REPORT S2-R26-RR-2

Guidelines for the Preservation of High-Traffic-Volume Roadways

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STRATEGIC HIGHWAY RESEARCH PROGRAM

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Guidelines for the Preservation of High-Traffic-Volume Roadways

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The research reported on herein was performed by Applied Pavement Technology, Inc., supported by Fugro Consultants, Inc., and consultants Dr. R. Gary Hicks, Gerry Eller, and Dean Testa. David Peshkin, Applied Pavement Technology, Inc., was the principal investigator. The other authors of this report are Kelly Smith, Angie Wolters, and James Krstulovich of Applied Pavement Technology, Inc., and Jim Moulthrop and Cesar Alvarado of Fugro Consultants, Inc. The authors also acknowledge the contributions to this research from Katie Zimmerman, Kurt Smith, and RoseMary Evans, all of Applied Pavement Technology, Inc. Finally, the research team acknowledges with appreciation the time and efforts of the many highway agencies (states, provinces, cities, toll authorities) who responded to the survey upon which much of this report is based.

FOREWORD

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

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

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

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

CONTENTS

CHAPTER 1

Introduction

Background

Since the early to mid-1990s, pavement preservation has grown from an obscure term to standard practice in most highway agencies. Each practitioner may approach this from a different vantage point, but at various times the driving forces behind this shift have included one or more of the following:

- A desire to improve overall pavement performance;
- Greater attention to customer satisfaction;
- Rising rehabilitation costs and constrained budgets; and
- A need to improve safety in a cost-effective manner.

Many agencies associate preservation with commonly used preventive maintenance treatments. As such, treatments such as chip seals or seal coats, crack filling, and slurry seals are synonymous with pavement preservation. Furthermore, these same treatments are almost always used on lower-volume roads. Inevitably, a strong link has developed between pavement preservation, preventive maintenance, and low-volume roads, even if it is purely circumstantial.

Nothing intrinsically limits pavement preservation to lower-volume roads, however. In terms of pavement performance, the same nonload factors that contribute to the deterioration of low-volume roads contribute to the deterioration of high-volume roadways. Similarly, most preservation treatments will have the same beneficial effects on a pavement regardless of traffic volumes. Even though higher traffic volume will have more effect on the structural aspect of the pavement, preservation will slow or retard the structural deterioration.

At the same time, it is recognized that there exist barriers to greater use of preservation treatments on high-traffic-volume roadways. Among these barriers are the following:

- Shorter available construction windows;
- Increased risk of failure associated with durability of treatment under higher traffic volume;
- Greater liability associated with failure;
- Negative public perceptions associated with certain treatments;
- Increased performance expectations; and
- Lack of agency experience.

The result is that where one agency will not use a certain treatment on pavements with average daily traffic (ADT) above 1,500 vehicles/day (vpd), another agency uses the same treatment routinely on pavements with ADT up to 20,000 vpd and higher.

None of these barriers is insurmountable, but each requires a targeted effort to address and overcome. A part of that effort is addressed in SHRP 2 Renewal Project R26: Preservation Approaches for High-Traffic-Volume Roadways. A primary objective of the project is to improve pavement preservation practices on high-traffic-volume roadways. One way that objective is being met is in the development of guidelines that can be used to preserve high-volume roadways in serviceable condition for longer periods of time, at a lower cost, in a safer manner, and with limited disruption to the traveling public.

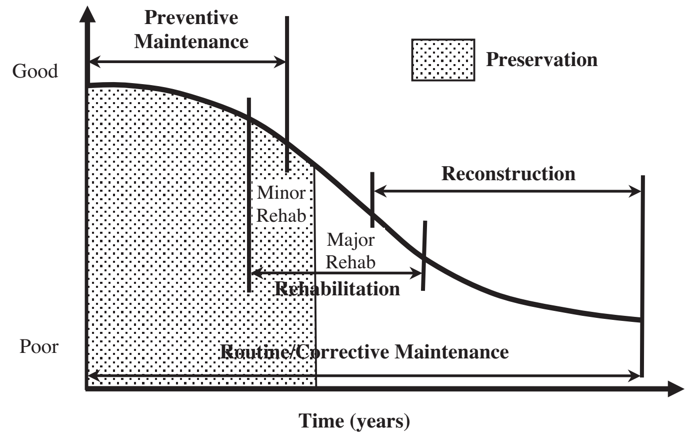
Purpose

The purpose of these guidelines is to provide direction to agencies on the selection and use of preservation treatments for high-traffic-volume roadways. These guidelines are based in large part on agency experience and practice, as provided in response to a detailed survey of practice and supplemented by the current practices gleaned from collected literature. It is expected that agencies using these guidelines will be able to extend their use of pavement preservation on high-traffic-volume roadways through a greater familiarity with the described treatments.

Users of these guidelines should be aware that achieving the desired results from pavement preservation is dependent upon many interacting factors, including proper project selection, materials availability and quality, contractor capabilities, construction practices, and ambient conditions at the time of placement. Users interested in applying these guidelines to identify applications with which they do not currently have experience are encouraged to collect additional information regarding the best practices of experienced users to achieve the best possible outcome.

Definitions

The proper application of these guidelines depends in part on an understanding of common terms used throughout the document. Terms such as "preservation" and "preventive maintenance," as well as other terms related to their use, are often used inconsistently, fostering misconceptions about the applicability of pavements and the selection of treatments. Therefore, the definitions of relevant terms are presented in this section to provide a consistent interpretation of all information presented in the guidelines. Additional definitions of terms are given in Appendix A.



Source: Adapted from Peshkin et al. 2007.

Figure 1.1. Relationship between pavement condition and different categories of pavement treatment.

- **Pavement preservation.** A network-level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices to extend pavement life, improve safety, and meet motorist expectations (Geiger 2005). Pavement preservation programs normally include a combination of preventive maintenance, minor rehabilitation, and routine maintenance work. However, the majority of work under typical pavement preservation programs is focused on preventive maintenance.
- **Preventive maintenance.** A planned strategy of cost-effective treatments applied to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity) (Geiger 2005). As illustrated in Figure 1.1, preventive maintenance activities are performed in the early years of a pavement's life, before the onset of significant structural deterioration. Example activities include crack sealing and filling, joint resealing, slurry seals, and chip seals.
- **Minor rehabilitation.** Nonstructural enhancements (e.g., thin hot-mix asphalt [HMA] overlay, mill and thin HMA overlay) made to an existing pavement section to either eliminate age-related, top-down surface cracking that develops in flexible pavements due to environmental exposure or to restore functionality of concrete pavements. Because of the nonstructural nature of minor rehabilitation techniques, these types of rehabilitation techniques are placed in the category of pavement preservation (Geiger 2005). As shown in Figure 1.1, minor rehabilitation generally occurs in the early to middle years of a pavement's life, when serviceability/ride quality issues become apparent.
- **Routine maintenance.** Planned work that is performed on a routine basis to maintain and preserve the condition of the highway system or respond to specific conditions and events that restore the highway system to an adequate level of service (Geiger 2005). Crack filling and sealing and drainage maintenance are preservation activities that can be classified as routine maintenance. These and other routine maintenance activities are often performed throughout a pavement's life, as indicated by Figure 1.1.
- **Corrective maintenance.** Maintenance activities performed in response to the development of a deficiency(ies) that negatively impacts the safe, efficient operations of the facility and future integrity of the pavement sections (Geiger 2005). Corrective maintenance (sometimes referred to as reactionary maintenance) is usually performed to fix a localized defect(s) due to unforeseen conditions and restore a pavement to an acceptable level of service. Example activities include pothole patching and concrete slab replacements. Corrective maintenance can be performed throughout a pavement's life, as indicated by Figure 1.1.
- **Major rehabilitation.** Structural enhancements that extend the service life of an existing pavement or improve its load-carrying capability or both (Geiger 2005).
- **Reconstruction.** Replacement of the entire existing pavement structure with the equivalent or increased pavement structure. Reconstruction usually requires the complete removal and replacement of the existing pavement structure. It may incorporate either new or recycled materials. Reconstruction is required when a pavement has either failed or has become functionally obsolete (Geiger 2005).
- **High-traffic-volume roadway.** These are rural roadways with ADT values greater than 5,000 vpd and urban roadways with ADT values greater than 10,000 vpd.

- **Surface type.** The type of pavement on the top or surface of a pavement structure. For this study, the preservation approaches developed for high-traffic-volume roadways provide options for both HMA and portland cement concrete (PCC) surface types. HMA-surfaced pavements include HMA on granular or stabilized base and HMA on PCC base (i.e., composite pavement). PCC-surfaced pavements include jointed plain concrete (JPC), jointed reinforced concrete (JRC), and continuously reinforced concrete (CRC) pavements.
- **Treatment type.** A specific work activity performed on a roadway pavement that is intended to treat one or more of the pavement's deficiencies. Examples include crack sealing, thin HMA overlay applications, and diamond grinding. In some cases, a combination of treatments may be needed to treat existing deficiencies
- **Treatment category.** A group of treatments with similar overall objectives and applied at similar times (Figure 1.1). For example, as described, preventive maintenance treatments are intended to preserve pavement integrity and prevent or retard future pavement deterioration. Other treatment categories include routine maintenance, minor rehabilitation, major rehabilitation, and reconstruction.
- **Distresses.** Visible indicators of pavement deterioration caused by factors such as load, environment, construction practices, materials, support conditions, design practices, or, most commonly, a combination of two or more of these. Distresses can be further divided into two broad categories, functional and structural:
  - **Functional distress.** Deterioration that affects the ability of the pavement to provide a safe, smooth, and quiet surface for driving. Most functional problems can be corrected with preservation treatments if there is no serious underlying structural problem.
  - **Structural distress.** Deterioration caused by excessive loading, insufficient thickness, or lack of structural support. Pavements with considerable structural distress are not good candidates for preservation treatments.

Organization of the Guide

This guide consists of three chapters and two appendixes. Following this introductory chapter, Chapter 2 discusses some key factors that affect the selection of a pavement-preservation project and treatment, including traffic level, existing pavement condition, climatic condition, available work hours, and treatment performance and cost. Chapter 3 presents the treatment selection process, beginning with the identification of candidate treatments and ending with the treatment selection based on various economic (including cost-effectiveness) and noneconomic factors. Appendix A contains one- to two-page technical summaries for the various preservation treatments. Appendix B provides two example exercises intended to illustrate certain portions of the treatment selection process.

CHAPTER 2

Factors Affecting Project and Treatment Selections for Pavement Preservation

There are many factors that affect the selection of a pavement-preservation project and treatment. For high-traffic-volume roadways in particular, the ability of the treatment to stand up to higher traffic volumes is certainly important. Other factors also increase in importance as the desire to minimize owner risk and disruption to the traveling public are considered. These guidelines identify the following factors, which are described in greater detail in the sections that follow:

- Traffic levels;
- Pavement condition;
- Climate/environment;
- Work zone duration restrictions;
- Expected treatment performance; and
- Costs.

Traffic Level

The traffic level is important for at least two reasons: it is a direct measure of the loadings applied to a roadway and it affects access to a roadway to perform preservation activities. Traffic levels may also be indirectly related to an agency's risk tolerance: the higher the ADT, the less likely the agency is to try a treatment that may not have a long life or, if it fails, may adversely affect many users.

One of the steps taken in developing these guidelines was to arrive at a definition of "high"-traffic-volume roadways. There is no national or American Association of State Highway and Transportation Officials (AASHTO) definition of high traffic volumes, probably because it is a local issue: what one agency defines as high traffic volume could easily be considered low traffic volume by another. To address this variability, a survey of state highway agencies' (SHA) practices was conducted in which agencies were asked how they defined low, medium, and high traffic on both rural and urban roadways. The responses were broken down using descriptive statistical analyses to plot histograms of ADT levels for rural and urban roadways. These plots were analyzed to determine at what ADT at least 50% of reporting agencies were represented. As a result of the responses and the analyses, it was determined that a reasonable definition of high traffic volume is 5,000 vpd for rural roadways and 10,000 vpd for urban roadways. This is described in greater detail in the project report.

The high-traffic-volume classification levels provided by the responding highway agencies were also analyzed for trends concerning preservation treatment use. According to survey responses, crack sealing, followed by crack filling, cold milling, and thin HMA overlays, are the treatments most extensively used on both rural and urban HMA-surfaced roadways. Similarly, joint resealing, crack sealing, and diamond grinding are the treatments with the greatest use on rural and urban PCC pavements. At the opposite end, preservation treatments such as cape sealing, fog sealing, and diamond grooving are used infrequently on high-traffic-volume roads. Tables 2.1 and 2.2 summarize the use of preservation treatments on HMA- and PCC-surfaced roadways, respectively. From this, the general practice of each treatment can be assessed according to the traffic level of the roadway.

In addition to determining the extent of treatment use, information was sought on which treatments are predominantly used on high-traffic-volume roadways and whether there is a difference in strategies for treating rural roadways as opposed to urban roadways. Overall, approximately 60% of agencies reported using a different set of treatments for rural high-traffic-volume roadways versus rural low-traffic-volume roadways, whereas a slightly lower margin of the majority reported using a different set of treatments for urban high-traffic-volume roadways versus urban low-traffic-volume roadways. However, there was little difference in treatment strategies between rural and urban high-traffic-volume roadways. Tables 2.3 and 2.4 list the preservation treatments used by at least 50% of highway agencies on their rural and urban high-traffic-volume roadways.

Table 2.1. Preservation Treatment Use on High-Traffic-Volume Rural and Urban HMA-Surfaced Roadways

Treatment	Treatment Usage: Rural (ADT >5,000 vpd)	Treatment Usage: Urban (ADT >10,000 vpd)
Crack filling	**Extensive**	**Extensive**
Crack sealing	**Extensive**	**Extensive**
Slurry seal	Limited	Limited
Microsurfacing	Moderate	Moderate
Chip seals	Moderate	Moderate
Ultra-thin bonded wearing course	Moderate	Moderate
Thin HMA overlay	**Extensive**	**Extensive**
Cold milling and overlay	**Extensive**	**Extensive**
Ultra-thin HMA overlay	Limited	Moderate
Hot in-place HMA recycling	Limited	Limited
Cold in-place recycling	Moderate	Moderate
Profile milling	Moderate	Moderate
Ultra-thin whitetopping	Limited	Limited

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

An important element of the overall traffic level is the average daily truck traffic (ADTT) or the percentage of the ADT that is made up of trucks. However, agencies did not report that truck traffic has a significant influence on preservation treatment selection.

Pavement Condition

In selecting the right preservation treatment for a pavement, the condition of the existing pavement is important. Not only is the overall condition important, but the specific distresses present on the pavement also impact the selection of the proper preservation treatment. It is rare to encounter a single pavement condition, so these guidelines have been structured such that the suitability of various treatments for combinations of pavement conditions has been considered, where possible.

Although it is always important to apply preservation treatments at the right time to address the right condition(s), this is especially applicable to high-traffic-volume roadways. For example, if two roads of the same design are constructed to the same standards under the same environmental conditions, it is expected that these roadways would perform identically

Table 2.2. Preservation Treatment Use on High-Traffic-Volume Rural and Urban PCC-Surfaced Roadways

Treatment	Treatment Usage: Rural (ADT >5,000 vpd)	Treatment Usage: Urban (ADT >10,000 vpd)
Concrete joint sealing	**Extensive**	**Extensive**
Concrete crack sealing	**Extensive**	**Extensive**
Diamond grinding	**Extensive**	**Extensive**
Diamond grooving	Moderate	**Extensive**
Partial-depth concrete patching	**Extensive**	Moderate
Full-depth concrete patching	**Extensive**	**Extensive**
Dowel bar retrofitting (i.e., load transfer restoration)	Moderate	Moderate
Ultra-thin bonded wearing course	Limited	Moderate
Thin HMA overlay	Limited	Moderate

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

Table 2.3. Preservation Treatments Commonly Used on High-Traffic-Volume HMA-Surfaced Roadways

Roadway Category: Rural (ADT >5,000 vpd)	Roadway Category: Urban (ADT >10,000 vpd)
Crack fill Crack seal Thin HMA overlay Cold mill and overlay Drainage preservation	Crack fill Crack seal Cold mill and overlay Drainage preservation

Table 2.4. Preservation Treatments Commonly Used on High-Traffic-Volume PCC-Surfaced Roadways

Roadway Category: Rural (ADT >5,000 vpd)	Roadway Category: Urban (ADT >10,000 vpd)
Joint seal Crack seal Diamond grinding Full-depth patching Partial-depth patching Dowel bar retrofitting	Joint seal Crack seal Diamond grinding Full-depth patching Partial-depth patching Dowel bar retrofitting Drainage preservation

under the same traffic conditions. However, when increased traffic loadings are applied, the pavement with the greater load will deteriorate faster. This can be illustrated with performance curves showing that the time for treatment application is reduced for pavements with higher traffic volumes.

