and specifications, are then incorporated into construction plans. To ensure that the right treatment is selected, the best possible estimates of performance and costs for the candidate treatments must be developed using project-specific data. This is often very challenging for treatments that have seen limited use or have generated only a few years of performance data. Likewise, such treatments may have shortcomings in the specifications governing their use. With time and increased practice, more data and information will become available which can lead to improvements in the design phase. As an additional consideration, designers should evaluate the merits of incorporating preventive maintenance into the design process and, if worthwhile, identify a feasible approach for doing so.
- **Construction**: Materials and construction engineers have the responsibility of ensuring that the treatment material(s) satisfies specification and job mix formula requirements, and that the treatment itself is applied according to the project specifications. Because poor construction quality can have a tremendous negative effect on treatment performance, it is not only paramount that quality be closely monitored during construction, but that any shortcomings in the quality testing and inspection process be identified and remedied. It is also important that poor quality on a project be reported to preservation, maintenance, and pavement management engineers, so that treatment performance models do not become biased by bad results.
- **In-Service Evaluation**: Although PPM treatment selection and performance will largely be evaluated using network-level condition data collected by pavement management, it is incumbent upon the PPM Lead to identify the best possible set of condition measures to use in these evaluations. In some cases, the desired measures may not be a part of what is commonly collected or reported in the PMS. While it may not be possible to use some measures, opportunities to use other desired measures should be explored. For instance, only a minor effort may be needed to process raw measurements of a particular distress from the automated survey into useful summary data that are not currently included in the PMS.

- **Maintenance and Rehabilitation**: However the PPM program is structured and administered, the bulk of the responsibility for the program rests with those involved in maintenance and rehabilitation decisions. The PPM Lead, whether a designated preservation engineer, a maintenance engineer, a pavement management engineer, or a design engineer, must command a thorough understanding of what treatments work well and in what circumstances, and translate that understanding into a formal preventive maintenance selection process. Because the status of PPM projects constantly changes and because technologies and business practices also change with time, there is always a need to assess shortcomings in the PPM program and to make improvements. Input on these shortcomings and possible improvements must be sought from personnel in the other key areas.

Placing the right treatment on the right road at the right time is a never-ending challenge that requires long-term dedication and support from nearly all departments within an agency. The involvement of external stakeholders, however, cannot be overlooked. Pavement preservation industry groups, contractors, material producers, researchers, and consultants bring a different knowledge base and set of perspectives to preventive maintenance that are often very valuable to upgrading the process. Engaging and communicating with these stakeholders through preservation-related conferences, meetings, workshops, and general outreach, facilitates the flow of information needed to help steer the PPM program.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). 2015. *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, Second Edition*. AASHTO, Washington, DC.

Applied Pavement Technology, Inc. (APTech). 2015a. *Consideration of Preservation in Pavement Design and Analysis Procedures*. NCHRP Report 810. National Cooperative Highway Research Program, Washington, DC. Online at http://www.trb.org/Main/Blurbs/172941.aspx.

Applied Pavement Technology, Inc. (APTech). 2015b. *Appendices to NCHRP Report 810: Consideration of Preservation in Pavement Design and Analysis Procedures*. National Cooperative Highway Research Program, Washington, DC. Online at http://www.trb.org/Main/Blurbs/172941.aspx.

Connecticut Department of Transportation (ConnDOT). 2011. "Pavement Preservation Manual." Version 10/25/2011. ConnDOT, Newington, CT. Online at http://www.ct.gov/dot/cwp/view.asp?a=1400&q=489424.

Crawford, R. and B. Luce. 2007. Maine DOT Pavement Preservation slide resentation. Northeast Pavement Preservation Partnership Meeting. Online at https://tsp2pavement.pavementpreservation.org/northeast-neppp/annual-meetings/2007-2/.

Daniel, J.S., G.R. Chehab, D. Ayyala, and I.M. Nogaj. 2012. *New England Verification of National Cooperative Highway Research Program (NCHRP) 1-37A Mechanistic-Empirical Pavement Design Guide (MEPG)*. Report No. NETCR87. New England Transportation Consortium, Burlington, VT.

Delatte, N.J. 2014. *Concrete Pavement Design, Construction, and Performance, 2nd Edition*. CRC Press, Boca Raton, FL.

Federal Highway Administration (FHWA). 1997. *Pavement Recycling Guidelines for State and Local Governments*. Publication No. FHWA-SA-98-042. FHWA, Washington, DC. Online at https://www.fhwa.dot.gov/pavement/recycling/98042/index.cfm.

Federal Highway Administration (FHWA). 2006. *Pavement Preservation Compendium II*. FHWA, Washington, DC.

Federal Highway Administration (FHWA). 2014. *Strategic Highway Research Program (SHRP) 2 Solutions: Preserving High-Traffic Roadways*. FHWA Publication HIF-14-019. FHWA, Washington, DC.

Geiger, D. 2005. Pavement Preservation Definitions. Memorandum. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Hallin, J.P., S. Sadasivam, J. Mallela, D.K. Hein, M.I. Darter, H.L. Von Quintus. 2011. *Guide for Pavement Type Selection*. NCHRP Report 703. National Cooperative Highway Research Program (NCHRP), Washington, DC.

Harrington, D. and G. Fick. 2014. *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition. ACPA Publication TB021.03P. American Concrete Pavement Association (ACPA), Washington, DC.

Lima, J. 2015. FHWA SHRP2 R26 Preservation of High Traffic Volume Highways slide presentation. Northeast Pavement Preservation Partnership Meeting. Online at https://tsp2pavement.pavementpreservation.org/northeast-neppp/annual-meetings/2015-2/.

Merritt, D.K., C.A. Lyon, and B.N. Persaud. 2015. *Evaluation of Pavement Safety Performance,* Publication No. FHWA-HRT-14-065. Federal Highway Administration (FHWA), Washington, DC.

Peshkin, D., T.E. Hoerner, and K.A. Zimmerman. 2004. *Optimal Timing of Pavement Preventive Maintenance Treatment Applications*. NCHRP Report 523. National Cooperative Highway Research Program (NCHRP), Washington, DC.

Peshkin, D., K.L. Smith, A. Wolters, J. Krstulovich, J. Moulthrop, and C. Alvarado. 2011a. *Guidelines for the Preservation of High-Traffic Volume Roadways*. SHRP 2 Report S2-R26-RR-2. Strategic Highway Research Program 2, Washington, DC.

Peshkin, D., K.L. Smith, A. Wolters, J. Krstulovich, J. Moulthrop, and C. Alvarado. 2011b. *Preservation Approaches for High-Traffic Volume Roadways*. SHRP 2 Report S2-R26-RR-1. Strategic Highway Research Program 2, Washington, DC.

Smith, K.D., D. Harrington, L. Pierce, P. Ram, and K.L. Smith. 2014. *Concrete Pavement Preservation Guide, 2nd Edition*. Federal Highway Administration, Washington, D.C.

Zhang, Z., R.B. Machemehl, I. Ahson, and R. Smith. 2003. "Definition of the Cradle-to-Grave Pavement Management Process," Research Product 0-4186-P1. Texas Department of Transportation, Austin, TX.

APPENDIX A. PAVEMENT PREVENTIVE MAINTENANCE TREATMENT TECHNICAL PROFILES

CRACK SEALING AND CRACK FILLING

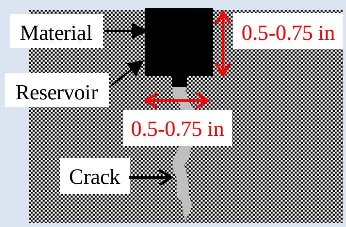
Treatment Description

Crack Filling (used by 2 NE SHAs)**—**Involves the placement of an adhesive material into and/or over non-working cracks (typically longitudinal cold-joint and reflective cracks, edge cracks, and distantly spaced block cracks) at the pavement surface in order to prevent the infiltration of moisture into the pavement structure and reinforce the adjacent pavement. Crack filling operations generally entail minimal crack preparation and the use of lower quality materials.