While the correct treatment application time depends on several factors, it is generally agreed that preservation treatments should be applied during the period when the pavement is in good condition. Accordingly, surveying existing conditions to determine whether the pavement is in good condition is an important part of the treatment selection process.

The selection of the correct type of preservation for distressed pavements generally depends on the location, density, and magnitude of the distress. For instance, where a surface treatment cannot be applied to a PCC pavement, such as a heavily trafficked urban roadway, diamond grinding is often performed to improve rideability. Resealing of joints in PCC pavements is done wherever poor sealing or lack of sealing is evident. On HMA-surfaced roadways, if transverse cracking is frequent but there is not a high degree of edge deterioration, a surface treatment such as a chip seal or slurry seal may be the best preservation strategy. If the transverse cracks are low to moderate in frequency and have progressed to a point of high edge deterioration, then crack repair or patching may be necessary. If cracks are moderate in density and have little deterioration, effective treatment can be accomplished by crack sealing or filling. Extensive longitudinal cracking in the wheel path is indicative of a structural problem, which makes the pavement a poor candidate for preservation treatment. While crack sealing is primarily performed on newer pavements with fairly narrow cracks, crack filling is most often reserved for more worn, older pavements with wider, more randomly occurring cracks.

Thin HMA overlays can be used on all types of roadways in good to fair condition for functional improvements. Such overlays are particularly suitable for high-traffic-volume roadways in urban areas, where longer life and relatively low-noise surfaces are desired. Similarly, slurry seals do not usually perform well if the underlying pavement contains extensive cracks (Morian et al. 1998).

Tables 2.5 and 2.6 reflect the state of the practice for treatment use by transportation agencies based on existing pavement surface conditions. In these tables, extensive use means that two-thirds or more of the highway agencies reported using a particular treatment to address a certain pavement deficiency. Moderate use represents use by between one-third and two-thirds of the agencies, while limited use represents use by less than one-third of the agencies. The results presented in these tables were combined with the application best practices information contained in the literature to formulate a decision matrix for identifying feasible treatments based on existing pavement condition. The decision matrix is a key part of the treatment selection framework/process presented later in this document.

Climate/Environment

Climatic conditions impact preservation treatment usage in at least two ways: determining construction timing and affecting treatment performance. While the applicability of many of the treatments might not be affected by differences in climate (such as ultra-thin friction courses for HMA-surfaced pavements or diamond grinding for PCC pavements), some treatments, especially those using asphalt emulsions, can only be applied in limited temperature and humidity conditions. Climate can directly affect curing time, which in turn impacts treatment feasibility and opening to traffic on high-volume roadways. For example, slurry seals require several hours, warmer temperatures, and direct sunlight to break and cure effectively; in environments where these conditions cannot be assured and traffic cannot be kept off the pavement, a slurry seal is not an appropriate treatment.

In addition to temperature and climate considerations during treatment placement, preservation treatments can experience differential performance in different climates. For example, although thin HMA overlays are used successfully in all climatic regions, they are susceptible to thermal cracking, which can be more pronounced in colder climates. The performance of ultra-thin HMA overlays is particularly limited in cold climates because of the thermal cracking issue and the challenges in achieving adequate density on thin lifts.

Cold-applied (emulsion-based) treatments must be placed during the day and in warm temperatures, while treatments constructed with hot asphalt binder can be placed at night and in cooler temperatures. Generally, the construction season runs from May to September to take advantage of the warmest months for the northern States (Gransberg 2005). Good performance of chip seals is related both to favorable climatic conditions during placement and also to favorable climatic conditions during the weeks following placement. A major cause of pavement failure is weather-related, such as when rain or extreme temperatures occur shortly after construction (Croteau et al. 2005). Some thin surfacings are also more susceptible to damage from certain types of snow plowing techniques and certain plow blades.

From agency-provided responses on preservation practices, information was obtained that permitted the categorization of practices according to climate region, which in turn could be evaluated to determine whether their treatment use was at least partially driven by climatic factors. For the three climatic regions identified—deep-freeze (northern-tier states, freezing index [FI] >400), moderate-freeze (middle-tier states, $50 < FI \leq 400$), and no-freeze (southern-tier states and portions of coastlines, $FI \leq 50$)—the general practice for

Table 2.5. Treatment Usage on HMA-Surfaced Roadways According to Pavement Condition

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

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

[a] Various forms of cracking.

Table 2.6. Treatment Usage on PCC-Surfaced Roadways According to Pavement Condition

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

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

using each treatment was summarized, with the results shown in Tables 2.7 and 2.8. In these tables, extensive treatment use in a climate region is understood as at least two-thirds of respondents in that region reporting using the treatment on high-traffic-volume roadways. Moderate use is defined as between one-third and two-thirds of respondents using the treatment. Limited use is defined as less than one-third of respondents reporting using that treatment.

Although there is variability among the climate regions regarding treatment usage, for the most part there is not a significant difference between treatment use on rural versus urban high-traffic-volume roadways within a climate region. Two treatments, slurry seal on HMA-surfaced pavements and thin PCC overlays on PCC pavements, were reportedly not used on either rural or urban high-traffic-volume roadways in deep-freeze environments. In other cases, such as use of ultra-thin whitetopping, limited use may be more likely attributed to high cost or lack of local experience, rather than climate-related performance issues.

Work Zone Duration Restrictions

The time available to apply a treatment is a practical consideration in treatment selection on high-traffic-volume roadways, as it dictates how much time is available to do the work.

Table 2.7. Preservation Treatment Use on High-Traffic-Volume HMA-Surfaced Roadways, by Climate Region

				Microsurfacing		Chip Seal		
Climatic Region	**Crack Fill**	**Crack Seal**	**Slurry Seal**	**Single Course**	**Multiple Course**	**Single Course**	**Multiple Course**	**With Polymer**
RURAL								
Deep freeze	**Extensive**	**Extensive**	None	Moderate	Moderate	**Extensive**	**Extensive**	**Extensive**
Moderate freeze	**Extensive**	**Extensive**	Moderate	**Extensive**	Moderate	Moderate	Limited	Limited
No freeze	Moderate	Moderate	Limited	Moderate	Limited	Moderate	Moderate	Moderate
URBAN								
Deep freeze	**Extensive**	**Extensive**	None	Moderate	Moderate	Moderate	Moderate	Moderate
Moderate freeze	**Extensive**	**Extensive**	Moderate	**Extensive**	**Extensive**	Moderate	Limited	Limited
No freeze	**Extensive**	**Extensive**	Moderate	Moderate	Limited	Moderate	Moderate	Moderate

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

(continued on next page)

One scheme for looking at available hours is to divide available closure times into three groups: less than 12 hours, 12 to 60 hours, and more than 60 hours. These groups are approximately equivalent to an overnight closure, a closure between one-day and one-weekend long, and a closure that is longer than a weekend, respectively (Peshkin et al. 2006), although these ranges would vary based on local patterns of use, peak-hour rates, and so on.

The survey feedback provided valuable information to identify facility closure times that State agencies typically use when performing preservation treatments associated with high-traffic-volume roadways (see Tables 2.9 and 2.10). Most preservation treatments on HMA-surfaced roads can be completed within a single shift or overnight closure. Specifically for HMA pavements, the overnight closure time was the most frequently selected available scenario under which 12 of the 13 treatment alternatives are typically applied. The methods most widely used with this length of closure include crack filling, crack sealing, slurry seals, microsurfacing, chip seals, ultra-thin bonded wearing courses, thin and ultra-thin HMA overlays, cold milling and overlay projects, and profile milling. It should be noted that most of these treatments are used under the same available work hour scenarios for both urban and rural areas. Hot in-place and cold in-place recycling are also used as single shift or overnight projects, but less frequently than the previously listed activities. Finally, ultra-thin whitetopping is more often performed as a weekend or extended closure project.

Many pavement preservation techniques for PCC can be completed during an overnight or single-shift closure. The results indicated that all of the preservation treatments for urban PCC roads are considered for overnight or single-shift closures. When conventional patching materials are used for partial- and full-depth repairs and for dowel bar retrofitting, longer closure times are required for the material to reach acceptable strength. On the other hand, use of high early strength PCC mixes and fast-track proprietary repair materials (and precast full-depth repair panels), usually enables these preservation treatments to be used in single-shift or overnight closures.

Expected Treatment Performance

Expected treatment performance also influences the selection of a preservation treatment. There may be higher expectations for treatment performance when there is more traffic because higher-traffic-volume roadways are expected to last longer. It is also harder to gain access to roads with higher traffic volumes, which contributes to the expectation that any work done on such roads should last longer. Also, as noted, there is a greater risk associated with a premature failure on such roads.

The measure of expected treatment performance used in these guidelines is expected treatment life in years. To clarify, this does not refer to how long the treatment "lasts," but rather to how long the treatment serves the purpose for which it was placed (i.e., provides a benefit). Since the purpose of preservation is to extend the life of a pavement, treatment performance must be measured in terms of the extension in service life imparted to the existing pavement by the treatment. This designation of performance is most compatible with the procedures needed to evaluate the cost-effectiveness of preservation treatments as part of a project-level treatment selection process.

General ranges in the expected performance of treatments applied to HMA-surfaced pavements and PCC roadways are

Table 2.7. (continued)

Climatic Region	Thin Bonded Course	Thin HMA Overlay	Cold Milling and Overlay	Ultra-Thin HMA Overlay	In-Place Recycling		Profile Milling	Ultra-Thin Whitetopping
					Hot	Cold		
RURAL								
Deep freeze	Moderate	**Extensive**	**Extensive**	Limited	Limited	Moderate	Limited	Limited
Moderate freeze	**Extensive**	**Extensive**	**Extensive**	Moderate	Limited	Moderate	Moderate	Limited
No freeze	Moderate	Moderate	Moderate	None	None	Limited	Moderate	Limited
URBAN								
Deep freeze	Moderate	**Extensive**	**Extensive**	Moderate	Limited	Moderate	Limited	Limited
Moderate freeze	**Extensive**	**Extensive**	**Extensive**	**Extensive**	Moderate	Limited	**Extensive**	Moderate
No freeze	Moderate	Moderate	**Extensive**	Limited	Limited	Moderate	Moderate	Limited

Table 2.8. Preservation Treatment Use on High-Traffic-Volume PCC-Surfaced Roadways, by Climate Region

Climatic Region	PCC Joint Sealing	PCC Crack Sealing	Diamond Grinding	Diamond Grooving	Partial-Depth Repair	Full-Depth Repair	Dowel Bar Retrofit	Thin PCC Overlay	Thin Bonded Course	Thin HMA Overlay
RURAL										
Deep freeze	Moderate	Moderate	Moderate	Limited	**Extensive**	**Extensive**	**Extensive**	None	Moderate	Limited
Moderate freeze	**Extensive**	**Extensive**	**Extensive**	Moderate	**Extensive**	**Extensive**	Moderate	Limited	Moderate	**Extensive**
No freeze	**Extensive**	**Extensive**	**Extensive**	Limited	**Extensive**	**Extensive**	Moderate	Limited	Limited	Limited
URBAN										
Deep freeze	**Extensive**	Moderate	Moderate	Limited	Moderate	**Extensive**	Moderate	None	Limited	Limited
Moderate freeze	**Extensive**	**Extensive**	**Extensive**	Moderate	**Extensive**	**Extensive**	Moderate	Limited	Moderate	Moderate
No freeze	**Extensive**	**Extensive**	**Extensive**	Moderate	**Extensive**	**Extensive**	**Extensive**	Limited	Moderate	Moderate

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

Table 2.9. Survey Results from Treatments Used During Different Closure Durations for HMA-Surfaced Pavements

	Rural			Urban		
Treatment	**Overnight or Single Shift**	**Weekend**	**Longer**	**Overnight or Single Shift**	**Weekend**	**Longer**
Crack filling	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Crack sealing	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Slurry seal	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Microsurfacing	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Chip seal	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Ultra-thin bonded wearing course	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Thin HMA overlay	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Cold milling and overlay	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Ultra-thin HMA overlay	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Hot in-place HMA recycling	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Cold in-place recycling	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Profile milling	**Extensive**	Limited	Limited	**Extensive**	Moderate	Limited
Ultra-thin whitetopping	Moderate	Limited	Moderate	Moderate	Moderate	Moderate

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

Table 2.10. Survey Results from Treatments Used During Different Closure Durations for PCC-Surfaced Pavements

	Rural			Urban		
Treatment	**Overnight or Single Shift**	**Weekend**	**Longer**	**Overnight or Single Shift**	**Weekend**	**Longer**
Concrete joint resealing	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Concrete crack sealing	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Diamond grinding	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Diamond grooving	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Partial-depth concrete patching	**Extensive**	Moderate	Moderate	**Extensive**	Moderate	Limited
Full-depth concrete patching	**Extensive**	Moderate	Moderate	Moderate	Moderate	Moderate
Dowel bar retrofitting	**Extensive**	Moderate	Moderate	Moderate	Moderate	Moderate
Ultra-thin bonded wearing course	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited
Thin HMA overlay	**Extensive**	Limited	Limited	**Extensive**	Limited	Limited

Note: Extensive = Use by ≥66% of respondents; Moderate = 33% to 66% usage; Limited = <33% usage.

summarized in Tables 2.11 and 2.12, respectively. These ranges are based on information reported by various sources, representing a variety of conditions, and using different performance measures. As such, these reported ranges may be based as much (or more) on perception instead of on well-designed, quantitative, experimental analyses.

Additional evaluation of treatment performance was performed in this study, taking into consideration factors such as traffic volume, climatic/environmental conditions, and existing pavement conditions. This evaluation, which is documented in the project report, resulted in refinements to some of the performance estimates listed above. The refined estimates are presented later in this document as part of the treatment selection process.

Costs

Although treatment costs do not affect treatment performance, certain cost considerations are inevitably a part of the treatment selection process. The cost of each treatment depends on features such as the size and location of the project, severity and quantity of distresses, and the quality of a treatment's constituent materials. It also depends on the type and amount of surface preparation work and the degree of traffic control required to accompany the treatment.

Allowing roads to deteriorate over time costs significantly more than maintaining roads in good condition. The cost for reconstruction of a 25-year-old roadway can be more than three times what it would have cost to "maintain" it using a

Table 2.11. Expected Performance of Preservation Treatments Applied to HMA-Surfaced Pavements

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

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

Note: NA = Not available.

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

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

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

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

Table 2.12. Expected Performance of Preservation Treatments Applied to PCC-Surfaced Pavements

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

Sources: Peshkin et al. 1999; Smith et al. 2008; Peshkin et al. 2007; Caltrans 2008; NDOR 2002.
Note: NA = Not available.

sequence of preservation treatments over the same 25 years. Hence, cost is a critical component in the selection of appropriate treatments at any traffic level.

Tables 2.13 and 2.14 list the typical unit-cost ranges and corresponding relative costs of preservation treatments applied to HMA- and PCC-surfaced roadways, respectively. The costs represent the in-place costs of the treatments, exclusive of traffic control costs and any associated surface preparation costs.

For HMA-surfaced roadways, the costs of crack sealing and filling are relatively low compared with other preservation techniques; however, the other preservation treatments can effectively address a broad range of conditions, so a direct comparison of costs is not appropriate. Reported cost estimates for slurry seals are approximately \$0.75 to \$1.00/yd^2, depending on the size of the project, materials used, and the rate of application. Costs for microsurfacing vary considerably, but normally range between \$1.50 and \$3.00/yd^2. While the cost of cold in-place recycling depends on numerous factors, including depth of milling and the properties of the existing pavement, average costs are approximately \$1.25 to \$3.00/yd^2. The cost of recycling can be four to six times more than the cost of chip seals and can be higher than the cost of constructing a thin HMA overlay.

For PCC-surfaced roadways, the cost for full-depth repairs on jointed pavements varies significantly. Typical costs in the year 2000 ranged from \$75 to \$150/yd^2. Diamond grinding costs were, on average, between \$1.75 and \$5.50/yd^2. Costs fluctuate depending on many factors, including the existing pavement's aggregate quality and PCC mix properties, average depth of removal, and smoothness requirements. SHAs have found that the cost of diamond grinding is generally lower than the cost of an HMA overlay, and such cost-effectiveness makes diamond grinding an appealing alternative for many concrete rehabilitation projects.

Table 2.13. Estimated Treatment Costs for Preservation Treatments on HMA-Surfaced Pavements

Treatment	Relative Cost ($ to $$$$)	Estimated Unit Cost
Crack filling	$	$0.10 to $1.20/ft
Crack sealing	$	$0.75 to $1.50/ft
Slurry seal	$$	$0.75 to $1.00/yd^2
Microsurfacing (single-course)	$$	$1.50 to $3.00/yd^2
Chip seal (single-course)	$$ (conventional) $$$ (polymer modified)	$1.50 to $2.00/yd^2 (conventional) $2.00 to $4.00/yd^2 (polymer modified)
Ultra-thin bonded wearing course	$$$	$4.00 to $6.00/yd^2
Thin HMA overlay (dense graded)	$$$	$3.00 to $6.00/yd^2
Cold milling and thin HMA overlay	$$$	$5.00 to $10.00/yd^2
Ultra-thin HMA overlay	$$	$2.00 to $3.00/yd^2
Hot in-place recycling (excluding thin HMA overlay for surface recycle and remixing types)	$$/$$$	$2.00 to $7.00/yd^2
Cold in-place recycling (excluding thin HMA overlay)	$$	$1.25 to $3.00/yd^2
Profile milling	$	$0.35 to $0.75/yd^2
Ultra-thin whitetopping	$$$$	$15.00 to $25.00/yd^2

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

Table 2.14. Estimated Treatment Costs for Preservation Treatments on PCC-Surfaced Pavements

Treatment	Relative Cost ($ to $$$$)	Estimated Unit Cost
Joint resealing	$	$1.00 to $2.50/ft
Crack sealing	$	$0.75 to $2.00/ft
Diamond grinding	$$	$1.75 to $5.50/yd²
Diamond grooving	$$	$1.25 to $3.00/yd²
Partial-depth patching	$$/$$$	$75 to $150/yd² (patched area) (equivalent $2.25 to $4.50/yd², based on 3% surface area patched)
Full-depth patching	$$/$$$	$75 to $150/yd² (patched area) (equivalent $2.25 to $4.50/yd², based on 3% surface area patched)
Dowel bar retrofitting	$$$	$25 to $35/bar (equivalent $3.75 to $5.25/yd², based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft)
Ultra-thin bonded wearing course	$$$	$4.00 to $6.00/yd²
Thin HMA overlay	$$$	$3.00 to $6.00/yd²

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

Although these estimated costs depend on the condition of a particular roadway, as well as local contracting and construction costs and materials and techniques used, the direct cost of the treatment is often the easiest to determine. Generally, this is available as historical cost data or estimated based on previous bids. In considering pavement condition, a pavement with more cracks will take more money per mile to seal or patch, and rougher pavements may take a higher quantity of emulsion for a chip seal. However, treatments such as milling and overlay or recycling are relatively independent of existing pavement condition, provided that the pavement is in sufficiently good shape to be a candidate for the treatment.

The cost of eventual rehabilitation should account for how often the preservation process will be repeated and what needs to be performed. For example, a chip seal at the end of its life span can generally be covered with another chip seal. However, if the project was an overlay in an urban area with curb and gutter, milling might be necessary to maintain profile before another overlay can be added.

Although less than a quarter of the survey respondents reported that they account for user costs when selecting a preservation treatment for high-traffic-volume roadways, these costs can represent a significant portion of the total cost and should be taken into account. Detailed guidance in computing certain forms of these costs is provided in Chapter 3.

CHAPTER 3

Treatment Selection Process

Treatments for HMA-Surfaced Pavements

The following treatments are applicable for use on high-traffic-volume HMA-surfaced pavements:

- Crack fill.
- Crack seal.
- Slurry seal (Type III).
- Microsurfacing.
- Chip seal:
  - Single-course;
  - Multiple-course; and
  - Polymer-modified.
- Ultra-thin bonded wearing course.
- Thin HMA overlay (0.875 to 1.5 in.).
- Ultra-thin HMA overlay (0.5 to 0.75 in.).
- Cold milling and HMA overlay.
- Hot in-place recycling (≤ 2.0 in.):
  - Surface recycling followed by HMA overlay;
  - Remixing followed by HMA overlay; and
  - Repaving.
- Cold in-place recycling (≤4.0 in.)—rural use only.
- Profile milling.
- Ultra-thin whitetopping.
- Drainage preservation.

These treatments are generally considered suitable for both rural and urban roadways and for different climatic conditions. However, some treatments may not be appropriate for all traffic and climatic conditions.

Hot in-place recycling is composed of the three basic techniques listed. While the latter two can be used in a preservation manner, they often are used in the context of major rehabilitation. Surface recycling, on the other hand, is well representative of a preservation activity. Like the remixing and repaving techniques, cold in-place recycling can be used in a preservation manner but is frequently considered to be major rehabilitation.

Tables A-1 through A-9 in Appendix A contain one- to two-page technical summaries for most of these treatments. The summaries include treatment descriptions, the key pavement conditions they address, and construction and other considerations (including expected performance and estimated costs). They also provide a listing of reference materials that users can access to get up-to-date information on each treatment.

Treatments for PCC-Surfaced Pavements

The following treatments are applicable for use on high-volume PCC-surfaced pavements:

- Concrete joint resealing.
- Concrete crack sealing.
- Diamond grinding.
- Diamond grooving.
- Partial-depth concrete pavement patching.
- Full-depth concrete pavement patching.
- Dowel bar retrofitting.
- Ultra-thin bonded wearing course.
- Thin HMA overlay (0.875 to 1.5 in.).
- Drainage preservation.

Again, these treatments are generally considered suitable for both rural and urban roadways and for different climatic conditions, but some treatments may not be appropriate for all traffic and climate conditions. Technical summaries for most of these treatments are provided in Tables A-10 through A-14 in Appendix A.

Preservation Treatment Selection

Selecting an appropriate preservation treatment for a given pavement at a given time is not a simple process. It requires a significant amount of information about the existing pavement, as well as the needs and constraints of the treatment to be performed. In addition, there are usually several possible solutions that can be considered, each with unique advantages and disadvantages. The process is further complicated when costs and cost-effectiveness are factored in.

Figure 3.1 presents a sequential approach for evaluating possible preservation treatments for an existing pavement and identifying the preferred one. This approach is developed specifically to address factors that are commonly considered for high-traffic-volume roadways. In this approach, the functional and structural performance of the existing pavement should first be established through condition surveys and/or the agency's pavement management system (PMS). The performance information should include both current and historical trends of overall condition (i.e., an aggregate/composite indicator of condition or serviceability); type, severity, and amount of individual distresses; and ride quality/smoothness measurements. For pavements perceived as having possible safety or noise issues, surface friction test results, crash data, and pavement–tire noise data should also be compiled.

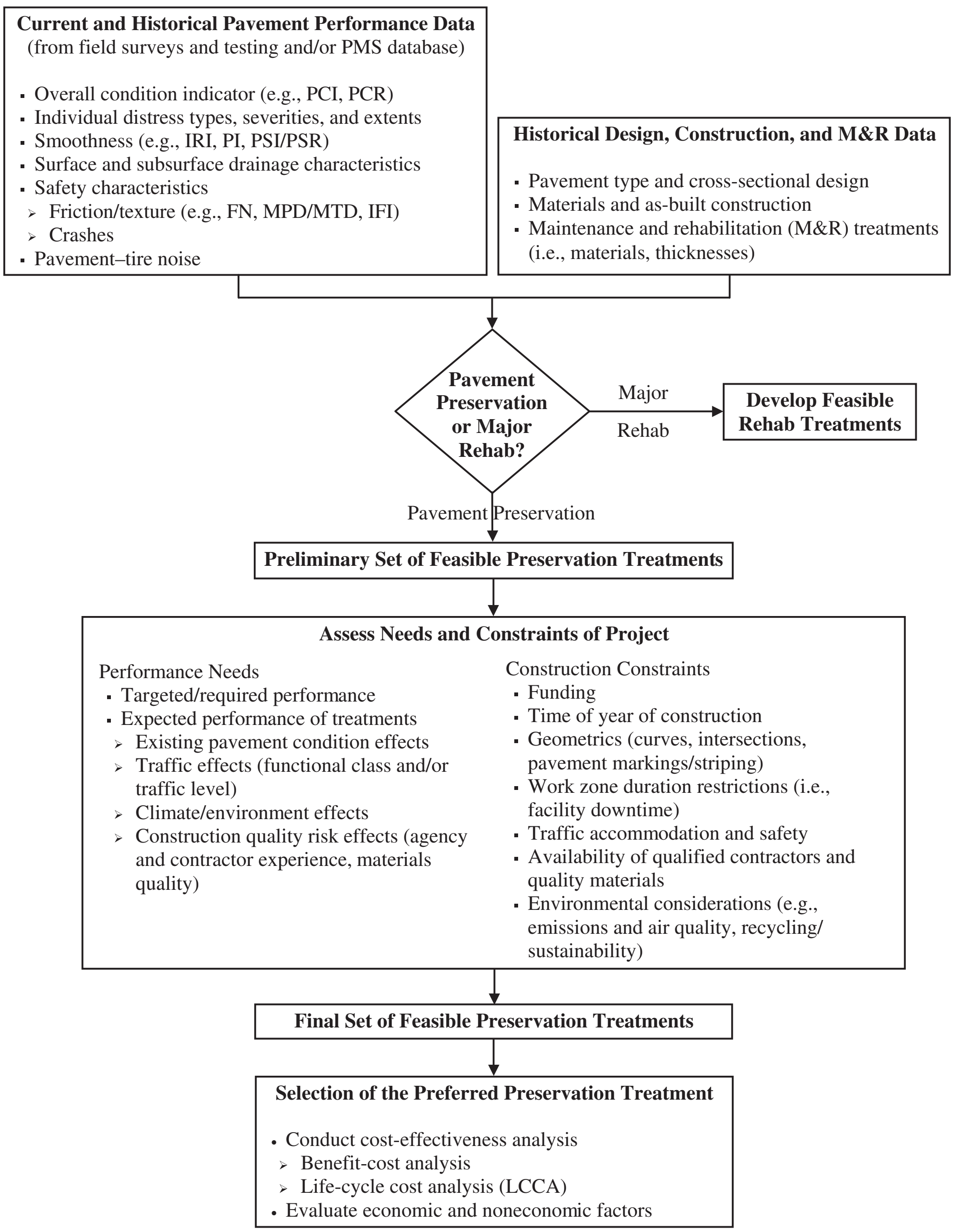


Figure 3.1. Process of selecting the preferred preservation treatment for high-traffic-volume roadways.

On the basis of the established performance information, a preliminary list of feasible preservation treatments should then be identified. This list represents a first cut of treatments capable of preserving the pavement structure and preventing or delaying future deterioration, given the pavement's current physical condition and rate of deterioration.

Next, the performance needs and construction constraints of the project should be assessed. On the basis of the traffic and climatic characteristics of the project and an acceptable level of risk, the list of feasible treatments can be narrowed to those whose expected performance satisfies the required or targeted performance level. Further refining of the list may occur after considering constraints such as available funding, the expected timing and allowable duration of the work, geometrics issues, and traffic control issues.

Once a final set of feasible preservation treatments has been identified, a cost-effectiveness analysis should be performed to determine which treatment provides the greatest return for the investment. This analysis may be done using either cost–benefit analysis or life-cycle cost analysis (LCCA) techniques. Results of the cost-effectiveness analysis should then be evaluated in conjunction with other economic factors and several nonmonetary factors to select the preferred preservation treatment.

Preliminary Identification of Feasible Preservation Treatments

As discussed previously in these guidelines, many pavement preservation treatments may be applicable for use on high-traffic-volume roadway pavements. Although a variety of factors must be considered in determining the feasibility of each treatment, a preliminary indication can be obtained by examining the current and historical performance of the pavement and the historical record of the pavement structure. By knowing the structural and functional adequacy of the pavement, its rate of deterioration, materials durability, and drainage adequacy, treatments can be identified according to their ability to address performance issues, whether through preventive or restorative means.

Perhaps the most crucial aspect of the treatment selection process is the proper assessment of pavement conditions. Although there is a common basis for the process used by SHAs to conduct field condition surveys and analyze/report the results, each process is unique in terms of survey mode (manual/visual versus automated), frequency, and sampling level; distress identification and recording protocol; and overall condition computation and reporting technique. Moreover, each agency has different testing (e.g., coring, deflection, friction/texture, noise) practices.

Because preservation seeks to address a variety of pavement deficiencies, good, up-to-date information is needed concerning the overall condition of the existing pavement and the individual distress types (and associated severities and extents) that are present. Combined with historical condition/distress data, pavement structure data (current age and design life, cross-section and materials), drainage data, and surface characteristics data (smoothness, friction, noise), this information will first indicate whether a major rehabilitation is warranted or if preservation options can be considered. If major rehabilitation is not warranted, then this same collection of data can be evaluated in greater detail to identify the most feasible preservation treatments.

Table 3.1 lists the types of distresses important in assessing preservation need. For each distress listed, information is provided that indicates whether preservation adequately addresses the distress and, if so, the manner in which it addresses the distress (i.e., prevention or slowing of future deterioration, restoration of functional attributes). If the existing distresses are primarily treatable through preservation and there is no excessive distress (large quantities and/or severe levels of distress) associated with structural or subsurface materials problems, then the pavement is likely a good candidate for preservation techniques. Otherwise, the agency should pursue a plan for major rehabilitation.

If preservation is deemed an acceptable approach, then the process of identifying candidate treatments can proceed. Tables 3.2 and 3.3 are evaluation matrices that can be used in the preliminary identification of feasible preservation treatments for existing HMA- and PCC-surfaced pavements. The tables list the "windows of opportunity" for each treatment in terms of the age and overall condition (using a PCI/PCR scale of 1 to 100) of the existing pavement at time of treatment application. They also identify how appropriate each treatment is for a given application in terms of how well it addresses a particular distress and corresponding severity level and how commensurate it is for addressing that distress and severity level. A similar representation is given concerning the appropriateness of treatments for surface characteristics issues (smoothness, friction, and noise). In interpreting this matrix, it is assumed that each distress exists in significant enough quantities to warrant considering a preservation treatment.

The "windows of opportunity" in the evaluation matrices provide a general sense as to *when* the preservation techniques are most beneficial. To key in on specific treatments suitable for an existing pavement, the distress and surface characteristics issues must be evaluated according to the indicator symbols provided in the matrices. In these matrices, a series of symbols are used to identify the appropriateness of a treatment:

● = highly recommended for application
⦿ = generally recommended
○ = provisionally recommended
✕ = not recommended.