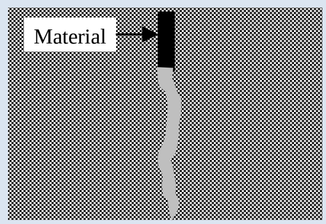
Crack Sealing (used by 6 NE SHAs)**—**Involves the placement of an adhesive material into and/or over working cracks (i.e., those that open and close with temperature changes, such as transverse thermal and reflective cracks, diagonal cracks, and certain longitudinal reflective cracks) at the pavement surface in order to prevent the infiltration of moisture into the pavement structure. Crack sealing operations typically require good crack preparation (i.e., routing or sawing a reservoir over the crack and power cleaning the reservoir) and the placement of high-quality flexible materials (i.e., thermosetting or thermoplastic bituminous materials that soften upon heating and harden upon cooling) into and possibly over the reservoir.

There are many configurations in which crack filler and sealant materials can be placed. Commonly used configurations are illustrated below.

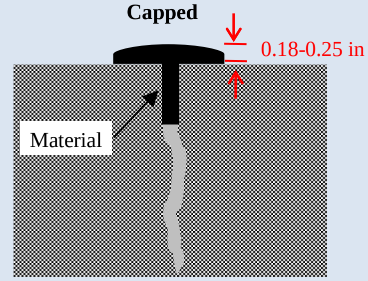
Standard Reservoir and Flush



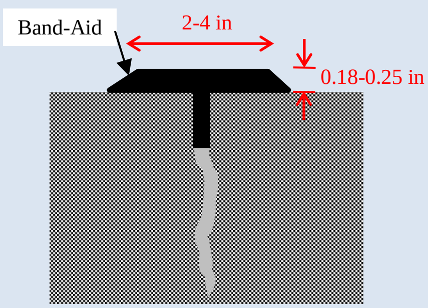
Simple Flush Fill



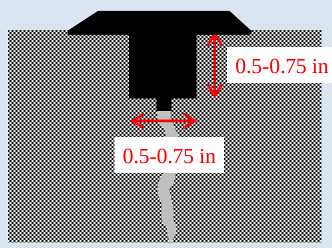
Capped



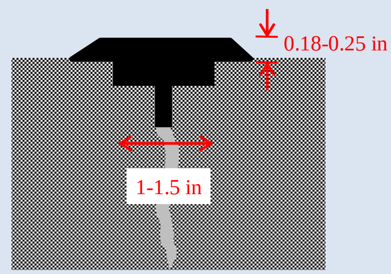
Simple Band-Aid



Standard Recessed Band-Aid



Shallow Recessed Band-Aid



Performance Objectives

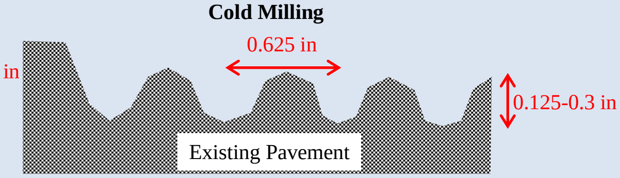
Seal/Waterproof Pavement—Prevent or slow the infiltration of moisture into the pavement surface.
Reduce/Eliminate or Stabilize Surface Defects (Cracking)—Restore the integrity of cracks through reinforcement and stabilization.

<table>
<tr><th colspan="2">PROFILE MILLING AND MICRO MILLING</th></tr>
<tr><td>Treatment Description</td><td>

Profile Milling (used by 4 NE SHAs)—Retexturing and/or reprofiling of the surface of an existing asphalt or composite pavement using a cold milling machine equipped with a fine-toothed, carbide-tipped cutting drum (700 to 1,000 teeth per 12.5-ft wide drum). The depth of surface material removal is typically ≤0.6 in for micromilling and ≤1 in for fine/precision milling. The resulting groove pattern includes a peak-to-valley depth of 0.08 to 0.16 in and an approximate spacing of 0.2 in for micromilling and 0.3 to 0.5 in for fine/precision milling (see figure below).
Standard Cold Milling(used by 3 NE SHAs)—Correction or restoration of the transverse profile (e.g. rut removal) and/or longitudinal profile (e.g., increase smoothness) and/or removal of surface distress of an asphalt or composite pavement using a cold milling machine equipped with a conventional carbide-tipped cutting drum (264 teeth per 12.5-ft wide drum). The depth of surface material removal is generally >1 in but is dictated in part by the depth of rutting and/or other surface distresses. The resulting groove pattern includes an approximate spacing of 0.625 in and a peak-to-valley depth of 0.125 to 0.3 in (see figure below). Since the texture produced by standard cold milling is somewhat rough and noisy, the milled surface is most often accompanied by the application of an asphalt-aggregate seal or HMA overlay.

Profile Milling

Cold Milling



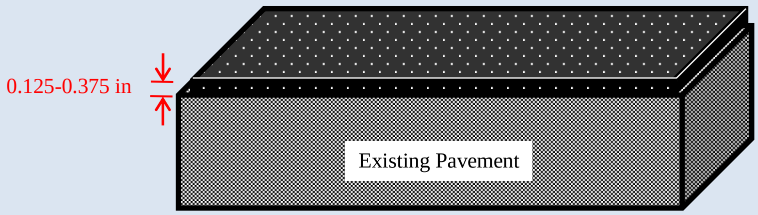
</td></tr>
<tr><td>PerformanceObj ectives</td><td>

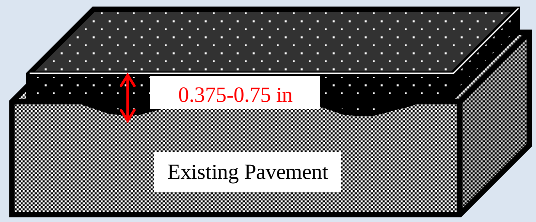
Improve Texture for Friction—Improve surface micro-texture and macro-texture to correspondingly increase friction.
Improve Profile (Surface Drainage and Ride)—Correct minor surface profile irregularities (including stable rutting) and correspondingly improve lateral surface drainage and ride quality.
Improve Texture for Splash/Spray and Hydroplaning Concerns—Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.
Enhance Bond of New Surfacing Layer—Improve macro-texture of existing pavement resulting in greater bonding area for placement of new surfacing and less chance of slippage.

</td></tr>
</table>

<table>
<tr><th colspan="2">SLURRY SEAL</th></tr>
<tr><td>Treatment Description</td><td>Slurry Seal—A mixture of well-graded aggregate (fine sand and mineral filler) and asphalt emulsion that is spread over the entire pavement surface with either a squeegee or spreader box attached to the back of a truck. Thickness application generally ranges between 0.125 and 0.375 in, as determined by the top-size of the aggregate. Slurry seals are effective in sealing low-severity surface cracks, waterproofing the pavement surface, and improving friction at speeds below 30 mi/hr.

Three types of slurry seal are available for use—Type I for parking areas and local roads/streets, Type II for collector roads/streets, and Type III for primary and interstate highways.

Slurry Seal
</td></tr>
<tr><td>Performance Objectives</td><td>Seal/Waterproof Pavement—Prevent or slow the infiltration of moisture into the pavement surface.
Rejuvenate Surface/Inhibit Oxidation—Enrich the hardened/oxidized existing surface and inhibit raveling.
Improve Texture for Friction—Improve surface micro-texture and macro-texture to correspondingly increase friction.</td></tr>
</table>