Table 3.1. Distresses Considered for Potential Preservation and the Manner in Which They Are Addressed by Preservation

HMA-Surfaced Pavements		PCC-Surfaced Pavements	
Distress Type	**Manner Addressed by Preservation**	**Distress Type**	**Manner Addressed by Preservation**
Alligator/fatigue cracking	—	Blowups	—[a]
Bleeding/flushing	Restore StrInt/Funct	Corner cracking	Prevent/Slow Det
Block cracking	Prevent/Slow Det	D-Cracking	—[a]
Bumps	Restore StrInt/Funct	Joint faulting	Restore StrInt/Funct Prevent/Slow Det
Corrugations	Restore StrInt/Funct[b]	Joint seal damage	Restore StrInt/Funct
Depressions/settlements	—	Joint spalling	Restore StrInt/Funct
Edge cracking	Prevent/Slow Det[c]	Longitudinal cracking	Prevent/Slow Det
Heaves/swells	—	Map cracking Non-ASR ASR	 Restore StrInt/Funct —
Joint Reflection cracking	Prevent/Slow Det[c]	Patches/patch deterioration	Prevent/Slow Det
Longitudinal cracking Wheelpath Nonwheelpath (cold joint)	 — Prevent/Slow Det[c]	Polishing	Restore StrInt/Funct
Patches/patch deterioration	Prevent/Slow Det	Popouts	Restore StrInt/Funct
Polishing	Restore StrInt/Funct	Punchouts	—[a]
Potholes	—	Scaling	Restore StrInt/Funct
Raveling/weathering	Restore StrInt/Funct Prevent/Slow Det	Transverse cracking	Prevent/Slow Det
Rutting Wear Stable (densification) Structural Mix/instability	 Restore StrInt/Funct Restore StrInt/Funct — —	Water bleeding/pumping	Prevent/Slow Det
Sags	Restore StrInt/Funct Prevent/Slow Det		
Segregation	Restore StrInt/Funct Prevent/Slow Det		
Shoving	Restore StrInt/Funct[b]		
Slippage cracking Deflection/fatigue-related Bond-related	 — Restore StrInt/Funct[b]		
Stripping[d]	—		
Transverse thermal cracking	Prevent/Slow Det[c]		
Water bleeding/pumping Subsurface drainage Porous surface	 — Prevent/Slow Det		

Note: — = Not adequately addressed by preservation; StrInt = Structural Integrity; Funct = Functionality; Det = Deterioration.

[a] Preservation suitable for isolated or limited occurrences of this distress.

[b] Effectiveness depends on depth of problem.

[c] Not suitable for severely deteriorated cracks.

[d] Manifested in other forms of distress, such as rutting, cracking, raveling, and shoving/corrugation.

The provisional recommendations given in the evaluation matrices suggest that engineering judgment is needed to account for other site-specific factors/conditions and for specific agency practices. Ideally, multiple treatment options should be identified, such that each option is shown to be at least generally recommended (⦿) for all of the identified distresses and surface characteristics. In some instances, it may be appropriate to consider combining treatments (e.g., crack sealing with chip sealing) to increase the number of feasible options.

What constitutes a surface characteristic issue depends in large part on agency policy and the characteristics and demands of the project. Generally speaking, the higher the traffic volume for a given roadway facility, the lower the maximum acceptable threshold for roughness. Also, the more difficult the driving environment (e.g., higher traffic volume, higher speed, more curves and intersections), the higher the minimum acceptable threshold for friction. In rural areas, pavement–tire noise is usually not considered an issue, whereas in urban residential areas, the contribution of pavement–tire noise (i.e., at-the-source noise) to overall wayside noise can be an important issue. This is particularly true where sound walls do not exist, traffic levels and speeds are high, and residences are in close proximity to the roadway.

For high-traffic-volume roadways, international roughness index (IRI) values above 100 to 110 in/mi may be perceived as an issue to be addressed by the preservation treatment. IRI values greater than 150 to 200 in/mi may be more indicative of the need for major rehabilitation. For high-speed (≥50 mph), high-traffic-volume roadways, smooth-tire 40-mph friction number (FN40S) values below 30 to 32 may be perceived as marginal or too low, prompting the need for a restoration treatment. Good practice dictates that this need be confirmed by examining wet-weather accident rates along the project length. Although there is no nationally recognized requirement for the maximum level of noise (either at the source or at a point on the wayside) that can be generated by a highway pavement, it should be pointed out that the quietest pavements generate on-board sound intensity (OBSI) levels (at-the-source noise) between 96 and 102 dB(A), whereas the loudest pavements generate OBSI levels in the 108 to 112 dB(A) range. Depending on the characteristics of a project located in a noise-sensitive environment, OBSI values above 106 to 108 dB(A) may be perceived as an issue to be addressed by the preservation treatment.

Finally, although the current age and conditions can be used to identify feasible treatments, it is important to consider when the preservation activity is expected or scheduled to occur. If there is a significant gap (≥1 year) between the time the latest condition data were collected and the time the treatment is likely to be constructed, then it is recommended that treatment selection be based on forecasted conditions, if possible. The forecasted conditions can be developed using the historical performance data (overall indicator, individual distress types and severities, smoothness, friction, and so on) collected for the subject pavement and projecting their trends to the time in which the preservation activity will occur. Depending on the time gap and the historical trends, this could greatly affect the types of preservation treatments identified as being feasible.

Final Identification of Feasible Preservation Treatments

Once a preliminary list of feasible treatments has been developed, further evaluation is needed to determine which of the treatments largely satisfies the needs and constraints of the project. The evaluation matrices in Tables 3.4 and 3.5 can be used for this purpose. The information presented serves as a guide with respect to the treatments most commonly and successfully used by highway agencies on high-traffic-volume roadways (subdivided by rural and urban settings) located in different climatic regions.

In these matrices, the appropriateness of a treatment is designated by the same series of symbols used in Tables 3.2 and 3.3 (● for highly recommended down to ✕ for not recommended). In addition to identifying work zone duration restrictions (i.e., the time period needed following the placement of a treatment until the treated pavement can be opened to traffic) associated with each treatment, these matrices also provide expected treatment performance ranges and relative treatment cost information. The expected performance ranges are based on high-traffic-volume application, but do not take into account the effects of existing pavement condition, climate, and construction quality risk. To account for these factors on each candidate treatment, it is suggested that values near the lower limit of the performance range be used for pavements in fair condition and located in a severe climate (i.e., deep-freeze climate zone). On the flip side, it is suggested that values near the upper limit of the range be used for pavements in good condition and located in a mild climate (i.e., nonfreeze climatic zone).

A logical, systematic way of accounting for construction quality risk is to apply a confidence factor to the expected performance range, with a factor of 1.0 representing 100% confidence, 0.75 representing 75% confidence, and so on. Thus, if the expected performance of a treatment ranges from 4.0 to 6.0 years and the level of confidence is 75% (reflecting some shortcomings in agency/contractor experience and/or materials quality), then the range would be reduced to between 3.0 to 4.5 years.

In addition to the treatment performance and relative cost information (which could be impacted by funding constraints)

Table 3.2. Feasibility Matrix for Preliminary Identification of Candidate Preservation Treatments for HMA-Surfaced Pavements

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

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

[a] Porous surface mix problem.

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

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

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

[e] Localized application in the case of bumps.

(continued on next page)

Table 3.2. (continued)

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

Table 3.3. Feasibility Matrix for Preliminary Identification of Candidate Preservation Treatments for PCC-Surfaced Pavements

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

Note: ● = Highly Recommended; ⊙ = Generally Recommended; ○ = Provisionally Recommended; × = Not Recommended.
[a] May be appropriate in conjunction with partial- and/or full-depth repairs to ensure smooth profile.
[b] Isolated incidences of D-cracking only.
[c] Isolated incidences of faulting only.
[d] Likely needed in conjunction with diamond grinding.

(continued on next page)

provided in Tables 3.4 and 3.5, factors such as the time of year of treatment construction, availability of quality materials and qualified contractors, roadway geometrics (e.g., horizontal and/or vertical curves, intersections, pavement markings/striping, curb-and-gutter), traffic accommodation and safety issues, and environmental considerations (e.g., emissions and air quality, recycling and sustainability issues), should be properly considered. This process should result in a final list of feasible treatments that can be analyzed for cost-effectiveness, leading to a selection of the preferred treatment.

Appendix B provides two example illustrations for using the feasibility matrices in Tables 3.2 through 3.5 to identify final treatment candidates. One example is for treatment of an HMA-surfaced pavement, while the other is for treatment of a PCC-surfaced pavement.

Treatment Cost-Effectiveness Analysis

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

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

Each approach requires reliable, up-to-date estimates of the cost and performance of the treatments to be analyzed. Historical bid price data are an excellent source for developing treatment cost estimates, but these data must be adjusted to current values to account for the effects of inflation. To the extent possible, care should be exercised in developing estimated costs so that they account for project-specific factors, such as size

Table 3.3. (continued)

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

(quantity of treatment needed), site-specific surface preparation requirements (such as material removal, patching, and cleaning), special traffic control requirements, and various contingencies (e.g., striping and pavement marker removal/replacement and associated shoulder work), that may have impacted the documented treatment costs. Also, to ensure a fair cost comparison of all treatment options, the final estimated costs should be based on a common unit of measure, such as $/yd² or $/lane-mi.

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

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

Equivalent Annual Cost

The EAC method of cost-effectiveness is an inverse measure of the proverbial "bang for the buck." It involves a simple calculation of the treatment unit cost divided by the expected treatment performance, as shown below.

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

In this analysis method, the expected treatment performance is the extension in service life of the pavement generated

Table 3.4. Feasibility Matrix for Final Identification of Candidate Preservation Treatments for HMA-Surfaced Pavements

	Treatment Durability								Work Zone Duration Restrictions				
	Rural Roads				Urban Roads								
		Climatic Zone				Climatic Zone							
Preservation Treatment	High Traffic ADT >5,000 vpd	Deep Freeze	Moderate Freeze	Nonfreeze	High Traffic ADT >10,000 vpd	Deep Freeze	Moderate Freeze	Nonfreeze	Overnight or Single Shift	Weekend	Longer	Expected Performance on High-Volume Facility (yr)	Relative Cost
Crack fill	●	●	●	●	●	●	●	●	●			2–3	$
Crack seal	●	●	●	●	●	●	●	●	●			2–6	$
Slurry seal (Type III)	○	×	⊙	⊙	○	×	⊙	⊙	●			3–5	$$
Microsurfacing: Single	⊙	⊙	●	⊙	⊙	⊙	●	⊙	●			3–5	$$
Microsurfacing: Double	⊙	⊙	●	⊙	⊙	⊙	●	⊙	●			4–6	$$/$$$
Chip Seal: Single Conventional Polymer modified	⊙	●	⊙	⊙	⊙	⊙	⊙	⊙	●			4–6	$$ $$$
Chip Seal: Double Conventional Polymer modified	⊙	●	⊙	⊙	⊙	⊙	⊙	⊙	●			6–8	$$/$$$ $$$
Ultra-thin bonded wearing course	⊙	⊙	●	⊙	⊙	⊙	●	⊙	●			5–8	$$$
Ultra-thin HMAOL	○	○	⊙	×	⊙	⊙	●	○	●			4–7	$$
Thin HMAOL	●	●	●	⊙	●	●	●	⊙	●			5–10	$$$
Cold milling and thin HMAOL	●	●	●	⊙	●	●	●	●	●			6–11	$$$
Hot in-place recycling Surf recycle and HMAOL Remixing and HMAOL Repaving	○	○	○	×	○	○	⊙	○	●			5–8 6–12 6–12	$$$ $$$ $$$
Cold in-place recycling and HMAOL	⊙	⊙	⊙	○	⊙	⊙	⊙	⊙	●			5–11	$$$
Profile milling	⊙	○	⊙	⊙	⊙	○	●	⊙	●			2–4	$
Ultra-thin whitetopping	○	○	○	○	○	○	⊙	○	×	○	⊙	NA	$$$$

Note: ● = Highly Recommended; ⊙ = Generally Recommended; ○ = Provisionally Recommended; × = Not Recommended.
$ (lowest relative cost) ↔ $$$$ (highest relative cost).

Table 3.5. Feasibility Matrix for Final Identification of Candidate Preservation Treatments for PCC-Surfaced Pavements

	Treatment Durability								Work Zone Duration Restrictions				
	Rural Roads				Urban Roads								
		Climatic Zone				Climatic Zone							
Preservation Treatment	**High Traffic ADT >5,000 vpd**	**Deep Freeze**	**Moderate Freeze**	**Nonfreeze**	**High Traffic ADT >10,000 vpd**	**Deep Freeze**	**Moderate Freeze**	**Nonfreeze**	**Overnight or Single Shift**	**Weekend**	**Longer**	**Expected Performance on High-Volume Facility (yr)**	**Relative Cost**
Concrete joint resealing	●	⊙	●	●	●	●	●	●	●			4–7	$
Concrete crack sealing	●	⊙	●	●	●	⊙	●	●	●			4–6	$
Diamond grinding	●	⊙	●	●	●	⊙	●	●	●			6–12	$$
Diamond grooving	⊙	×	⊙	×	●	×	⊙	⊙	●			6–12	$$
Partial-depth patching	●	●	●	●	⊙	⊙	●	●	●[a]	●[a]	●	5–15	$$/$$$
Full-depth patching	●	●	●	●	●	●	●	●	●[a]	●[a]	●	10–15	$$/$$$
Dowel bar retrofitting	⊙	●	●	●	⊙	⊙	⊙	●	●[a]	●[a]	●	10–15	$$$
Ultra-thin bonded wearing course	○	⊙	⊙	×	⊙	×	⊙	⊙	●			5–7	$$$
Thin HMA overlay	○	×	●	×	⊙	×	⊙	⊙	●			5–8	$$$

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

$ (lowest relative cost) ↔ $$$$ (highest relative cost).

[a] Use of high early strength or fast-track proprietary materials make these treatments suitable options for overnight, single-shift, and weekend closures. Use of conventional PCC repair materials generally requires “longer” closures.

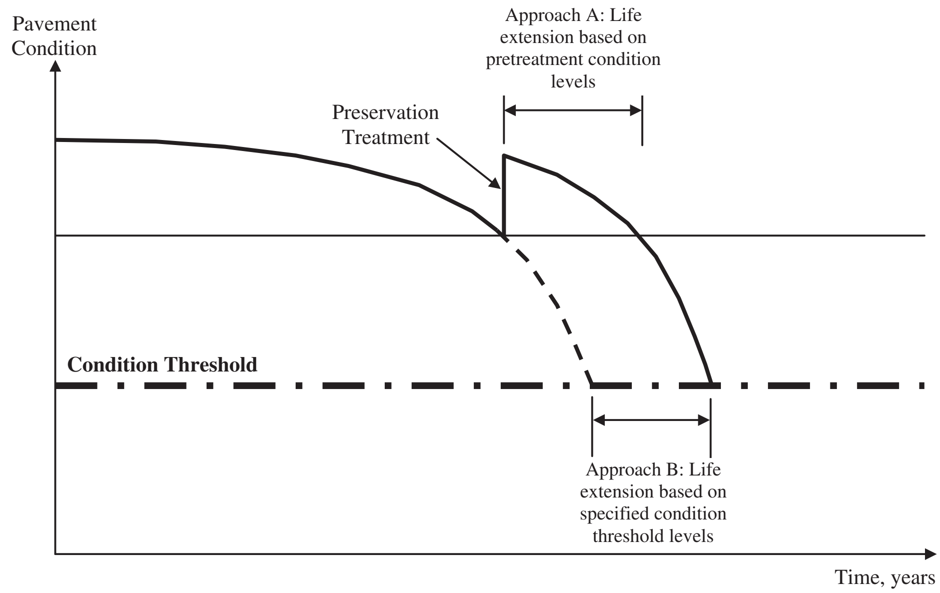


Figure 3.2. Estimation of preservation treatment performance using two approaches to pavement life extension.

by the preservation treatment. Although this extension may be easily identified as (a) the time taken for the pavement condition or serviceability/smoothness to return to the level it was at immediately prior to the treatment, a more discerning appraisal uses (b) the *difference* between the time taken for the treated pavement to deteriorate to a certain threshold level and the time taken for the untreated pavement to deteriorate to the same threshold level. Both approaches are illustrated in Figure 3.2.

Benefit-Cost Ratio

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

In the BCR method, the benefits associated with a particular preservation strategy are evaluated from the standpoint of benefits accrued to the highway user over a selected analysis period (usually 25 to 40 years, beginning from the original construction). They are quantified by computing the area under the pavement performance curve, which is defined by the expected timings of future preservation and rehabilitation treatments and the corresponding jumps and subsequent deterioration in condition or serviceability/smoothness. The expected timings are determined from service life analyses of the existing pavement and the specific rehabilitation treatments, and from the service life extensions estimated for the preservation treatment.