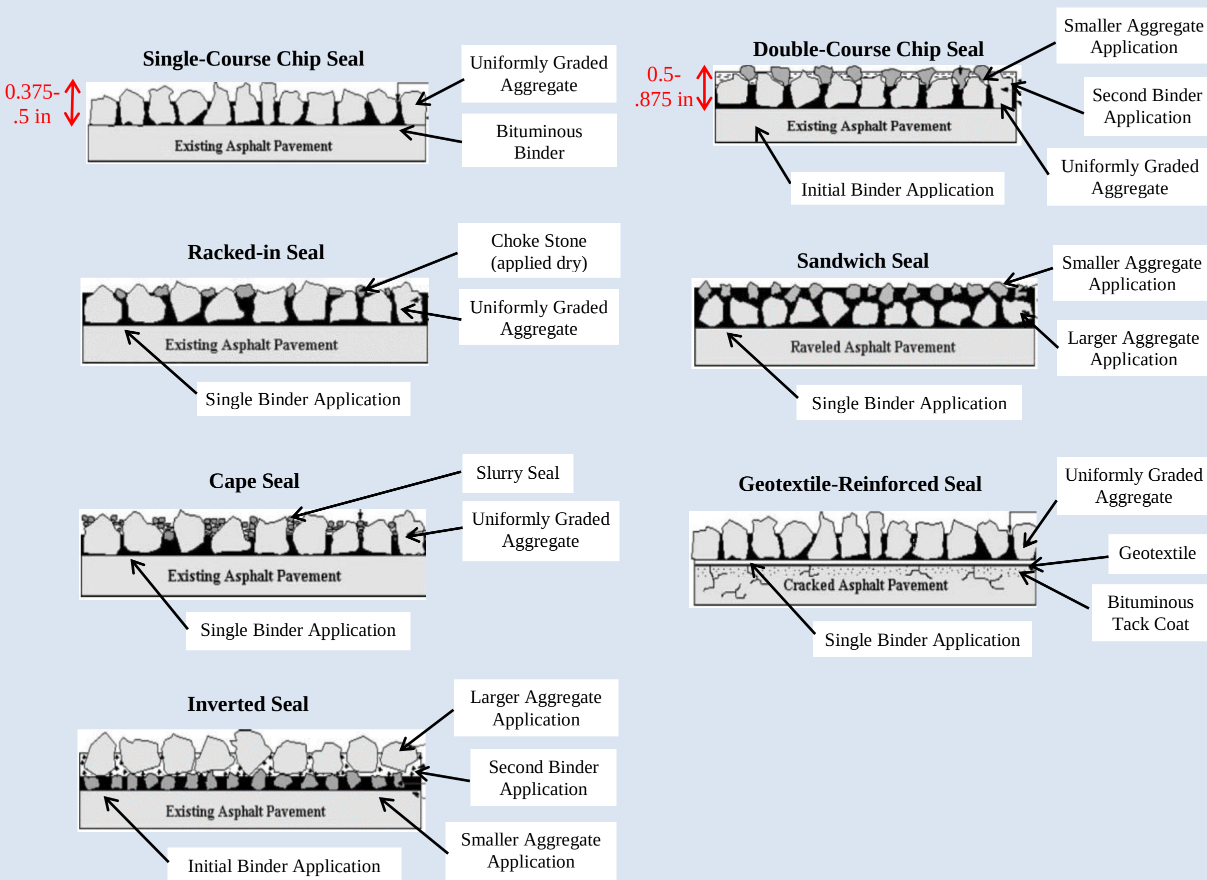
MICRO SURFACING	
Treatment Description	***Micro surfacing (used by 3 NE SHAs)***—A mixture of crushed, well-graded aggregate, mineral filler (portland cement), and polymer-modified emulsified asphalt spread over the full width of pavement with either a squeegee or spreader box. An extension of the slurry seal, micro surfacing is designed with high quality well-graded aggregates and advanced emulsions to allow for a thicker lift application without sacrificing stability. Micro surfacing is used primarily to inhibit raveling and oxidation and is particularly effective at improving surface friction and addressing rutting (up to 1.5 in deep) and surface irregularities through multiple applications. Micro surfacing is usually applied in either a single or double application. The thickness of a single application generally ranges between 0.25 and 0.5 in (thickness is usually 2 or 3 times the top-size stone in the aggregate gradation), while the thickness of a double application generally ranges between 0.375 and 0.75 in. A double application typically involves a rut-filling application or scratch/leveling course followed by a full-lane width surface course. Two types of micro surfacing are available for use—Type II for surface courses on local and collector roads/streets surface courses and for scratch/leveling courses, and Type III for surface courses on primary and interstate highways and for rut-filling and scratch/leveling courses. **Single Micro Surfacing**  **Double Micro Surfacing (w/ rut-filling)** 
Performance Objectives	***Seal/Waterproof Pavement***—Prevent or slow the infiltration of moisture into the pavement surface. ***Rejuvenate Surface/Inhibit Oxidation***—Enrich the hardened/oxidized existing surface and inhibit raveling. ***Improve Texture for Friction***—Improve surface micro-texture and macro-texture to correspondingly increase friction. ***Improve Profile (Surface Drainage and Ride)***—Correct minor surface profile irregularities (including stable rutting) and correspondingly improve lateral surface drainage and ride quality.

CHIP SEAL

Treatment Description

***Chip Seal (used by 3 NE SHAs)*—**A chip seal consists of a sprayed application of asphalt (commonly emulsion, although heated asphalt cement and cutbacks are used as well) to the pavement surface followed by the application of aggregate chips, which are then immediately rolled to achieve 50 to 70 percent embedment. Emulsion-based chip seals include conventional unmodified, high-float, and polymer-modified emulsions. Chip seals can include precoated aggregate chips, with hot asphalt cement typically used for the coating. Chip seals can be applied in a single layer (typically between 0.375 and 0.5 in thick), in multiple layers (e.g., a double chip seal is typically between 0.5 and 0.875 in thick), or in combination with other treatments, such as micro surfacing/slurry seal, which is called a cape seal. Chip seal design variations include the following, which are also illustrated below (Gransberg and James 2005):

- **Racked-in Seal**—Chip seal that is temporarily protected from damage through the application of choke stone that becomes locked in the voids, preventing aggregate particles from dislodging before the binder is cured. Often used in locations where there are large numbers of turning movements.
- **Sandwich Seal (dry-matting)**—Chip seal involving one binder application sandwiched between two separate aggregate applications. Particularly useful for restoring surface texture on raveled surfaces.
- **Inverted Seal (used by 1 NE SHA)**—Inverted double chip seal, in which a smaller-sized aggregate chip seal is placed first, followed by a larger-sized aggregate chip seal. Typically used to correct bleeding.
- **Cape Seal**—Combination of a chip seal and micro surfacing/slurry seal, with the latter treatment placed atop the chip seal typically 4 to 10 days after placement of the chip seal. Primary purposes are the same as a chip seal; the micro surfacing/slurry seal finish increases the life of the chip seal by the enhanced binding of the aggregate chips and it reduces concerns associated with loose chips and a rough surface.
- **Geotextile-Reinforced Seal**—Application of geotextile over a tack coat, followed by application of a single-course chip seal.



Performance Objectives

***Seal/Waterproof Pavement*—**Prevent or slow the infiltration of moisture into the pavement surface.
***Rejuvenate Surface/Inhibit Oxidation*—**Protect pavement surface from further oxidation.
***Reduce/Eliminate or Stabilize Surface Defects*—**Eliminate raveling/weathering and mitigate other surface defects, such as surface cracks and bleeding.
***Improve Texture for Friction*—**Improve surface micro-texture and macro-texture to correspondingly increase friction.
***Improve Profile (Surface Drainage and Ride)*—**Correct minor surface profile irregularities and correspondingly improve (to some extent) lateral surface drainage and ride quality.
***Improve Texture for Splash/Spray and Hydroplaning Concerns*—**Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.

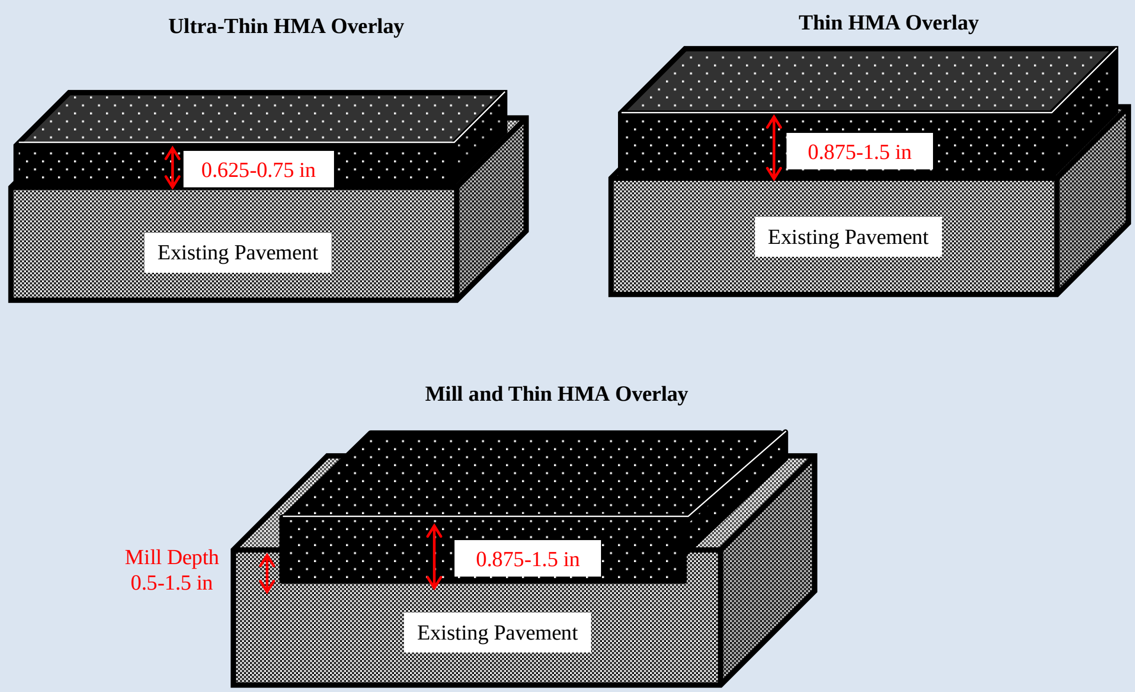
THIN AND ULTRA-THIN HMA OVERLAYS (WITH OR WITHOUT MILLING)