The top portion of Figure 3.3 illustrates the assessment of benefits using the area-under-the-performance-curve approach. A treatment alternative with more area under the curve yields greater benefit through higher levels of condition or serviceability/smoothness provided to the highway users.

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

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

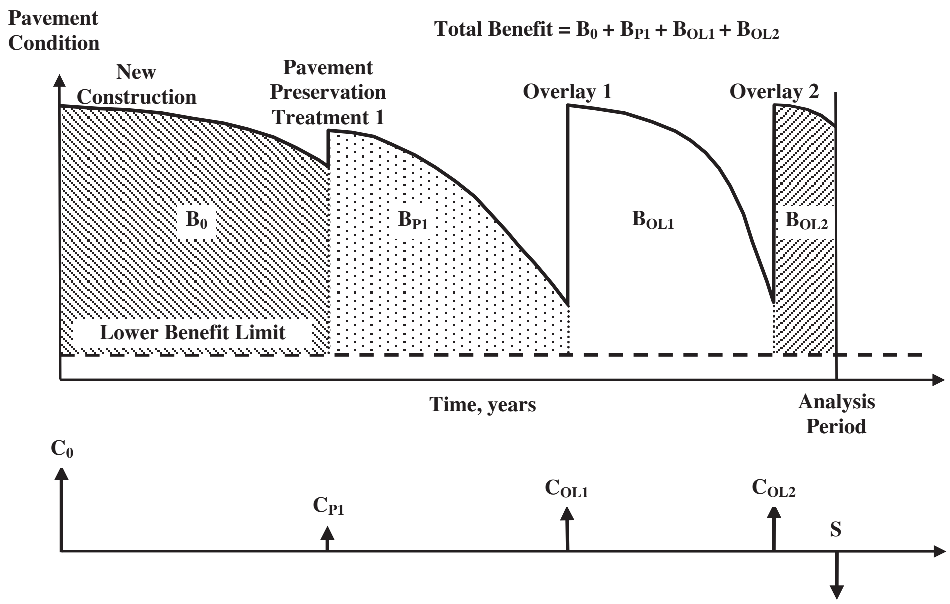


Figure 3.3. Illustration of benefits and costs associated with a pavement preservation treatment strategy.

where

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

The bottom portion of Figure 3.3 illustrates the stream of costs included in the LCCA. These costs occur in accordance with the preservation and rehabilitation treatment timings established and used in the analysis of benefits. They represent the costs paid by the agency to construct the existing pavement and apply the subsequent preservation and rehabilitation treatments.

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

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

$$B/C = \text{Benefit}/\text{NPV} \quad (3)$$

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

Consideration of User Costs

User costs are defined as nonagency costs that are borne by the users of a pavement facility (Peshkin et al. 2004). User costs can be incurred through various mechanisms and at any time over the life of a project. Overall, there are five primary mechanisms of user costs:

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

costs are primarily comprised of the costs of human fatalities, nonfatal injuries, and accompanying property damage.
- *Discomfort costs.* Costs associated with driving in congested traffic or on rough roads.
- *Environmental costs.* Costs associated with traffic noise and with the operation of construction equipment in work zones.

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

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

The inclusion of user costs as part of any economic analysis of pavements is a controversial issue. While there is general agreement that traffic delays increase user costs, the actual costs can be difficult to quantify and often overwhelm the direct agency costs, particularly for high-volume facilities (Peshkin et al. 2004).

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

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

- In the EAC method, two aspects of user costs can be considered. The first aspect is the work zone user costs associated with each alternative preservation treatment. Since the work zone characteristics of each alternative will vary based on application rates, material setting/curing times, and other construction factors, the delays experienced as a result of the different work zone requirements will also vary.
- The second aspect is the work zone user costs associated with the timing of an assumed future rehabilitation at the end of the preservation treatment's expected life. A preservation treatment with a longer forecasted life results in a delay in the timing of the assumed rehabilitation. When discounted to present-day costs, the work zone user costs associated with the rehabilitation will be lower than the same rehabilitation work zone user costs associated with a shorter life-preservation treatment. This is illustrated in Figure 3.4.
- In the BCR method, the user costs of all future preservation and rehabilitation treatments associated with each preservation strategy can be computed as part of the LCCA. Although the user cost NPV results may be combined with the agency cost NPV results, it is generally recommended that they be examined separately because of the possibility that they will overwhelm the agency costs.

Selection of the Preferred Preservation Treatment

Although treatment cost-effectiveness is a major consideration in the selection of the preferred treatment, it is not the final answer in the process. The reality of the decision-making process is that many other factors (economic and noneconomic) must be considered along with cost-effectiveness. Some of these factors may have been previously considered as part of the steps to identify feasible treatments, yet may also be desired for consideration in the final selection. Examples include the availability of qualified (and properly equipped) contractors and quality materials, the anticipated level of traffic disruption, and surface characteristics issues.

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

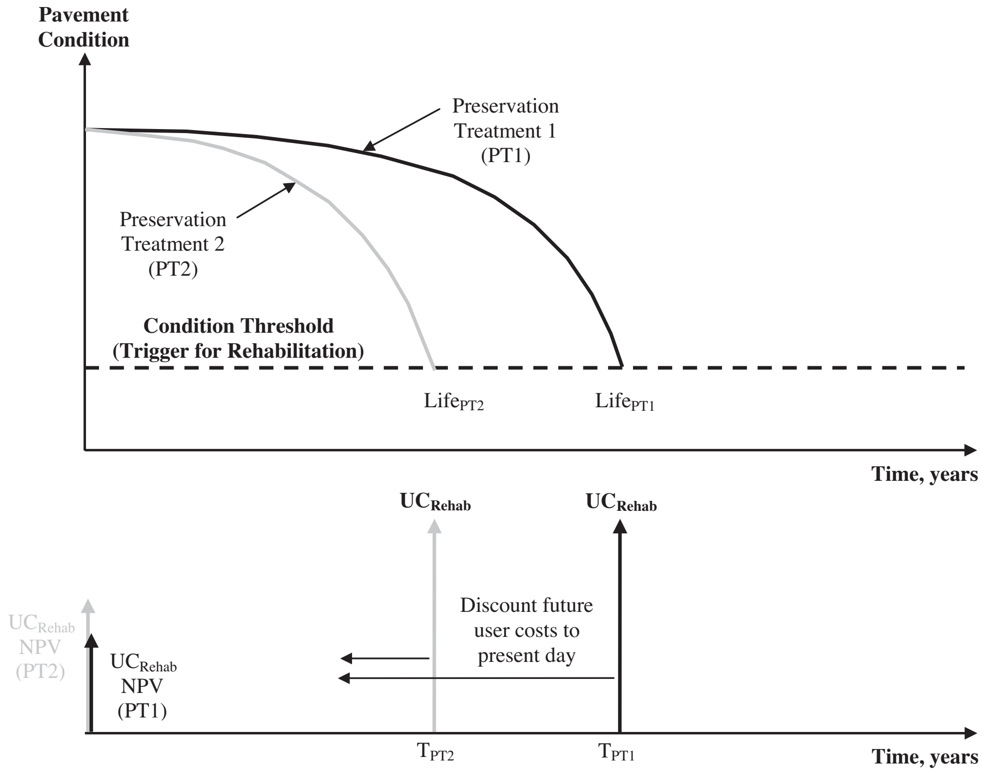


Figure 3.4. Effect of preservation treatment life on discounted rehabilitation user costs.

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

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

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

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

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

A decision matrix that incorporates these factors and illustrates the assignment of weights and the basis for rating scores is provided in Table 3.6.

Table 3.6. Example of Preservation Treatment Decision Matrix

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

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

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APPENDIX A

Preservation Treatment Summaries

This appendix contains technical summaries for each of the preservation treatments covered in this document. The summaries, which are presented in a tabular format, include treatment descriptions, the key pavement conditions they address, and construction and other considerations (including expected performance and estimated costs). They also provide a listing of reference materials that users can access to get up-to-date information on each treatment.

Table A.1. Technical Summary for Crack Sealing and Crack Filling

<table>
<tr><th colspan="3">Crack Sealing and Crack Filling</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Crack filling involves the placement of an adhesive material into and/or over nonworking 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 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.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking
• Transverse cracking
• Reflection cracking
• Minor block cracking</td><td>Structural: Crack sealing may be applied to structural (i.e., fatigue or reflection) cracks early in their development. While sealing provides no structural benefit, keeping moisture out of the pavement structure may slow down the progression of load-related cracking.</td></tr>
<tr><td>Noise: Overband applications may increase pavement noise. Similarly, wide cracks contribute to a louder riding surface.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Material selection requirements to consider include adhesion, softening resistance, flexibility, pot life, weather resistance, and cure time.
• In deciding between hot- and cold-applied crack fillers, consider the size and types of cracks. Hot-applied crack fillers are better suited to 0.5 in. wide or larger expanding cracks (large longitudinal, transverse, and reflective cracks), while cold crack fillers work better in smaller cracks less than 0.5 in. wide.
• Cracks should be clean and dry. Cleaning is essential to good bond and maximum performance.
• A variety of placement configurations are used based on local experience, materials, snow plow use, anticipated subsequent treatments, and aesthetic considerations.
• Sealants and fillers should be allowed to set before being subjected to traffic.
• Sealants and fillers require curing before another treatment is applied to the surface. Emulsions usually require several days to cure, while hot-applied crack fillers take 3 to 4 months.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Crack filling: $0.10 to $1.20/ft ($)
• Crack sealing: $0.75 to 1.50/ft ($)</td><td>Treatment Life (yr):
• Crack filling: 2 to 4
• Crack sealing: 3 to 8

Pavement Life Extension (yr):
• Crack filling: NA
• Crack sealing: 2 to 5</td></tr>
<tr><td colspan="2">• Safety: Extensive crack sealing may require blotting to maintain the pavement's skid resistance.
• Risk: Improper installation can cause sealant or filler material to fail. Overband applications should be avoided on heavily trafficked roadways due to high tensile stresses directly above crack edges, resulting in edge separations. Overband applications are susceptible to snowplow damage.
• Climate: Placement should take place during moderate temperatures when the pavement is dry. The manufacturer's guidelines should be followed, but a good range of ambient temperatures is 45°F to 65°F.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Tracking of seal or fill material by tire action may obscure lane markings and adversely affect skid resistance. Applying a blotter coat of sand can reduce such "tracking." There are other products and means available to reduce surface tackiness.
• There is a point at which excessive cracking is better addressed by a "blanket" solution, such as a surface treatment or milling. Aesthetic considerations may limit the acceptable amount of crack sealed surface.
• Rough riding surface may occur during warm months when sealant or filler material is compressed and bulges out of the crack.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Manual of Practice: Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements. Report FHWA-RD-99-147. Federal Highway Administration, U.S. Department of Transportation, 1999.
• Pavement Preservation Checklist Series: 1. Crack Seal Application. Publication FHWA-IF-02-005. Federal Highway Administration, U.S. Department of Transportation, 2001.</td></tr>
</table>

Table A.2. Technical Summary for Slurry Seals

<table>
<tr><th colspan="3">Slurry Seals</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Slurry seals are 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. Slurry seals are effective in sealing low-severity surface cracks, waterproofing the pavement surface, and improving friction at speeds below 30 mph.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking
• Transverse cracking
• Raveling/weathering
• Friction loss
• Moisture infiltration
• Roughness</td><td>Structural: Slurry seals do not add structural capacity.

Pavement with cracking and areas of high deflection are not good candidates for slurry seals.</td></tr>
<tr><td>Noise: Slurry seals are partly capable of reducing tire–pavement noise.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Special consideration should be given to raised pavement markers and bump grinding prior to treatment placement.
• It is strongly recommended to address needed patching and crack sealing prior to placement.
• Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants.
• Aggregates should be clean, angular/cubical, durable, and uniform.
• Industry guidelines and recommendations regarding application temperatures and dry conditions should be followed.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Single-course: $0.75 to $1.00/yd² ($$)</td><td>Treatment Life (yr):
• 3 to 5

Pavement Life Extension (yr):
• 4 to 5</td></tr>
<tr><td colspan="2">• Risk: Slurry seals can accelerate the development of stripping in susceptible HMA pavements.
• Climate: Slurry seals perform effectively in all climatic conditions. However, best performance occurs in warm climates with low daily temperature cycles.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Slurry seals can be modified (i.e., aggregate quality, gradation) to accommodate higher traffic volumes (Type 3).
• Dusting with a blotter material can allow earlier opening of intersections and turning lanes.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Recommended Performance Guidelines for Emulsified Asphalt Slurry Seal. Report A105. International Slurry Surfacing Association, Annapolis, Md., 2005.
• Pavement Preservation Checklist Series: 13. Slurry Seal Application. Publication FHWA-IF-06-014. Federal Highway Administration, U.S. Department of Transportation, 2005.
• Slurry Seal/Micro-Surface Mix Design Procedure. Phase I Report, Caltrans Project 65A0151. California Department of Transportation, Sacramento, 2004.</td></tr>
</table>

Table A.3. Technical Summary for Microsurfacing

<table>
<tr><th colspan="3">Microsurfacing</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Microsurfacing is a mixture of crushed, well-graded aggregate, mineral filler (portland cement), and latex-modified emulsified asphalt spread over the full width of pavement with either a squeegee or spreader box. Microsurfacing is used primarily to inhibit raveling and oxidation, as well as being effective at improving surface friction and filling minor irregularities and rutting (up to 1.5 in. deep).

Microsurfacing is usually applied in either a single or double application. A double application involves a rut-filling application followed by a full-lane width application.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking
• Transverse cracking
• Raveling/weathering
• Friction loss
• Moisture infiltration
• Bleeding
• Roughness</td><td>Structural: Microsurfacing does not add structural capacity. However, it can seal low-severity cracks, including fatigue cracks, and can be used to fill stable rutting up to 1.5 in. deep.