Treatment Description

Thin and Ultra-Thin HMA Overlays (used by 5 NE SHAs)—Composed of asphalt binder and aggregate combined in a central mixing plant and placed with a paving machine in thicknesses ranging from 0.625 to 0.75 in for ultra-thin and 0.875 to 1.5 in for thin. Conventional HMA overlays can be distinguished by their aggregate gradation:

- **Dense-graded**—a well-graded, relatively impermeable mix, intended for general use.
- **Open-graded**—an open-graded, permeable mix designed using only crushed aggregate and a small percentage of manufactured sand.
- **Gap-graded**—a gap-graded mix designed to maximize rut resistance and durability using stone-on-stone contact. Most commonly, this is stone matrix asphalt (SMA).

Additionally, it is recommended to mill the existing pavement surface when surface distresses (e.g., segregation, raveling, or block cracking) are evident; other benefits include improving surface friction, maintaining clearance of overhead structures, and providing an improved bonding surface.



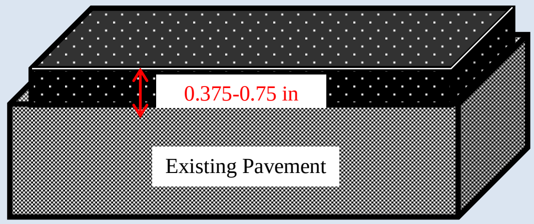
Perf. Objectives

Seal/Waterproof Pavement—Prevent or slow the infiltration of moisture into the pavement surface.
Reduce/Eliminate or Stabilize Surface Defects—Eliminate raveling/weathering and mitigate other surface defects, such as surface cracks and bleeding.
Improve Texture for Friction—Improve micro-texture and macro-texture to correspondingly increase friction.
Improve Profile (Surface Drainage and Ride)—Correct minor surface profile irregularities and correspondingly improve (to some extent) lateral surface drainage and ride quality.
Improve Texture for Pavement/Tire Noise—Improve micro-texture and macro-texture to correspondingly reduce noise.
Improve Texture for Splash/Spray and Hydroplaning Concerns—Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.

<table>
<tr><th colspan="2">ULTRA-THIN BONDED WEARING COURSE</th></tr>
<tr><td>Treatment Description</td><td>

Ultra-Thin Bonded Wearing Course (UTBWC) (used by 5 NE SHAs)—Also known as an ultra-thin friction course, an ultra-thin bonded wearing course may be used as an alternative treatment to chip seals, micro surfacing, or thin HMA overlays. This consists of a gap-graded, polymer-modified HMA layer (typically between 0.375 and 0.75 in thick) placed on a tack coat (heavy, polymer-modified emulsified asphalt). It is effective at treating minor surface distresses and increasing surface friction. UTBWC was originally developed as a proprietary product called NovaChip®, but since the patent expired, several State transportation departments have developed their own specification for this treatment (Merritt et al. 2015).

Ultra-Thin Bonded Wearing Course



</td></tr>
<tr><td>Performance Objectives</td><td>

Seal/Waterproof Pavement—Prevent or slow the infiltration of moisture into the pavement surface.
Rejuvenate Surface/Inhibit Oxidation—Protect pavement surface from further oxidation.
Reduce/Eliminate or Stabilize Surface Defects—Eliminate raveling/weathering and mitigate other surface defects, such as surface cracks and bleeding.
Improve Texture for Friction—Improve micro-texture and macro-texture to correspondingly increase friction.
Improve Profile (Surface Drainage and Ride)—Correct minor surface profile irregularities and correspondingly improve (to some extent) lateral surface drainage and ride quality.
Improve Texture for Pavement/Tire Noise—Improve micro-texture and macro-texture to correspondingly reduce noise.
Improve Texture for Splash/Spray and Hydroplaning Concerns—Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.

</td></tr>
</table>

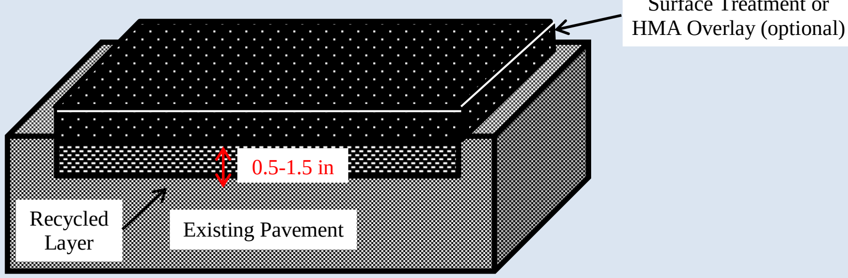
HOT IN-PLACE RECYCLING

Treatment Description

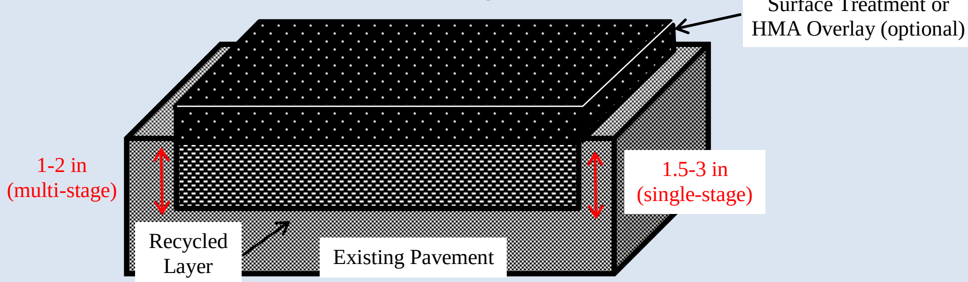
Hot In-Place Recycling (HIR) (used by 2 NE SHAs)—As a preservation treatment, hot in-place recycling (HIR) corrects surface distresses within the top 2 in of an existing HMA pavement by softening the surface material with heat, mechanically loosening/scarifying it and mixing it with recycling agent, aggregate, rejuvenators, and/or virgin asphalt. HIR consists of three different techniques:

- **Surface Recycling**—pavement surface (typically top 0.5 to 1.5 in) is heated, loosened/scarified, combined with new asphalt, and re-laid for the purpose of minor mix improvement/modification. In single-pass surface recycling (low volume roads), the recycled mix is re-laid and serves as the final wearing surface. In double-pass surface recycling (moderate to high volume roads), an HMA overlay or a surface treatment is applied over the recycled surface.
- **Remixing**—pavement is heated, loosened/scarified, combined with virgin aggregate and new asphalt (and/or new HMA), and re-laid for significant mix improvement/ modification and/or modest pavement strengthening. In single-stage recycling, the treatment depth is generally between 1.0 and 2.0 in. In multi-stage recycling, the treatment depth is typically between 1.5 and 3.0 in, and is carried out in two to four sequential layers. The recycled mix can serve as the final wearing surface (low-volume roads) or can serve as a base for an HMA overlay or surface treatment (moderate to high volume roads).
- **Repaving**—pavement surface is heated, loosened/scarified, combined with new asphalt, and re-laid in tandem with an HMA overlay for the purposes of pavement strengthening and restoration of surface profile and/or friction. In the single-pass method, the hot recycled mix is screeded, a new HMA mix is place on top of the uncompacted recycled layer, and the two layers are compacted as one thick, thermally bonded lift. In the multiple-pass method, the hot recycled mix is screeded, new HMA mix is placed on the uncompacted recycled layer using a separate paving machine, and the two layers are compacted as one thick, thermally bonded lift. Repaving is surface recycling with an integrally applied thermally bonded overlay.