Pavement with cracking and areas of high deflection are not good candidates for microsurfacing.</td></tr>
<tr><td>Noise: Microsurfacing may reduce tire–pavement noise depending on the aggregate used.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Special consideration should be given to raised pavement markers and bump grinding prior to treatment placement.
• It is strongly recommended to address needed patching and crack sealing prior to placement.
• Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants.
• Aggregates should be clean, angular/cubical, durable, and uniform, as well as chemically compatible with emulsion system.
• Industry guidelines and recommendations regarding application temperatures and dry conditions should be followed.
• Microsurfacing typically can carry traffic after approximately 1 hour.
• Allow minimum 7 days before applying permanent pavement markers and striping.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Single-course: $1.50 to $3.00/yd² ($$)</td><td>Treatment Life (yr):
• Single-course: 3 to 6
• Multiple-course: 4 to 7

Pavement Life Extension (yr):
• Single-course: 3 to 5
• Multiple-course: 4 to 6</td></tr>
<tr><td colspan="2">• Risk: Early damage can occur at down grade locations or where there is heavy truck turning; in such areas, rolling before opening to traffic may improve durability. Vehicle damage can occur if seals do not set or bond, which will occur if placed during inclement weather.
• Climate: Placement should occur when temperature is 50°F and rising, and the forecast for the next 24 hours is above 40°F. Placement should avoid rain and hot or freezing temperatures.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Similar to slurry seals, microsurfacing can be modified (i.e., aggregate quality, gradation) to also accommodate higher traffic volumes.
• Dusting with a blotter material can allow earlier opening of intersections and turning lanes.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Recommended Performance Guidelines for Microsurfacing. Report A143. International Slurry Surfacing Association, Annapolis, Md., 2005.
• Pavement Preservation Checklist Series: 5. Microsurfacing Application. Publication FHWA-IF-03-002. Federal Highway Administration, U.S. Department of Transportation, 2002.
• Slurry Seal/Micro-Surface Mix Design Procedure. Phase I Report, Caltrans Project 65A0151. California Department of Transportation, Sacramento, 2004.</td></tr>
</table>

Table A.4. Technical Summary for Chip Seals

<table>
<tr><th colspan="3">Chip Seals</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Chip seals consist of a sprayed application of asphalt (commonly an emulsion, although heated asphalt cement and cutbacks are used as well) directly to the pavement surface (0.35 to 0.50 gal/yd^2), followed by application of aggregate chips (15 to 50 lb/yd^2), which are then immediately rolled to achieve 50% to 70% embedment. The treatment is used to seal the pavement surface against weathering, raveling, or oxidation, correct minor roughness or bleeding, and improve friction. Chip seals can be applied in multiple layers (e.g., double chip seal), and in combination with other treatments, such as microsurfacing, which is called a cape seal and reduces concerns associated with loose chips and a rough surface. Chip seal design variations include the following (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. Inverted double chip seal, in which a smaller-sized aggregate chip seal is placed first, followed by a larger-sized aggregate chip seal.
• Cape seal. Combination of a chip seal and slurry seal, with the slurry seal 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 slurry cover increases the life of the chip seal by the enhanced binding of the aggregate chips.
• Geotextile-reinforced seal. Application of geotextile over a tack coat, followed by application of a single-course chip seal.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking
• Transverse cracking
• Block cracking
• Friction loss
• Bleeding
• Roughness
• Moisture infiltration</td><td>Structural: Adds no structural benefit. Because of its flexibility, a chip seal is more effective at sealing low- to medium-severity fatigue cracks in comparison with other treatments.</td></tr>
<tr><td>Noise: Will typically require application of a slurry seal or microsurfacing to provide a quiet riding surface.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Application rates depend upon aggregate gradation and maximum size, as well as absorption of existing pavement surface.
• Special consideration should be given to raised pavement markers and bump grinding prior to treatment placement.
• Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants.
• Chip spreader should follow immediately behind asphalt distributor and rollers close behind spreader.
• Normal traffic speeds should not resume until after curing (typically 2 hours).
• Avoid prematurely applying permanent pavement markers and striping.
• Brooming is often required to remove loose chips; however, brooming before the emulsion has set hard may strip away properly seated aggregate.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Single-course conventional: $1.50 to $2.00/yd^2 ($$)
• Single-course polymer-modified: $2.00 to $4.00/yd^2 ($$$)</td><td>Treatment Life (yr):
• Single-course: 3 to 7
• Double-course: 5 to 10
Pavement Life Extension (yr):
• Single-course: 5 to 6
• Double-course: 8 to 10</td></tr>
<tr><td colspan="2">• Safety: Loose aggregate may increase stopping distance, reduce vehicle control.
• Risk: Primary risk is due to damage claims from loose aggregate. Pilot cars can be used to minimize damage to the fresh surface, as well as windshield/vehicle damage due to whip-off on high speed roadways.
• Climate: Performs well in all climatic environments. Placement should occur when the temperature in the shade is above 55°F. Avoid placement during cold and/or wet weather conditions.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• With special design and placement considerations, treatment can perform well on high-volume roads. For example, use a rapid-set emulsion or polymer- or rubber-modified binder in the mix design, apply a smaller sized “choke” aggregate to lock in larger chips, limit excess chips to 5% to 10%, or apply a cape seal (slurry or microsurfacing seal over the chip seal).
• The dusting of a blotter material can be used to allow for earlier opening of intersections and turning lanes.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Gransberg, D., and D. M. B. James. NCHRP Synthesis of Highway Practice 342: Chip Seal Best Practices. Transportation Research Board of the National Academies, Washington, D.C., 2005.
• Pavement Preservation Checklist Series: 2. Chip Seal Application. Publication FHWA-IF-02-046. Federal Highway Administration, U.S. Department of Transportation, 2002.</td></tr>
</table>

Table A.5. Technical Summary for Ultra-Thin Bonded Wearing Course

<table>
<tr><th colspan="3">Ultra-Thin Bonded Wearing Course</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Also known as an ultra-thin friction course, an ultra-thin bonded wearing course may be used as an alternative treatment to chip seals, microsurfacing, or thin HMA overlays. This consists of a gap-graded, polymer-modified HMA layer (0.4 to 0.8 in. thick) placed on a tack coat (heavy, polymer-modified emulsified asphalt). It is effective at treating minor surface distresses and increasing surface friction.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking*
• Transverse cracking*
• Block cracking*
• Raveling/weathering
• Friction loss
• Bleeding
• Roughness</td><td>Structural: Treatment does not add structural benefit, but does retard fatigue cracking and can address stable rutting less than 0.5 in. deep.</td></tr>
<tr><td>Noise: Effective tire-pavement noise reduction similar to that of open-graded, thin HMA overlays.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Requires special paving equipment and a license to place.
• Special consideration should be given to bump grinding prior to treatment placement.
• Cracks greater than 0.25 in. wide should be sealed prior to placement.
• Strongly recommended to repair localized structural problems prior to placement.
• Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants. Oil and fuel stains should be thoroughly cleaned as well.
• Treatment can be opened to traffic shortly after the rolling operation is complete and the material has cooled below 185°F (potentially as soon as half an hour after placement).</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• $4.00 to 6.00/yd² ($$$)</td><td>Treatment Life (yr):
• 7 to 12
Pavement Life Extension (yr):
• NA</td></tr>
<tr><td colspan="2">• Climate: Performs well in all environments. Placement should occur when the temperature is above 50°F. Avoid placement during cold and/or wet weather conditions. Placement on a damp pavement surface is acceptable; however, the pavement should be free of standing water, and favorable weather conditions should be expected to follow.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Typically a proprietary product (e.g., NovaChip).
• Capable of withstanding high ADT and truck levels better than many other thin treatments.</td></tr>
<tr><td>Additional Resources</td><td colspan="2"></td></tr>
</table>

*High severity cracking can be better addressed with cold milling and overlay.

Table A.6. Technical Summary for Thin and Ultra-Thin HMA Overlays

Thin and Ultra-Thin HMA Overlays (with or without milling)	
Treatment Description	Thin and ultra-thin HMA overlays are 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 1.50 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; typically smoother than dense-graded HMA. • **Stone matrix asphalt (SMA).** A gap-graded mix designed to maximize rut resistance and durability using stone-on-stone contact. 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.
Conditions Addressed	**Functional/Other** • Longitudinal cracking • Transverse cracking • Raveling/weathering • Block cracking • Friction loss • Bleeding • Roughness • Splash and spray (open graded) **Structural:** While thin and ultra-thin HMA overlays should not be used to address structural deficiencies, greater structural benefit in terms of load-carrying capability is possible the thicker the overlay. Rutting can be addressed with a separate rut-fill application before overlay placement. **Noise:** Open-graded thin HMA overlays are effective at reducing tire–pavement noise. Cold milling provides a smoother riding surface by removing vertical deformations.
Construction Considerations	• Maximum size aggregate should not be more than one-half the overlay thickness (note that Superpave mix designs have their own requirements). • If milling is not done in conjunction with overlay application, special consideration should be given to bump grinding prior to treatment placement. • Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants; a tack coat applied prior to overlay application will improve bond to existing surface. • Because thin and ultra-thin HMA overlays dissipate heat rapidly, it is important to specify minimum placement temperatures and to obtain timely compaction. • Treatment can be opened to traffic after approximately 1 to 2 hours. Recommendations for obtaining a quality milled surface: • Perform pavement patching prior to milling. • Remove pavement castings and cover holes prior to milling. • Use a good working milling machine (12-ft recommended width). • Control milling speed to achieve a smooth, uniform surface (≤30 ft/min). • Use a 30-ft ski and stringline to control grade and longitudinal guidance.
Miscellaneous Considerations	**Cost (Relative Cost, $ to $$$$):** • Dense-graded ultra-thin: $2.00 to $3.00/yd² ($$) • Dense-graded thin (no milling): $3.00 to $6.00/yd² ($$$) • Dense-graded thin (with milling): $5.00 to $10.00/yd² ($$$) **Treatment Life (yr):** • Dense-graded ultra-thin: 4 to 8 • Dense-graded thin (no milling): 5 to 12 • Dense-graded thin (with milling): 5 to 12 **Pavement Life Extension (years):** • Dense-graded ultra-thin: NA • Dense-graded thin: (no milling): NA • Dense-graded thin: (with milling): NA • **Risk:** Though not significantly affected by ADT or truck levels, certain combinations of loadings, environmental conditions, and pavement structure can initiate top-down cracking. Performance will vary according to factors affecting pavement weathering/raveling. Furthermore, treatment can be subject to delamination and reflective cracking. A tack coat prior to overlay placement will help improve bond. • **Climate:** Dense-graded and gap-graded mixes perform well in all environments. The performance of open-graded mixes can be significantly adversely impacted by freeze-thaw environments.
Other Remarks	
Additional Resources	• Newcomb, D. E. *Information Series 135: Thin Asphalt Overlays for Pavement Preservation.* National Asphalt Pavement Association, Lanham, Md., 2009. • *Pavement Preservation Checklist Series: 3. Thin HMA Overlay Application.* Publication FHWA-IF-02-049. Federal Highway Administration, U.S. Department of Transportation, 2002.

Table A.7. Technical Summary for Hot In-Place Recycling

Hot In-Place Recycling		
Treatment Description	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 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, combined with new asphalt, and relaid for the purpose of minor mix improvement/modification. In single-pass surface recycling (low-volume roads), the recycled mix is relaid 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, combined with virgin aggregate and new asphalt (and/or new HMA), and relaid for significant mix improvement/modification and/or modest pavement strengthening. 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, combined with new asphalt, and relaid in tandem with an HMA overlay for the purposes of pavement strengthening and restoration of surface profile and/or friction. Repaving is surface recycling with an integrally applied thermally bonded overlay.	
Conditions Addressed	**Functional/Other** • Alligator, thermal, and surface cracking • Raveling/weathering • Friction loss • Bleeding • Roughness • Corrugation • Rutting	**Structural:** Treatment may add some structural benefit if additional surfacing is placed, and will reduce surface rutting. However, HIR is not recommended where there are excessive subgrade failures, wide cracking, or HMA thickness less than 3 in. **Noise:** Dependent on type and characteristics of finished surface. For example, HIR accompanied by an HMA overlay will result in a low-noise pavement, whereas higher noise levels will be experienced by HIR "capped" with a chip seal.
Construction Considerations	• Requires a length train of specialized equipment. • Recommended to repair localized structural problems prior to placement. • Presence of rubber in the surface lift (e.g., rubberized seals, some crack fillers) requires special attention during the HIR mix design process. • Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants. • Like HMA overlays, treatment can be opened to traffic after approximately 1 to 2 hours.	
Miscellaneous Considerations	**Cost (Relative Cost, $ to $$$$):** • Surface recycle (excluding thin HMA overlay): $2.00 to $3.00/yd² ($$) • Remix (excluding thin HMA overlay): $3.00 to $6.00/yd² ($$$) • Repaving: $3.50 to $7.00/yd² ($$$)	**Treatment Life (yr):** • Surf recycle and HMA overlay: 6 to 10 • Remix and thin HMA overlay: 7 to 15 • Repaving: 6 to 15 **Pavement Life Extension (yr):** • Surf recycle and HMA overlay: NA • Remix and thin HMA overlay: NA • Repaving: NA
	• **Safety:** Crack sealant should be removed prior to placement to reduce risk of flash fires or excessive blue smoke. • **Climate:** Although HIR treatment can perform well in all climatic conditions, placement should not occur when temperature is below 50°F, or when it is raining.	
Other Remarks	• HIR is appropriate for low- to high-volume roads; however, the surface recycling and remixing techniques should be supplemented with an overlay or surface treatment when used on moderate- to high-volume roads. Also, because the recycling equipment is relatively large, short road sections, particularly in urban settings, are not suitable. • HIR can be expected to produce about 1 to 2 lane mi/day. However, nighttime operations will be subject to reduced production rates and increased cost.	
Additional Resources	• *Basic Asphalt Recycling Manual.* Asphalt Recycling and Reclaiming Association, Annapolis, Md., 2004. • *Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book.* Publication FHWA-SA-98-042. Federal Highway Administration, U.S. Department of Transportation, 1997. • *Pavement Preservation Checklist Series: 11. Hot In-Place Recycling Application.* Publication FHWA-IF-06-011. Federal Highway Administration, U.S. Department of Transportation, 2005.	

Table A.8. Technical Summary for Cold In-Place Recycling

Cold In-Place Recycling		
Treatment Description	Cold in-place recycling (CIR) is 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 relaid 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. Its 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 overlay or surface treatment.	
Conditions Addressed	**Functional/Other** • Longitudinal, transverse, and surface cracking • Raveling/weathering • Friction loss • Bleeding • Roughness • Corrugation • Rutting • Bumps/sags	**Structural:** CIR may add some structural benefit if additional surfacing is placed, and it will reduce surface rutting. As a preservation treatment, CIR is not recommended where there are excessive subgrade failures, wide cracking, or HMA thickness less than 3 in. **Noise:** Dependent on type and characteristics of finished surface. For example, CIR accompanied by an HMA overlay will result in a low-noise pavement, whereas higher noise levels will be experienced by CIR "capped" with a chip seal.
Construction Considerations	• Requires a lengthy train of specialized equipment, which can create difficulties when working on roads with tight situations or when the project has limited areas for overnight parking/storage of the equipment. • Recommended to repair localized structural problems prior to placement. • Presence of rubber in the surface lift (e.g., rubberized seals, some crack fillers) requires special attention during the CIR mix design process. • Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants. • Depending on the type of emulsion used and the environmental conditions, the CIR-recycled layer can be compacted after 1 to 2 hours, when the emulsion begins to break. • Placement of an HMA wearing course or surface treatment on the CIR-recycled layer requires that the recycled layer be given proper curing time (typically, 10 to 14 days).	
Miscellaneous Considerations	**Cost (Relative Cost, $ to $$$$):** • CIR (excluding thin HMA overlay): $1.25 to $3.00/yd² ($$)	**Treatment Life (yr):** • CIR and thin HMA overlay: 6 to 15 **Pavement Life Extension (yr):** • CIR and thin HMA overlay: NA
	• **Climate:** Curing problems can occur if CIR is undertaken in cold, damp conditions typical of late fall or early spring weather.	
Other Remarks		
Additional Resources	• *Basic Asphalt Recycling Manual*. Asphalt Recycling and Reclaiming Association, Annapolis, Md., 2004. • *Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book*. Publication FHWA-SA-98-042. Federal Highway Administration, U.S. Department of Transportation, 1997. • *Cold Recycling Manual,* 2nd ed. Wirtgen Group, Windhagen, Germany, 2004. • *Pavement Preservation Checklist Series: 12. Cold In-Place Recycling Application*. Publication FHWA-IF-06-012. Federal Highway Administration, U.S. Department of Transportation, 2005.	

Table A.9. Technical Summary for Ultra-Thin Whitetopping

<table>
<tr><th colspan="3">Ultra-Thin Whitetopping</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Ultra-thin whitetopping (UTW) involves the placement of a thin (2 to 4 in.) PCC layer, with slab dimensions between 2 and 6 ft, over an existing HMA-surfaced pavement. The primary purpose of UTW 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.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal, transverse, and surface cracking
• Raveling/weathering
• Friction loss
• Roughness
• Corrugation
• Rutting
• Shoving</td><td>Structural: UTW provides structural benefit, bonding to the existing HMA to increase load-carrying capacity. However, because UTW is a composite, the existing pavement and subbase should be structurally sound themselves to ensure overlay performance.</td></tr>
<tr><td>Noise: Noise considerations are typical of PCC pavements. On high-speed facilities in noise-sensitive environments, certain forms of texturing, such as longitudinal tining, are more suitable than other forms, such as uniform transverse tining, because they generate lower pavement–tire noise.

Producing smooth UTW surfaces also requires care during placement, such as maintaining consistent concrete production and avoiding interruptions in the forward motion of the screed or paver, which can lead to a bump or irregularities in the surface.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Before placement, distresses in the existing HMA pavement should be repaired, after which the surface should be cleaned (a mechanical broom or low pressure washer are adequate) of material detrimental to bonding the overlay to the existing pavement.
• Just before placement, the HMA surface should be lightly wetted (no pools of water) to prevent water from being drawn from the fresh concrete.
• If fiber reinforcement is used, efforts to minimize fiber balling should be taken.
• During placement, concrete should be placed evenly across the width of the paving area to avoid segregation and minimize additional spreading.
• Floating should be kept to a minimum. If finishing requires the frequent use of floats, adjustments may need to be made to the concrete mix or finishing machines.
• When whitetopping an uneven surface, placement should be such that the design thickness is maintained at the thinnest sections.
• Timing joint cutting is critical in preventing early age distress; sawing too early can result in raveling, while sawing too late may lead to random cracking. Early entry sawing can help to ensure that the joints are cut in a timelier manner.
• Opening to traffic is contingent upon concrete strength development and joint sawing.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• $15.00 to $25.00/yd^2 ($$$$)</td><td>Treatment Life (yr):
• NA

Pavement Life Extension (yr):
• NA</td></tr>
<tr><td colspan="2">• Risk: Lack of bond can result in corner breaks and/or surface failure.
• Climate: Although UTW can perform well in all climatic conditions, placement should not occur when temperature is below 50°F, or when it is raining. During construction, the most detrimental effects of climatic conditions occur at extreme temperature conditions, specifically at air temperatures greater than 90°F or less than 39°F.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• If not inlaid, curb and gutter may need to be replaced to meet the elevation of the UTW treatment.
• Transitions to adjacent pavement can be susceptible to damage if measures are not taken to provide adequate support or load transfer, such as gradually increasing whitetopping thickness to meet that of a new full-depth pavement or installing expansion joints for transitioning to an existing pavement.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Rasmussen, R. O., and D. K. Rozycki. NCHRP Synthesis of Highway Practice 338: Thin and Ultra-Thin Whitetopping. Transportation Research Board of the National Academies, Washington, D.C., 2004.</td></tr>
</table>

Table A.10. Technical Summary for Joint Resealing and Crack Sealing

<table>
<tr><th colspan="3">Joint Resealing and Crack Sealing</th></tr>
<tr><td>Treatment Description</td><td colspan="2">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.

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 (liquid sealants generally require the installation of backer rod to prevent the sealant from seeping down in the joint).

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.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking*
• Transverse cracking
• Corner cracking*</td><td>Structural: Crack sealing may be applied to structural cracks early in their development. While sealing provides no structural benefit, keeping moisture and incompressible materials out of the pavement structure may retard the rate of deterioration.</td></tr>
<tr><td>Noise: Overband applications and wide joints/cracks may generate excessive noise levels under traffic.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Critical material characteristics to consider when selecting a sealant include adhesiveness, cohesiveness, durability, extensibility, resilience, curing time, and shelf/pot life.
• Effective cleaning of the joint or crack is essential to achieving good bond and ultimately the performance of the sealant. The old sealant material must be removed from each joint/crack face, either by sawing or through mechanical means. After removal of the sealant material, the joint/crack faces should be sandblasted to remove any slurry or laitance.
• A variety of placement configurations may be employed, the selection of which is based on the sealant material used, local experience, snow plow use, anticipated subsequent treatments, and aesthetic considerations.
• Sealants should be "tack free" before being subjected to traffic (typically 1 to 2 hours).</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Joint resealing: $1.00 to $2.50/ft ($)
• Crack sealing: $0.75 to $2.00/ft ($)</td><td>Treatment Life (yr):
• Joint resealing: 2 to 8
• Crack sealing: 4 to 7

Pavement Life Extension (yr):
• Joint resealing: 5 to 6
• Crack sealing: NA</td></tr>
<tr><td colspan="2">• Risk: Improper installation can cause the sealant or filler material to fail. Overband applications should be avoided on heavily trafficked roadways due to high tensile stresses directly above crack edges, resulting in edge separations. Overband applications are also susceptible to snow plow damage.

• Climate: Performs well in all climatic environments. Sealants perform best in dry, warm environments without large daily temperature cycles. Placement should take place when the pavement is dry and during moderate temperatures (typically 45°F to 65°F, although the manufacturer's recommendations should be followed).</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Because resealing concrete joints is not a seasonal maintenance activity, periodic inspections should be scheduled to determine when treatment is necessary.
• If tracking is a concern, a detackifier or toilet paper can be applied.
• Increases in pavement roughness may occur during warm months when the sealant or filler material is compressed and bulges out of the joint or crack, particularly on long-jointed pavements or when excessive sealant was applied.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Manual of Practice: Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavement Joints. Report FHWA-RD-99-146. Federal Highway Administration, U.S. Department of Transportation, 1999.
• Smith, K. D., T. E. Hoerner, and D. G. Peshkin. Concrete Pavement Preservation Workshop—Reference Manual. Federal Highway Administration, U.S. Department of Transportation, 2008.
• Pavement Preservation Checklist Series: 6. Joint Sealing PCC Pavements. Publication FHWA-IF-03-003. Federal Highway Administration, U.S. Department of Transportation, 2002.</td></tr>
</table>

*Crack sealing is most effective when cracks do not exhibit faulting or spalling.

Table A.11. Technical Summary for Diamond Grinding and Grooving

<table>
<tr><th colspan="3">Diamond Grinding and Grooving</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Diamond grinding 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 saw blades. Diamond grinding removes joint faulting and other surface irregularities, thereby restoring a smooth-riding surface while also increasing surface friction and reducing noise emissions.

Diamond grooving 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.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Joint faulting (grinding)
• Slab curling/warping (grinding)
• Friction loss (grinding/grooving)
• Splash and spray (grooving)</td><td>Structural: Diamond grinding and diamond grooving do not provide any structural benefit to the existing pavement, nor do they address or correct the mechanisms of the pavement distress. However, diamond grinding does reduce dynamic loading effects by removing faulting and improving the overall smoothness of the pavement, which is linked to extended pavement life.</td></tr>
<tr><td>Noise: Diamond grinding is the most effective means of mitigating tire-pavement noise on existing concrete pavements. Diamond grooving may also reduce tire-pavement noise if done longitudinally.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• Aggregate type and hardness must be known because this will influence costs and productivity.
• Transverse grooving will be more difficult to do under traffic.
• Spacing of the diamond grinding saw blades is critical to the life expectancy and friction of the resulting pavement texture. For soft aggregate (such as limestones), the spacing between blades is typically about 0.10 in., whereas for harder aggregate (such as river gravels) the spacing between blades is on the order of 0.08 in.
• Grinding slurry must be collected on-site and disposed of in accordance with local regulations.
• Slab stabilization, full-depth repairs, and spall repairs should be completed prior to grinding. Joint resealing should follow grinding to ensure proper sealant depth.
• Diamond grooving should be done according to recommendations of the International Grinding and Grooving Association (IGGA, www.igga.net), which specifies 0.75 in. spacing and 0.125 in. width and depth.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• Diamond grinding: $1.75 to $5.50/yd² ($$)
• Diamond grooving: $1.25 to $3.00/yd² ($$)</td><td>Treatment Life (yr):
• Diamond grinding: 8 to 15
• Diamond grooving: 10 to 15

Pavement Life Extension (yr):
• Diamond grinding: NA
• Diamond grooving: NA</td></tr>
<tr><td colspan="2">• Safety: Safety is improved by restoring pavement surface texture, providing directional stability and increasing skid resistance, and reducing potential for hydroplaning, as well as lane-shoulder drop-off; furthermore, diamond grooving reduces splash and spray visibility issues associated with wet weather.
• Risk: Though diamond grinding addresses pavement faulting, if the faulting mechanisms (e.g., poor load transfer, pumping, loss of support) are not addressed, faulting will reoccur. Also, more frequent grinding may be necessary to maintain surface friction on high-traffic-volume roadways where polishing of the aggregate is a problem, especially if soft aggregate was used.
• Climate: Climate and age may most significantly impact the rate of macrotexture reduction on a diamond-ground surface; wet-freeze areas generally exhibit larger macrotexture reduction than dry, nonfreeze areas.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Usually, PCC pavements can be ground up to three times without significantly affecting fatigue life.
• Can be accomplished during off-peak hours with short lane closures and without encroaching into adjacent lanes.
• Neither grinding nor grooving affect overhead clearances, bridge approach elevations, or the hydraulic capacity of curbs and gutters.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Smith, K. D., T. E. Hoerner, and D. G. Peshkin. Concrete Pavement Preservation Workshop—Reference Manual. Federal Highway Administration, U.S. Department of Transportation, 2008.
• Federal Highway Administration, U.S. Department of Transportation. Concrete Pavement Rehabilitation Guide for Diamond Grinding. www.fhwa.dot.gov/pavement/concrete/diamond.cfm. Accessed Oct. 13, 2010.
• Pavement Preservation Checklist Series: 7. Diamond Grinding of PCC Pavements. Publication FHWA-IF-03-040. Federal Highway Administration, U.S. Department of Transportation, 2005.</td></tr>
</table>

Table A.12. Technical Summary for Partial-Depth Repair

Partial-Depth Repair		
Treatment Description	Partial-depth repairs address small, shallow areas of deteriorated PCC pavements. These deteriorated areas are removed and replaced with an approved repair material, thereby 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.	
Conditions Addressed	**Functional/Other** • Joint spalling caused by non-materials-related sources, such as incompressible materials or joint inserts • Localized crazing or scaling caused by weak concrete or clay balls	**Structural:** Partial-depth repairs restore the structural integrity of localized areas of deteriorated concrete. **Noise:** Partial-depth repairs may result in increased roughness if not finished properly. Diamond grinding is generally recommended to blend the repaired surface with the surrounding pavement.
Construction Considerations	• It is important to properly determine repair boundaries, prepare the patch area, and finish, texture, and cure the repair material according to governing specifications. • Material selection depends on various factors, such as opening requirements, ambient temperature, cost, and size and depth of patch. • Proper and adequate preparation of the area to be patched is critical to ensure treatment success. The patch limits should extend 2 to 6 in. beyond the area of unsound concrete. • Minimum spall repair dimensions are 4 by 12 in. (i.e., 12 in. along a transverse joint and 4 in. away from the transverse joint). • Vertical faces are necessary when patching with most cementitious repair materials. Certain proprietary repair materials may be capable of successfully patching tapered sections. • After concrete removal, the repair area should be prepared by sandblasting or waterblasting, and airblasted clean immediately prior to the placement of the repair material. • When specified, bonding agents (e.g., portland cement grout or epoxy resin) should be appropriate for the time available before opening to traffic, and they should be compatible with concrete pavement. • Inserting a compressible bond breaker prevents intrusion of the patch material into the joint, which could result in premature compressive failure of the repair. • If the depth of the repair exceeds one-third of the slab thickness, then the placement of a full-depth repair should be considered. • Small milling machines (oriented either parallel or perpendicular to the joint) have been effectively used for concrete removal when spalling exists along the entire length of a joint. • Commercial rapid setting patch materials can allow for quick opening to traffic.	
Miscellaneous Considerations	**Cost (Relative Cost, $ to $$$$):** • $75 to $150/yd^2 (patched area) ($$/$$$)	**Treatment Life (yr):** • 5 to 15 **Pavement Life Extension (yr):** • NA
	• **Safety:** Safety can be improved by repairing severe spalls, which can cause vehicle damage due to loose debris. • **Risk:** Performance failures are often caused by the following: bond failure, compression failure, variability and improper use of repair material, insufficient consolidation, and differences of the coefficient of thermal expansion between the existing pavement and patch. • **Climate:** PCC patches should not be placed when the air temperature or pavement temperature is below 40°F, unless adequately insulated. Furthermore, temperatures below 55°F will usually require a longer cure period. Placement should not proceed if rain is imminent.	
Other Remarks	• Not applicable where spalling caused by dowel bar misalignment or lockup; cracking caused by improper joint construction; working cracks caused by shrinkage, fatigue, or foundation movement; and spalling caused by materials-related distress (e.g., D-cracking or alkali-silica reactivity). • Full-depth repair is necessary if dowel bars or tie bars are exposed in the patch area. • Where the amount of patching is extensive, an overlay should be considered.	
Additional Resources	• *Manual of Practice: Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements*. Report FHWA-RD-99-152. Federal Highway Administration, U.S. Department of Transportation, 1999. • Smith, K. D., T. E. Hoerner, and D. G. Peshkin. *Concrete Pavement Preservation Workshop—Reference Manual*. Federal Highway Administration, U.S. Department of Transportation, 2008. • *Pavement Preservation Checklist Series: 9. Partial-Depth Repair of PCC Pavements*. Publication FHWA-IF-03-042. Federal Highway Administration, U.S. Department of Transportation, 2005.	

Table A.13. Technical Summary for Full-Depth Repair

<table>
<tr><th colspan="3">Full-Depth Repair</th></tr>
<tr><td>Treatment Description</td><td colspan="2">Full-depth repairs are 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.</td></tr>
<tr><td rowspan="2">Conditions Addressed</td><td rowspan="2">Functional/Other
• Longitudinal cracking
• Transverse cracking
• Divided slab
• Corner breaks
• Joint spalling
• Punchouts
• Blowups
• D-cracking or ASR distress*</td><td>Structural: Subgrade repairs may be addressed when installing a full-depth repair.
Helps restore structural integrity but does not address any structural inadequacy in existing pavement.</td></tr>
<tr><td>Noise: Additional joints introduced by full-depth repairs add to pavement roughness, which can increase tire-pavement noise. Diamond grinding should be considered after full-depth repairs are made.</td></tr>
<tr><td>Construction Considerations</td><td colspan="2">• It is important to properly prepare the base, restore joint load transfer, and finish, texture, and cure the patch material per governing specifications. Proper curing is even more important when incorporating set accelerating mix components.
• Material selection depends on various factors but is largely a function of the opening requirements of the repair.
• Proper and adequate preparation of the area to be patched is critical to ensure treatment success. The patch limits should extend 2 to 6 in. beyond the area of unsound concrete.
• Repair boundaries should be sawed full-depth with diamond saw blades. To prevent subbase damage, the saw must not penetrate more than 0.5 in. into the subbase.
• To expedite construction, contractors often make all of the required full-depth saw cuts before initiating slab removal activities. When this is done, it is important to limit (no more than 2 days typically) traffic loading between the time of sawing and concrete removal to avoid pumping and erosion beneath the slab.
• Minimum repair dimensions: 6 ft long and 12 ft wide (full lane width)
• Effective load transfer is critical to performance. Typically, 1.5-in.-diameter dowels, with either three to five bars clustered in the wheel path or placed continuously across the joint on 12-in. centers.
• The lift-out method of removing deteriorated concrete from the repair area is recommended so as to minimize disturbance to the base, as well as generally providing the best results and highest productivity for comparable cost.
• Replacing damaged subbase or subgrade materials with concrete is recommended to prevent settlement of the repair, as it is very difficult to adequately compact granular material in a confined area.
• Transverse and longitudinal repair joints should be sealed so as to reduce spalling and to minimize infiltration of moisture and incompressible materials.</td></tr>
<tr><td rowspan="2">Miscellaneous Considerations</td><td>Cost (Relative Cost, $ to $$$$):
• $75 to $150/yd² (patched area) ($$/$$$)</td><td>Treatment Life (yr):
• 5 to 15
Pavement Life Extension (yr):
• NA</td></tr>
<tr><td colspan="2">• Risk: Performance failures are often caused by the following: inadequate load transfer, poor base preparation, variability of repair material, insufficient consolidation, and differences of the coefficient of thermal expansion between the existing pavement and patch.
• Climate: PCC patches should not be placed when the air temperature or pavement temperature is below 40°F, unless adequately insulated. Furthermore, temperatures below 55°F will usually require a longer cure period. Placement should not proceed if rain is imminent.</td></tr>
<tr><td>Other Remarks</td><td colspan="2">• Not cost effective or desirable if deterioration is widespread.
• Where the amount of slab cracking is extensive (say, more than 5% to 10% of the slabs are cracked), a structural overlay may be required.
• Generally, half lane-width repairs are used only on continuously reinforced concrete pavements and are not recommended for jointed concrete pavements.</td></tr>
<tr><td>Additional Resources</td><td colspan="2">• Smith, K. D., T. E. Hoerner, and D. G. Peshkin. Concrete Pavement Preservation Workshop—Reference Manual. Federal Highway Administration, U.S. Department of Transportation, 2008.
• Pavement Preservation Checklist Series: 10. Full-Depth Repair of PCC Pavements. Publication FHWA-IF-03-043. Federal Highway Administration, U.S. Department of Transportation, 2005.</td></tr>
</table>

*Can serve to temporarily treat materials-related distresses.