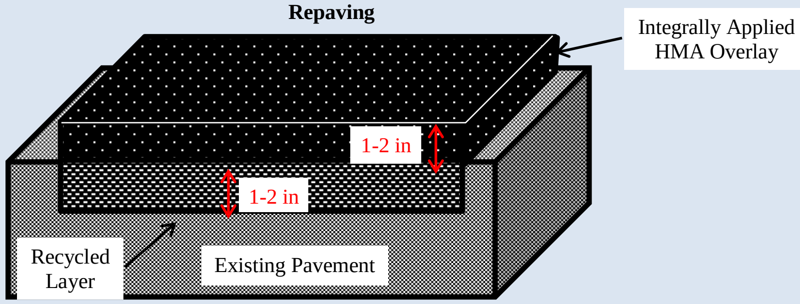
Surface Recycling



Remixing

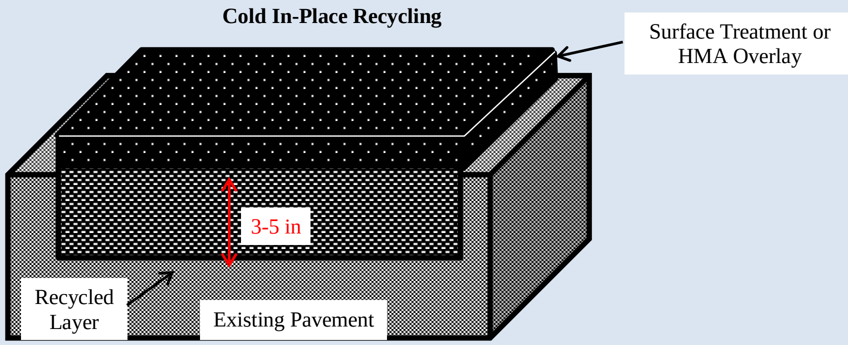


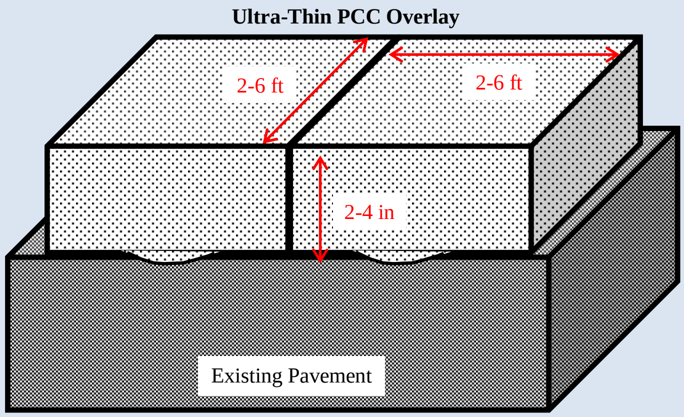
Repaving

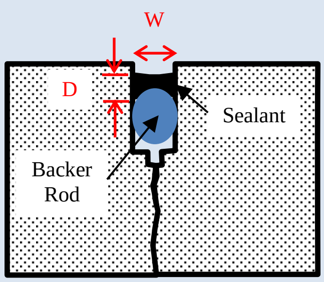
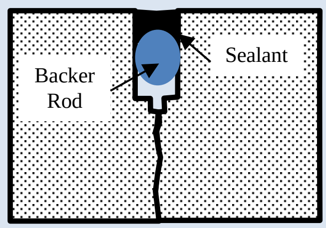
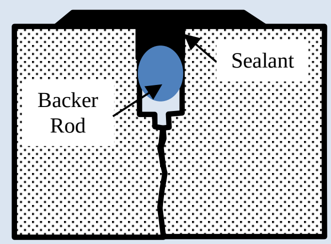


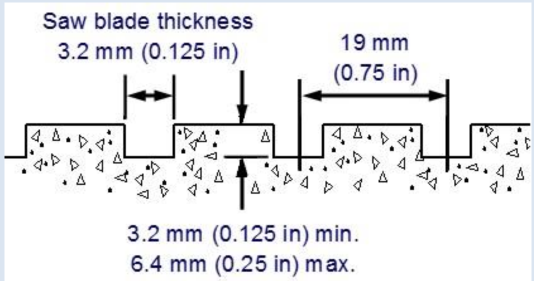
Performance Objectives

Rejuvenate Surface/Inhibit Oxidation—Enrich or remove/replace the hardened/oxidized existing surface.
Reduce/Eliminate or Stabilize Surface Defects—Eliminate raveling/weathering and eliminate or mitigate other surface defects, such as surface cracks and bleeding.
Improve Texture for Friction—Improve micro-texture and macro-texture to correspondingly increase friction.
Improve Profile (Surface Drainage and Ride)—Correct surface profile irregularities (including stable rutting) and correspondingly improve lateral surface drainage and ride quality.

COLD IN-PLACE RECYCLING	
Treatment Description	***Cold In-Place Recycling (CIR) (used by 2 NE SHAs)—***A process that consists of milling and sizing reclaimed asphalt pavement (RAP) and mixing in-place the RAP with recycling additive and new aggregate (either in the milling machine's cutting chamber or in a mix paver) to produce a recycled cold mix, which is then re-laid and compacted as a new base course. As a preservation treatment, CIR is primarily used to restore profile/cross-slope and/or mitigate surface and other upper layer distresses. It's depth of application in a preservation capacity is limited to 3 to 4 in. For moderate- to high-volume roadways, the CIR recycled layer is accompanied by an HMA overlay or surface treatment. 
Performance Objectives	***Rejuvenate Surface/Inhibit Oxidation—***Enrich or remove/replace the hardened/oxidized existing surface. ***Reduce/Eliminate or Stabilize Surface Defects—***Eliminate raveling/weathering and eliminate or mitigate other surface defects, such as surface cracks and bleeding. ***Improve Texture for Friction—***Improve micro-texture and macro-texture to correspondingly increase friction. ***Improve Profile (Surface Drainage and Ride)—***Correct surface profile irregularities (including stable rutting) and correspondingly improve lateral surface drainage and ride quality.

ULTRA-THIN PCC OVERLAY	
Treatment Description	***Ultra-Thin PCC Overlay (used by no NE SHAs)***—Involves the placement of a thin (2 to 4 in) PCC layer, with slab dimensions between 2 and 6 ft, over an existing AC-surfaced pavement. The primary purpose of an ultra-thin PCC overlay is to eliminate surface distresses (e.g., raveling and cracking), correct various forms of deformation (e.g., corrugations and rutting), and improve friction and smoothness (Smith et al. 2014). 
Performance Objectives	***Reduce/Eliminate or Stabilize Surface Defects***—Eliminate raveling/weathering and mitigate other surface defects, such as surface cracks and bleeding. ***Improve Texture for Friction***—Improve micro-texture and macro-texture to correspondingly increase friction. ***Improve Profile (Surface Drainage and Ride)***—Correct surface profile irregularities (including stable rutting) and correspondingly improve lateral surface drainage and ride quality.

JOINT RESEALING AND CRACK SEALING	
Treatment Description	***Joint Resealing and Crack Sealing (used by 3 NE SHAs)***—Joint resealing and crack sealing of PCC pavements prevents moisture and incompressible materials from infiltrating the pavement structure. This helps to slow or minimize the development of moisture-related distresses (such as pumping or faulting) and to prevent the occurrence of spalling, blowups, and other pressure-related distresses that might be caused by incompressible materials collecting in the joints (Smith et al. 2014). Joint resealing consists of removing existing deteriorated transverse and/or longitudinal joint sealant (if present), refacing and pressure-cleaning the joint sidewalls, and installing new sealant material. The three primary configurations for joint resealing are shown below. Liquid sealants generally require the installation of backer rod to (a) prevent the sealant from seeping down into the joint and (b) provide a shape factor (i.e., ratio of sealant width [W] to sealant depth [D]) that minimizes the stresses that develop within the sealant and along the sealant/pavement interface (Smith et al. 2014). Typical shape factors are 1:1 for polymerized/rubberized asphalt sealants and polysulfide/polyurethane sealants and 2:1 for silicone sealants. The overbanded configuration is perceived to perform better because of the additional bonding area, but is subject to traffic wear on high-trafficked pavements or damage by snowplow blades, and can negatively affect ride quality (Smith et al. 2014). Crack sealing consists of sawing, power cleaning, and sealing cracks (typically transverse, longitudinal, and corner-break cracks wider than 0.125 in) in concrete pavement using high-quality sealant materials. It is primarily intended to slow the rate of deterioration by preventing the intrusion of incompressible materials and reducing the infiltration of water into the crack. **Recessed Joint Reseal Configuration**  **Flush-Filled Joint Reseal Configuration**  **Overbanded Joint Reseal Configuration** 
Performance Objectives	***Seal/Waterproof Pavement***—Prevent or slow the infiltration of moisture into the pavement surface. ***Prevent Intrusion of Incompressibles***—Prevent sand, dirt, pebbles, and other small particles from penetrating into the crack/joint and resulting in spalling when slabs expand in high temperatures.

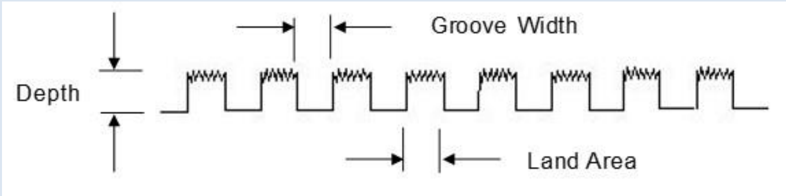
DIAMOND GROOVING	
Treatment Description	***Diamond Grooving (used by no NE SHAs)***—Consists of cutting narrow, discrete grooves into the pavement surface, which helps to reduce hydroplaning, vehicle splash and spray, and wet-weather crashes. The grooves may be created in the pavement either longitudinally (in the direction of traffic) or transversely. Longitudinal grooving is more commonly done on in-service roadways because it is less intrusive to adjacent traffic lane operations; transverse grooving provides a more direct drainage route and contributes to braking forces, but may also contribute to noise emissions. Typical groove dimensions are shown in the figure below (Smith et al. 2014). **Diamond Grooving Dimensions** 
Performance Objectives	***Improve Texture for Friction—***Improve macro-texture to correspondingly increase friction. ***Improve Texture for Pavement/Tire Noise—***Improve micro-texture and/or macro-texture to correspondingly reduce noise. ***Improve Texture for Splash/Spray and Hydroplaning Concerns—***Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.

DIAMOND GRINDING

Treatment Description

Diamond Grinding (used by 2 NE SHAs)—Consists of removing a thin layer of concrete (usually between 0.12 and 0.25 in) from the pavement surface, using special equipment fitted with a series of closely spaced, diamond-tipped saw blades that form longitudinal grooves/channels in the pavement surface. Diamond grinding removes joint faulting and other surface irregularities, thereby restoring a smooth-riding surface while also increasing surface friction and reducing noise emissions. Typical groove dimensions are shown in the figure and table below (Smith et al. 2014).

Diamond Grinding Dimensions



	Range	Hard Aggregate	Soft Aggregate
Groove Width, in	0.09-0.15	0.09-0.15	0.09-0.15
Land Area, in	0.07-0.13	0.07-0.11	0.09-0.13
Depth, in	0.04-0.12	0.04-0.12	0.04-0.12
No. of Blades, per ft	50-60	53-60	50-54

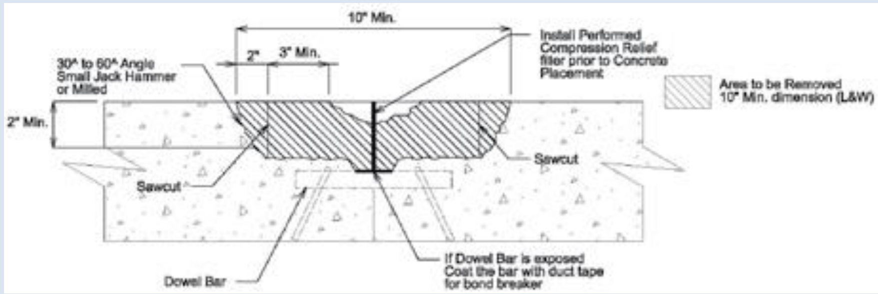
Performance Objectives

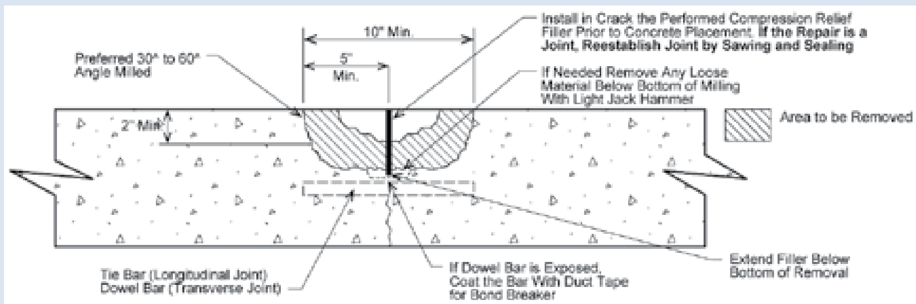
Improve Texture for Friction—Improve micro-texture and macro-texture to correspondingly increase friction.
Improve Profile (Surface Drainage and Ride)—Correct surface profile irregularities, such as faulted joints/cracks and curled/warped slabs, and correspondingly improve ride quality and lateral and longitudinal surface drainage.
Improve Texture for Pavement/Tire Noise—Improve micro-texture and/or macro-texture to correspondingly reduce noise.
Improve Texture for Splash/Spray and Hydroplaning Concerns—Improve macro-texture to correspondingly reduce splash/spray generation and/or vehicle hydroplaning potential.

PARTIAL-DEPTH AND FULL-DEPTH REPAIR

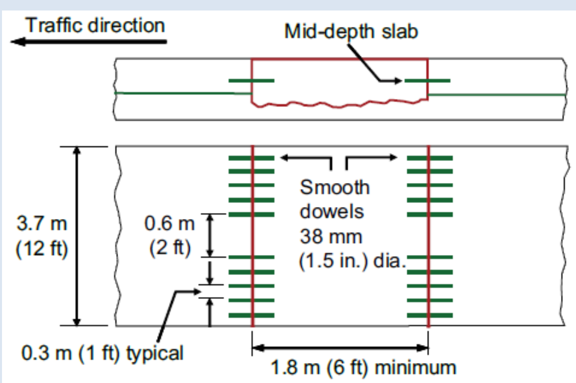
Treatment Description

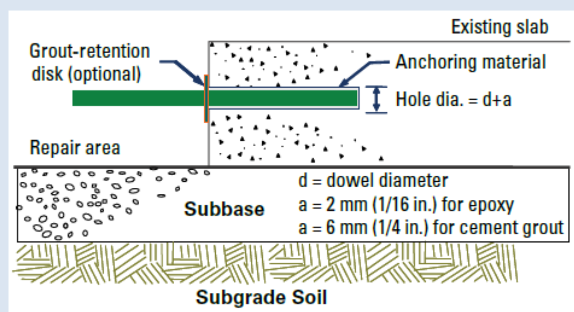
Partial-Depth Repair (PDR) (used by 3 NE SHAs)—Form of patching that addresses small, shallow areas of deteriorated PCC. These deteriorated areas are removed and replaced with an approved repair material, thereby restoring or maintaining the serviceability of the pavement. Partial-depth repairs should be used to correct joint spalling and other surface distresses that are limited to the upper third of the slab. Typical partial-depth repair details are illustrated below (Smith et al. 2014).





Full-Depth Repair (FDR) (used by 2 NE SHAs)—Cast-in-place or precast concrete repairs that extend through the full thickness of the existing slab, requiring full-depth removal and replacement of full lane-width areas. Full-depth repairs are effective at correcting slab distresses that extend beyond one-third the pavement depth, such as longitudinal and transverse cracking, corner breaks, and deep joint spalling. Typical full-depth repair details are illustrated below (Smith et al. 2014)





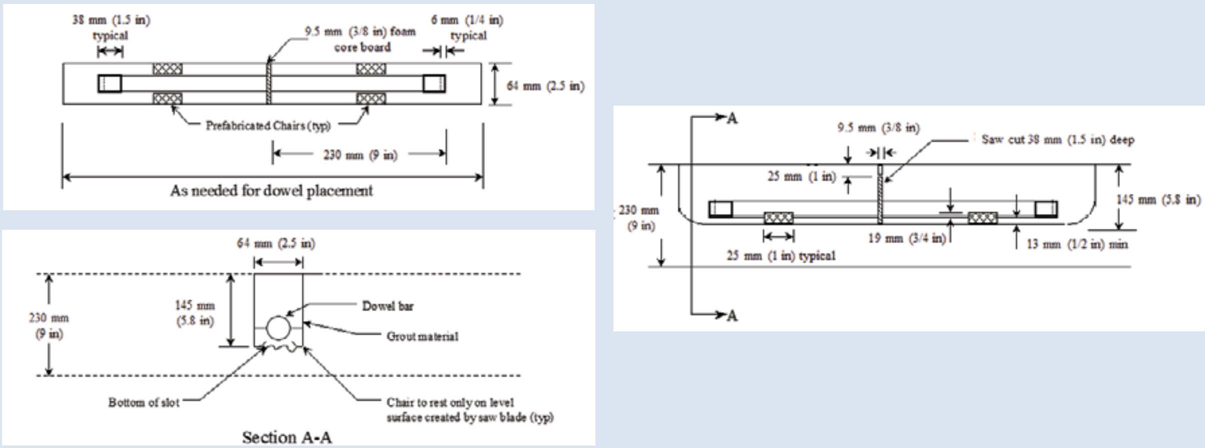
Performance Objectives

Seal/Waterproof Pavement—Prevent or slow the infiltration of moisture into the pavement surface.
Prevent Intrusion of Incompressibles—Prevent sand, dirt, pebbles, and other small particles from penetrating into the crack/joint and resulting in spalling when slabs expand in high temperatures.
Improve Profile (Surface Drainage and Ride)—Correct surface profile irregularities, such as faulted joints/cracks and curled/warped slabs, and correspondingly improve ride quality and lateral and longitudinal surface drainage.