Table A.14. Technical Summary for Load-Transfer Restoration

Load Transfer Restoration (Dowel Bar Retrofitting)		
Treatment Description	Load transfer restoration (LTR) consists of placing mechanical load transfer devices (typically dowel bars) across joints or cracks in an existing jointed PCC pavement. These devices 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.	
Conditions Addressed	**Functional/Other** • Joint faulting • Pumping • Corner breaks	**Structural:** The load transfer efficiency of a joint or crack strongly influences the structural performance of a PCC pavement; poor load transfer can result in pumping, faulting, corner breaks, and spalling. **Noise:** LTR is often performed in conjunction with diamond grinding, which reduces tire-pavement noise.
Construction Considerations	• There are different patterns for placing dowel bars in a load transfer restoration project, but the use of three or four dowel bars clustered in each wheel path is typical. • Careful consideration must be given to selecting patch material and isolating the joint for repair. • Special diamond slot cutters capable of creating multiple cuts in a single operation should be employed for highest productivity. Slots created with milling machines typically cause excessive spalling on the surface and do not create uniform slot widths. • Dowel bar slots should be sawed to a depth sufficient to place the center of the dowel bar within 1 in. of the mid-depth of the pavement, and they should be aligned to avoid existing longitudinal cracks. Additionally, slots should be centered over the transverse joint or crack, allowing equal lengths of the dowel to span it, and slots should be parallel to the roadway's centerline, regardless of joint skew. • Transverse joints/cracks should be maintained with a compressible insert. The transverse joint or crack should be caulked sufficiently to prevent any of the patching material from entering the joint/crack. • The chairs should be strong enough to allow full support of the dowel bar, as well as allowing ≥0.5-in. clearance between the bottom of the dowel and the bottom of the slot. • End caps should allow ≥0.25 in. of movement at each end of the dowel bar. • Patching material should be placed in a manner that does not disturb the dowel bar within the slot; thus, patching material should not be dumped into the slots, instead should be placed on the surface adjacent to the slot and shoved into the slot.	
Miscellaneous Considerations	**Cost (Relative Cost, $ to $$$$):** • $25 to $35/bar (equivalent $3.75 to $5.25/yd^2, based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft) ($$$)	**Treatment Life (yr):** • 10 to 15 **Pavement Life Extension (yr):** • NA
	• **Risk:** The alignment of dowel bar slots must be parallel to the roadway centerline, regardless of transverse joint skew; slots perpendicular to skewed joints will cause joint lockup and lead to cracking. Additionally, slots sawed too deeply will contribute to corner cracks under traffic loading. • **Climate:** PCC patches should not be placed when the air temperature or pavement temperature is below 40°F, unless adequately insulated. Furthermore, temperatures below 55°F will usually require a longer cure period.	
Other Remarks	• Most effective to apply treatment as structural distresses (e.g., pumping or corner breaks) are just beginning to manifest. Generally want less than 10% slab cracking and faulting of no more than 0.5 in. • The higher the traffic volume and percentage of trucks, the greater the potential need for load transfer restoration; low-traffic-volume roadways that are not doweled may not need such treatment. • Diamond grinding should be done in conjunction with load transfer restoration to ensure a smooth riding surface.	
Additional Resources	• Smith, K. D., T. E. Hoerner, and D. G. Peshkin. *Concrete Pavement Preservation Workshop—Reference Manual.* Federal Highway Administration, U.S. Department of Transportation, 2008. • *Pavement Preservation Checklist Series: 8. Dowel Bar Retrofit for Portland Cement Concrete Pavements.* Publication FHWA-IF-03-041. Federal Highway Administration, U.S. Department of Transportation, 2005.	

APPENDIX B

Examples of Identifying Feasible Preservation Treatments

This appendix presents two example exercises intended to illustrate how the feasibility matrices in Tables 3.2 through 3.5 can be used to identify feasible preservation treatments for a particular project. The first example is for treatment of an existing HMA-surfaced pavement, while the second is for treatment of an existing PCC-surfaced pavement. Each example includes a description of the project, presentation of the pavement condition and other relevant project information, and a discussion of the analyses performed to arrive at a final list of feasible treatments.

Example 1: Rural, HMA Roadway

Project Description

The project featured in this example is set in a rural, deep-freeze environment and involves a four-lane interstate facility. The roadway is 8.4 mi long and has an ADT of 14,000 vpd, with 11% trucks. The posted speed limit is 65 mph and access is controlled through three distantly spaced interchanges. The project terrain is flat to mildly rolling, and there are no significant horizontal curves.

The existing pavement structure was built as a reconstructed pavement in 2001 and was designed for a 20-year period. The pavement consists of 8.5 in. of HMA (1.5 in. surface course, 2.0-in. intermediate course, and 5.0-in. base course) on top of 8 in. of dense-graded aggregate base and a lime-stabilized subgrade. Since construction, the pavement has undergone three condition surveys and two tests each for smoothness and friction. The results of these surveys/tests, which are based on an evaluation of the outside/driving lane, are summarized in Table B-1.

The agency thinking is that either some form of preservation can be performed in 2010 or that a more significant rehabilitation can be done in the 2013–2015 time frame. Funding for a 2010 preservation activity is largely available and, if preservation is deemed appropriate, the agency's goal is for the treatment to perform adequately for at least 4 years. The agency perceives no constraints regarding the availability of locally qualified contractors and good quality materials. And, finally, traffic conditions are such that lane closure durations longer than 1 day are acceptable.

Preliminary Feasibility Analysis

The existing pavement condition data listed in Table B-1 indicate that there is little structural deterioration and that the vast majority of the deficiencies can be treated through preservation techniques. The overall condition levels—PCR in the low- to mid-80s—are such that preventive maintenance techniques and some minor rehabilitation techniques would be appropriate, even after factoring in the reduction expected to occur between 2009 and 2010.

The most prevalent deficiencies are low- and medium-severity raveling, medium- and high-severity transverse thermal cracking, low-severity longitudinal cold-joint cracking, and low- and high-severity stable rutting. Smoothness levels have gradually decreased, but are still reasonably high. Friction along the project has remained at satisfactory levels.

Evaluating the condition data in the backdrop of the preliminary feasibility matrix given in Table 3.2, it can be seen that the following treatments are generally or highly recommended for treating the above distresses:

- **Raveling.** Slurry seal, single- and double-course microsurfacing, single-course conventional chip seal, ultra-thin bonded wearing course, ultrathin HMA overlay, and thin HMA overlay.
- **Transverse thermal cracking.** Crack sealing, slurry seal, single- and double-course microsurfacing, single- and double-course conventional chip seal, single- and double-course polymerized chip seal, ultra-thin bonded wearing course, ultrathin HMA overlay, thin HMA overlay, mill

Table B.1. Summary of Pavement Condition Data

Existing Pavement Condition Parameters	Condition Survey Year			Smoothness Testing Year		Friction Testing Year	
	2005	2007	2009	2007	2009	2007	2009
PCR							
Eastbound (EB)	95	90	81				
Westbound (WB)	96	92	84				
Raveling, LS (% area)							
EB	3.0	11.2	18.4				
WB	1.1	3.5	6.8				
Raveling, MS (% area)							
EB	1.3	4.7	7.3				
WB	0.0	0.0	1.5				
Segregation, LS (% area)							
EB	0.0	0.0	0.0				
WB	6.5	4.5	3.2				
Segregation, MS (% area)							
EB	0.0	0.0	0.0				
WB	0.5	3.2	4.7				
Trans-thermal cracking, LS (cracks/mi)							
EB	60	92	87				
WB	45	96	102				
Trans-thermal cracking, MS (cracks/mi)							
EB	6	35	49				
WB	11	52	64				
Long cold-joint cracking, LS (ft/mi)							
EB	120	967	2,412				
WB	75	624	1,798				
Long cold-joint cracking, MS (ft/mi)							
EB	0	54	367				
WB	0	24	165				
Stable rutting, LS (0.125 to 0.375 in.) (ft/mi)							
EB	110	1,256	5,868				
WB	45	735	3,987				
Stable rutting, MS (0.5 to 1.0 in.) (ft/mi)							
EB	0	151	1,268				
WB	0	54	862				
Fatigue cracking, LS (% wheel path area)							
EB	0.2	1.0	2.2				
WB	0.0	0.3	1.5				
IRI (Average ± Std Dev) (in./mi)							
EB				96.4 ± 9.7	112.5 ± 12.0		
WB				88.5 ± 6.2	105.7 ± 10.3		
FN40S (Average ± Std Dev)							
EB						45.4 ± 3.2	43.6 ± 2.6
WB						47.1 ± 4.5	43.8 ± 4.9

and HMA overlay, HIR remixing and HMA overlay, HIR repaving, and CIR.
- **Longitudinal cold-joint cracking.** Crack filling, slurry seal, single- and double-course microsurfacing, single- and double-course conventional chip seal, single- and double-course polymerized chip seal, ultra-thin bonded wearing course, ultrathin HMA overlay, thin HMA overlay, HIR recycling and HMA overlay, HIR remixing and HMA overlay, HIR repaving, and CIR.
- **Stable rutting.** Double microsurfacing, single- and double-course conventional chip seal, single- and double-course polymerized chip seal, thin HMA overlay, cold mill and thin HMA overlay, HIR surface recycling and HMA overlay, HIR remixing and HMA overlay, HIR repaving, and CIR.

Treatments appropriate for all four distress types include double microsurfacing, single-course conventional chip seal, ultrathin HMA overlay, and thin HMA overlay.

Final Feasibility Analysis

Evaluating these four treatments using the feasibility matrix in Table 3.4, it can be seen that one treatment—ultra-thin HMA overlay—probably lacks the durability for a deep-freeze climate. Also, the expected performance lives of the double microsurfacing and single-course conventional chip seal in a deep-freeze climate are probably such that they barely meet the agency's performance goal of 4 years.

From the results of this analysis, it is reasonable to proceed with a cost-effectiveness analysis that includes double microsurfacing, single-course conventional chip seal, and thin HMA overlay as the treatment alternatives. If agency experience has indicated that the durability of ultra-thin HMA overlays is not significantly affected by the harsh climate, then this treatment could also be evaluated for cost-effectiveness.

Example 2: Urban, PCC Roadway

Project Description

The project featured in this example is set in an urban, moderate-freeze environment and involves a six-lane freeway that is 4.3 mi long. The existing pavement structure is a 9.5-in. doweled jointed plain concrete (JPC) pavement (15-ft joint spacing) resting on a 4-in. asphalt-treated base (ATB) and a lime-stabilized subgrade. The pavement was built in 1996 with a 25-year design life. Current traffic consists of a 55,000 ADT and 16.8% trucks. The posted speed limit is 55 mph and there are four interchanges along the length of the project. The terrain is flat and there are no horizontal curves.

Automated pavement-condition surveys (including smoothness) have been performed on the outside/driving lane every third year since construction. Friction tests for this same lane were performed in 2000, 2004, and 2008. The results of the condition, smoothness, and friction surveys are summarized in Table B-2. In addition to these results, on-board sound intensity (OBSI) testing performed in 2008 indicated that the pavement–tire noise levels generated by the transversely tined concrete ranged from 106 to 108 dB(A).

Agency funding for some form of preservation is available for the 2010 construction season. The agency's goal for preservation treatment performance is 8 years. Traffic conditions are such that lane closure durations longer than a 2-day weekend are unacceptable. Also, there are no perceived availability constraints regarding locally qualified contractors and good-quality materials.

Preliminary Feasibility Analysis

The existing pavement condition data listed in Table B-2 indicate that there is no need for major rehabilitation in the near future. Only a few slabs have structural cracks and the rate at which these cracks have developed is low. The table also indicates that the deficiencies are mostly functional and that the overall condition and smoothness levels are in the proper ranges for preservation, even after factoring in the condition changes expected to occur between 2008 and 2010.

The most prevalent deficiencies are transverse and longitudinal joint seal damage, transverse and longitudinal joint spalling, and polished aggregate. Friction trends have confirmed the polishing problem and current friction levels are either in or are approaching the marginal zone. Agency review of wet-weather accident rates has indicated a possible concern with the friction levels.

Evaluating the condition data in the backdrop of the preliminary feasibility matrix given in Table 3.3, it can be seen that the following treatments are generally or highly recommended for treating the above distresses:

- **Polishing.** Diamond grinding, ultra-thin bonded wearing course, and thin HMA overlay.
- **Joint seal damage.** Joint resealing.
- **Joint spalling.** Partial-depth patching.
- **Corner cracking.** Crack sealing, full-depth patching.
- **Transverse cracking.** Crack sealing.
- **Friction.** Diamond grinding, diamond grooving, ultra-thin bonded wearing course, and thin HMA overlay.

Although none of these treatments address all six deficiencies, some combination treatments can be formed that will collectively address them. Possible combinations include the following:

- Diamond grinding, crack sealing, and joint resealing;
- Limited partial- and full-depth patching, diamond grinding, and joint resealing;

Table B.2. Summary of Pavement Condition Data

Existing Pavement Condition Parameters	Condition Survey/Smoothness Testing Year				Friction Testing Year		
	1999	2002	2005	2008	2000	2004	2008
PCR							
Northbound (NB)	95	92	89	84			
Southbound (SB)	98	96	93	88			
Polishing (% wheel path area)							
NB	1.8	5.2	22.4	63.0			
SB	0.9	4.5	24.8	58.4			
Trans-joint seal damage, LS (joints/mi)[a]							
NB	56	102	123	103			
SB	45	110	145	122			
Trans-joint seal damage, MS (joints/mi)[a]							
NB	5	63	93	143			
SB	2	48	85	156			
Trans-joint seal damage, HS (joints/mi)[a]							
NB	0	8	15	38			
SB	0	2	21	30			
Long joint seal damage, (ft/mi)[b]							
NB	0	56	287	784			
SB	0	108	402	1,026			
Trans-joint spalling, LS (joints/mi)[a]							
NB	2	9	23	42			
SB	0	4	15	21			
Trans-joint spalling, MS (joints/mi)[a]							
NB	0	1	5	22			
SB	0	0	1	11			
Long joint spalling, LS (ft/mi)[b]							
NB	14	25	54	130			
SB	10	24	48	164			
Long joint spalling, MS (ft/mi)[b]							
NB	0	2	38	116			
SB	0	0	29	84			
Corner cracking, LS (slabs/mi)							
NB	0	2	3	5			
SB	0	1	1	3			
Corner cracking, MS (slabs/mi)							
NB	0	0	1	3			
SB	0	0	1	2			
Transverse cracking, LS (slabs/mi)							
NB	0	2	3	5			
SB	0	0	0	2			
IRI (Average ± Std Dev) (in./mi)							
NB	88 ± 7	106 ± 5	113 ± 6	120 ± 5			
SB	86 ± 6	97 ± 5	106 ± 8	114 ± 5			
FN40S (Average ± Std Dev)							
NB					35.2 ± 4.6	32.4 ± 3.9	28.8 ± 2.0
SB					36.1 ± 5.5	35.0 ± 4.5	31.4 ± 3.6

[a] Out of 352 total transverse joints/mi.

[b] Out of 10,560 ft/mi (longitudinal lane-shoulder joint and longitudinal lane-lane joint).

- Limited partial- and full-depth patching, ultra-thin bonded wearing course; and
- Limited partial- and full-depth patching, thin HMA overlay.

Final Feasibility Analysis

Evaluating these four combination treatments using the feasibility matrix in Table 3.5, it can be seen that none are sufficiently impacted by the climate in terms of durability. Also, the treatment performance and closure duration requirements appear to be satisfied by all four treatments. Hence, based on this analysis, it is reasonable to proceed with a cost-effectiveness analysis that includes all four combination treatments.

*Membership as of October 2010.

Related SHRP 2 Research

Modular Pavement Technology (R05)
Composite Pavement Systems (R21)
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