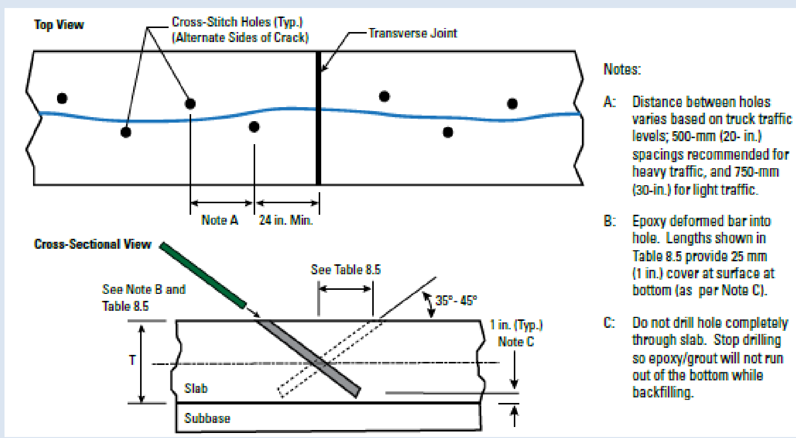
DOWEL BAR RETROFIT AND CROSS-STITCHING

Treatment Description

Dowel Bar Retrofit (DBR) (used by no NE SHAs)—Consists of placing mechanical load transfer devices (i.e., dowel bars) across joints or cracks in an existing jointed PCC pavement. The process entails cutting slots (3 to 4 per wheelpath) across a joint or crack, removing the concrete within the slots, inserting the dowel bars into the slots, and placing and consolidating patching material around the bars in the slots. The dowel bars increase the load transfer capacity of the joint or crack, thereby reducing deflections and decreasing the potential for the development of pumping, faulting, and corner breaks. Poor load transfer at existing joints or cracks may result from an undoweled jointing situation (in which excessive joint or crack openings leads to reduced aggregate interlock), corrosion of existing load transfer devices, and poor pavement drainage resulting in loss of underlying support (Smith et al. 2014). Typical DBR details are illustrated below (Smith et al. 2014).



Cross-Stitching—Repair technique for longitudinal cracks/joints in which deformed tie bars are inserted and grouted into angled (35° typically) drilled holes across the crack/joint. The purpose of cross-stitching is to maintain aggregate interlock and provide added reinforcement and strength to minimize vertical and horizontal movement or widening at the crack/joint (Smith et al. 2014). Typical cross-stitching details are presented below (Smith et al. 2014).



Angle	Slab Thickness, mm (in)							
	200 (8)	225 (9)	250 (10)	275 (11)	300 (12)	325 (13)	350 (14)	375 (15)
Distance from Crack to Hole, mm (in)								
35°	145 (5.75)	165 (6.50)	180 (7.25)	195 (7.75)	210 (8.50)	—	—	—
40°	—	—	—	165 (6.50)	180 (7.25)	195 (7.75)	205 (8.25)	—
45°	—	—	—	—	150 (6.00)	165 (6.50)	175 (7.00)	190 (7.50)
Length of Bar, mm (in)								
35°	240 (9.50)	275 (11.00)	315 (12.50)	365 (14.50)	400 (16.00)	—	—	—
40°	—	—	—	315 (12.50)	350 (14.00)	400 (16.00)	465 (18.50)	—
45°	—	—	—	—	300 (12.00)	350 (14.00)	415 (16.50)	450 (18.00)
Diameter of Bar, mm (in)								
	19 (0.75)	19 (0.75)	19 (0.75)	19 (0.75)	19 (0.75)	25 (1.0)	25 (1.0)	25 (1.0)

Performance Objectives

Improve Profile (Surface Drainage and Ride)—Increase load transfer efficiency and reduce potential for crack/joint faulting and growth, and correspondingly improve long-term ride quality and (to some extent) lateral and longitudinal surface drainage.

APPENDIX B. PAVEMENT CONDITION AND DISTRESSES

Overall Pavement Condition

Figure 18 illustrates a range of overall condition levels for asphalt/composite and concrete pavements. PPM is generally most suitable for pavements in good condition; however, some treatments can be successfully applied to pavements in fair condition.

Figure 18. Example illustrations of overall pavement condition (Harrington and Fick 2014).

Pavement Distresses

The presence of distresses and the severity level and extent of those distresses are key to determining if a PPM treatment is appropriate or whether major rehabilitation is necessary. In cases where a manual pavement survey is needed to supplement past network-level automated surveys, every effort should be made to evaluate the same distresses covered in the automated survey and use the same basic criteria for measuring the severity and quantifying the extent of the distresses. If certain distresses are not included in the automated survey but would add value to determining the suitability of PPM treatments, then those should be evaluated as well.

In the FHWA's long-term pavement performance (LTPP) program, a detailed distress survey procedure and standardized definitions are available (Miller and Bellinger 2003). That document describes and illustrates the appearance of each distress type at different severity levels, and specifies the standard units in which the distress is measured. Another useful document for evaluating pavement distress is the pavement condition index (PCI) procedure as defined in ASTM D 6433-11, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*. In addition to describing how to identify and quantify distress severity levels, it provides the procedure for computing the overall distress index, PCI.

Examples of a few of the more common distress types for asphalt/composite and concrete pavements are provided in tables 39 and 40, respectively. These tables also briefly discuss the applicability of PPM for addressing the distresses.

Table 39. Asphalt/composite pavement distresses and applicability of PPM.

Distress	Example Illustration	Applicability of PPM
Alligator Cracking		Generally <u>not</u> applicable. However, isolated areas of cracking may be treated or repaired separately prior to applying a particular PPM treatment that addresses other deficiencies. Also, thicker/deeper treatments may be acceptable for more extensive areas of low-severity cracking.
Block Cracking		Applicable for most combinations of severity and extent.

Distress	Example Illustration	Applicability of PPM
Edge Cracking		Applicable. However, extensive amounts of high-severity edge cracking may be better addressed through rehabilitation.
Longitudinal WP Cracking		Generally <u>not</u> applicable. However, isolated areas of cracking may be treated separately prior to applying a particular PPM treatment that addresses other deficiencies. Also, thicker/deeper treatments may be acceptable for more extensive areas of low-severity cracking.
Longitudinal Non-WP Cracking		Applicable for all severity levels. However, extensive amounts of high-severity longitudinal cracking, such as at the centerline joint, may be better addressed through localized repairs.
Raveling/ Weathering		Applicable for most combinations of severity and extent.

Distress	Example Illustration	Applicability of PPM
Rutting		Applicable for most combinations of severity and extent, provided that the rutting is primarily due to densification or abrasion/wear. Some PPM treatments may be acceptable for mix instability rutting if the problem is confined to the top 2 or 3 in of the surface.
Transverse Thermal Cracking		Applicable for most combinations of severity and extent.

Table 40. Concrete pavement distresses and applicability of PPM.

Distress	Example Illustration	Applicability of PPM
Corner Breaks		Generally <u>not</u> applicable. However, isolated corner breaks may be patched or repaired as part of a broader PPM treatment that addresses other deficiencies.
Durability ("D") Cracking		Generally <u>not</u> applicable. However, isolated areas of "D" cracking may be treated with full-depth repair as part of a broader PPM treatment that addresses other deficiencies.
Joint Faulting		Applicable for most combinations of severity and extent. If rate of faulting development is high, other treatments may be necessary to slow the re-occurrence of faulting.
Joint Spalling		Applicable for all severity levels. However, extensive amounts of medium- and high-severity spalling may be better addressed through rehabilitation.
Joint Seal Damage		Applicable for all combinations of severity and extent.

Distress	Example Illustration	Applicability of PPM
Scaling		Applicable for all combinations of severity and extent.
Transverse Cracking		Applicable for low-severity cracking and possibly medium-severity cracking. Isolated cracked slabs may be treated with full-depth repair as part of a broader PPM treatment that addresses other deficiencies.

APPENDIX C. PAVEMENT CONDITION SURVEY FORMS

Asphalt and Composite Pavement Distress Survey Form (Detailed)

Surveyor(s): Survey Date: Temperature:
Location (route/road): Direction: From/To MP:
From/To Description: Segment Length:

Distress Category	Distress Type	Rating Criteria and Severity Level Descriptions	Severity Level Low	Severity Level Medium	Severity Level High
Surface Distress	Bleeding/Flushing	Extent: Record surface area affected for all severity levels combined			
	Polishing	Extent: Record surface area affected for all severity levels combined			
	Raveling/Weathering	Extent: Record surface area affected at each severity level *Low: Loss of fine aggregate* *Med: Loss of fine aggregate and some coarse aggregate* *High: Loss of coarse aggregate*			
	Water Bleeding/ Pumping	Extent: Record number of occurrences and length of affected pavement for all severity levels combined			
Deformation Distress	Bumps/Sags	Extent: Record number of bumps/sags at each severity level *Low: <0.25 in average depth* *Med: ≥0.25 and ≤1 in average depth* *High: >1 in average depth*			
	Corrugations and Shoving	Extent: Record surface area affected at each severity level *Low: <0.25 in average depth* *Med: ≥0.25 and ≤1 in average depth* *High: >1 in average depth*			
	Patch/Patch Deterioration	Extent: Record number of patches and surface area affected at each severity level *Low: Minor or no distress in patches, with rutting ≤0.25 in (no pumping)* *Med: Moderately distressed patches or rutting 0.25 to 0.5 in (no pumping)* *High: Severely distressed patches including rutting >0.5 in (possible pumping)*			
	Potholes	Extent: Record number of potholes and surface area affected at each severity level *Low: Depth < 1 in* *Med: Depth ≥ 1 in and ≤ 2 in* *High: Depth > 2 in*			
	Rutting	Extent: Record maximum rut depth in each wheelpath on 50-ft intervals			
Cracking Distress	Block Cracking	Extent: Record surface area affected at each severity level *Low: Cracks with average width <0.25 in or sealed cracks with sealant in good condition* *Med: Cracks with average width between 0.25 and 0.75 in, or cracks with average width < 0.75 in and accompanied by adjacent low-severity cracks* *High: Cracks with average width > 0.75 in, or cracks with average width < 0.75 in and accompanied by adjacent moderate to high-severity cracks*			
	Alligator Cracking	Extent: Record surface area affected at each severity level *Low: Area of cracks with no or only a few interconnection, cracks not spalled or sealed, no pumping* *Med: Interconnected cracks forming complete pattern, cracks may be slightly spalled and/or sealed, no pumping* *High: Interconnected cracks forming complete pattern, cracks moderately to severely spalled, loose or missing pieces, cracks may be sealed, pumping possible*			
	Edge Cracking	Extent: Record length of pavement edge affected at each severity level *Low: Cracks with no breakup or loss of material* *Med: Cracks with some breakup or loss of material for ≤10% of length* *High: Cracks with considerable breakup and loss of material for >10% of length*			
	Longitudinal Wheelpath Cracking	Extent: Record length of cracking affected at each severity level *Low/Med/High: Same as block cracking (above)*			
	Longitudinal Non-Wheelpath Cracking[1]	Extent: Record length of cracking affected at each severity level *Low/Med/High: Same as block cracking (above)*			
	Transverse Thermal Cracking[2]	Extent: Record number and length of cracks at each severity level *Low/Med/High: Same as block cracking (above)*			

[1] For composite pavement, longitudinal joint reflection cracking.
[2] For composite pavement, transverse joint reflection cracking.

Predominant Distresses: (1) (2) (3)

Drainage Condition Notes (e.g., edge drains, ditches, inlets, pavement and shoulder cross-slopes):

Material-Related Distress Notes (e.g., asphalt stripping):

Ride Quality: Excellent Good Fair Poor Very Poor

Concrete Pavement Distress Survey Form (Detailed)

Surveyor(s): Survey Date: Temperature:
Location (route/road): Direction: From/To MP:
From/To Description: Segment Length:

Distress Category	Distress Type	Rating Criteria and Severity Level Descriptions	Severity Level Low	Medium	High
Surface Distress	Map Cracking and Scaling (non-ASR)	Extent: Record number of occurrences and surface area affected for all severity levels combined			
	Polished Aggregate	Extent: Record surface area affected for all severity levels combined			
Joint Deficiencies	Longitudinal Joint Seal Damage	Extent: Record number of longitudinal joints that are sealed and total length of joints with joint seal damage			
	Transverse Joint Seal Damage	Extent: Record whether transverse joints have been sealed and, if so, record number of sealed joints at each severity level *Low: Damage over <10% of joint length* *Med: Damage over 10 to 50% of joint length* *High: Damage over >50% of joint length*			
	Longitudinal Joint Spalling	Extent: Record length of spalling at each severity level *Low: Spalls < 3 in wide with loss of material, or spalls with no loss of material and no patching* *Med: Spalls 3 to 6 in wide, with loss of material* *High: Spalls >6 in wide with loss of material or is broken into ≥2 pieces or contains patch material*			
	Transverse Joint Spalling	Extent: Record number of joints affected and length of spalling at each severity level *Low: Same as longitudinal joint spalling (above)* *Med: Same as longitudinal joint spalling (above)* *High: Same as longitudinal joint spalling (above)*			
Cracking Distress	Corner Breaks	Extent: Record number of corner breaks at each severity level *Low: Crack not spalled for >10% of length, no faulting, and corner piece not broken into ≥2 pieces and has no loss of material and no patching* *Med: Crack spalled at low severity for >10% of length, or faulting <0.5 in, and corner piece broken into ≥2 pieces* *High: Crack spalled at medium to high severity for >10% of length, or faulting ≥0.5 in, or corner piece broken into ≥2 pieces or contains patching*			
	Durability Cracking	Extent: Record number of slabs and surface area affected at each severity level *Low: Cracks are tight, with no loose/missing pieces and no patching* *Med: Cracks are well-defined and some spalls are loose or displaced* *High: Cracks are well-developed with significant amount of loose/missing pieces*			
	Longitudinal Cracking	Extent: Record length of cracking at each severity level *Low: Crack width <0.125 in with no spalling or faulting, or well-sealed* *Med: Crack width 0.125 to 0.5 in or with faulting ≤0.5 in* *High: Crack width >0.5, or faulting >0.5 in*			
	Transverse Cracking	Extent: Record number and length of cracking at each severity level *Low: Crack width <0.125 in with no spalling or faulting, or well-sealed* *Med: Crack width 0.125 to 0.25 in or with spalling <0.125 in, or with faulting ≤0.25 in* *High: Crack width >0.25 or with spalling ≥3 in, or faulting >0.25 in*			
Miscellaneous Distress	Blowups	Extent: Record number of blowups for all severity levels combined			
	Transverse Joint/ Crack Faulting	Extent: Record faulting depth in outside wheelpath on specified intervals			
	Patch/Patch Deterioration	Extent: Record number of patches and surface area affected at each severity level (and record patch material type) *Low: Minor or no distress in patches, with no faulting (no pumping)* *Med: Moderately distressed patches, with faulting or settlement ≤0.25 in (no pumping)* *High: Severely distressed patches, or faulting or settlement >0.25 in (possible pumping)*			
	Water Bleeding/ Pumping	Extent: Record number of occurrences and length of affected pavement for all severity levels combined			

Predominant Distresses: (1) (2) (3)

Drainage Condition Notes (e.g., edge drains, ditches, inlets, pavement and shoulder cross-slopes):

Material-Related Distress Notes (e.g., alkali-silica reactivity [ASR]):

Ride Quality: Excellent Good Fair Poor Very Poor