Consideration of Pavement Preservation in Mechanistic-Empirical Design and Analysis of Pavement Structures

Requested by:

American Association of State Highway
and Transportation Officials (AASHTO)

Standing Committee on Highways

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DISCLAIMER

ABSTRACT

Through the efforts of the NCHRP, AASHTO has approved the release of a dramatically different approach to pavement then that featured in the various versions of AASHTO's pavement design published and modified between 1972 and 1998. This approach is termed "mechanistic-empirical," and it is a process in which the responses of trial designs (in terms of deflections, strains, and stresses) are analyzed in terms of their contribution to certain performance measures and the trial design is modified until specified design conditions are satisfied.

The design procedure, as described in the mechanistic-empirical pavement design guide (MEPDG) focuses on new design and structural rehabilitation. As such, it does not consider the contributions to overall pavement performance of pavement preservation programs in general, or preventive maintenance treatments specifically. This report states the case for the need to consider the contributions of pavement preservation in the MEPDG process, and describes both short-term and long-terms approaches to accomplish that.

1. PAVEMENT DESIGN, PAVEMENT PERFORMANCE, AND PAVEMENT PRESERVATION

Introduction

Pavements are designed, constructed, and maintained to provide a desired level of performance for a given set of load, material, and climatic inputs (AASHTO 1993). As described by the American Association of State Highway and Transportation Officials (AASHTO), aspects of pavement performance include considerations of functional performance, structural performance, and safety (AASHTO 1993, p. I-7). Structural performance relates to the physical condition of the pavement and is a measure of the load-carrying capability of the pavement structure. Functional performance refers to how well the pavement serves the traveling public, for which riding comfort is the dominant characteristic.

Since the early 1960s, the AASHTO pavement design procedure has been based on the "serviceability-performance" concept, in which pavements are designed to maintain an acceptable level of serviceability over an established time period. The "performance period" is defined by AASHTO as "the period of time that an initial (or rehabilitated) structure will last before reaching its terminal serviceability" (AASHTO 1993, p. I-11).

Designing a pavement for 20 years of performance was long the accepted standard among highway agencies, although over time this has changed[1]. One reason for this change is the many well designed and constructed pavements that have lasted much longer than the 20 years for which they were originally designed. Other reasons include recognition on the part of owner agencies of the impact and costs of work-zone related user delay from more frequent maintenance and rehabilitation activities, and the overall desire for extended pavement performance.

Designing pavements for longer lives raises the question of whether it is possible to achieve longer lasting pavements, or even pavements that last 20 years, without some sort of intermediate, non-structural treatment. This is a question on which the current 1993 AASHTO Guide is mostly silent. While it notes that "in actual practice the performance period can be significantly affected by the type and level of maintenance applied," (AASHTO 1993, p. II-7) there is little general discussion of what this entails, or any specific mention of how maintenance affects performance. It would be interesting to know whether the pavement design engineer had a specific program of treatments in mind that would need to be applied in order to attain the desired performance over a pavement's design period, or whether the need for intermediate treatments over a design period was even contemplated as part of the design process.

While the intent of the pavement designer may be unknown, most maintenance engineers know that the vast majority of pavements will not achieve their design life without some sort of pavement maintenance. So while pavement design focuses largely on providing the required

[1] The AASHTO Guide (1993) notes that "pavements were originally designed and analyzed for a 20-year performance period since the original Interstate Highway Act in 1956 required that traffic be considered through 1976." Longer design and analysis periods are now routine, with AASHTO recommending up to 50 years for high-volume roads.

structure to carry the design loads at an acceptable level of serviceability, pavement maintenance concerns itself with what needs to be done to the pavement surface to reach the design life.

To address a growing interest on the part of owners in constructing pavements that last longer and provide better service, and in the face of declining transportation agency budgets and resources, more and more agencies are turning to preventive maintenance or pavement preservation to maximize the life of pavement networks, obtain desired levels of performance, and make the best use of limited funding. In its most basic sense, preventive maintenance means keeping good roads in good condition, and this is an approach that proactive maintenance managers have been using for decades to extend the life of roads and delay the need for more costly rehabilitation and reconstruction. However, whereas in the past this may have been an isolated practice, since the mid to late 1990s preventive maintenance and pavement preservation programs have proliferated to the point where most state highway agencies, and many other smaller agencies, are actively involved in the practice.[2] [Widely used definitions of preventive maintenance, pavement preservation, maintenance, rehabilitation, and related terms are provided in appendix A. In this document, the terms pavement preservation and preventive maintenance are used almost interchangeably, with preference given toward "preventive maintenance" because it is the practice that is most different from how agencies have maintained pavement networks in the past.]

A typical pavement deterioration curve is shown in figure 1, illustrating how the pavement condition decreases as a function of time. The beneficial effect of preventive maintenance on pavement performance is shown by the dashed line in figure 1, which represents the modified performance of a pavement with preventive maintenance in a generic plot of condition versus time.

Preventive maintenance is not directly associated with a specific treatment, but rather with the timing of the treatment application. A treatment may be considered "preventive" when placed on a pavement in good condition, while that same treatment applied late in the life of the pavement provides little or no benefit (other than as a stopgap measure until funding or programming is available to implement a longer term action).[3] When pavement preventive maintenance is performed in a timely manner on a good candidate pavement, it is expected to have a positive effect on pavement performance, as indicated by one or more of the following results:

[2] A 1999 survey of state highway agencies reported that 36 of 41 respondents had a pavement preservation program (AASHTO 1999). In a 2004 nationwide NCHRP survey, 30 of 35 respondents reported having a pavement preservation program (Peshkin and Hoerner 2004). A 2006 survey for the Montana Department of Transportation had responses from 34 state and 5 Canadian provinces and reported that over 90 percent of respondents have a preventive maintenance program for pavements (Cuelho et al. 2006).

[3] The "preventive" nature of the first case actually incorporates the concept of cost effectiveness: both treatments actually provide some benefit, but the benefit of the treatment applied to the good pavement lasts much longer than the benefit of the treatment applied as a stopgap.

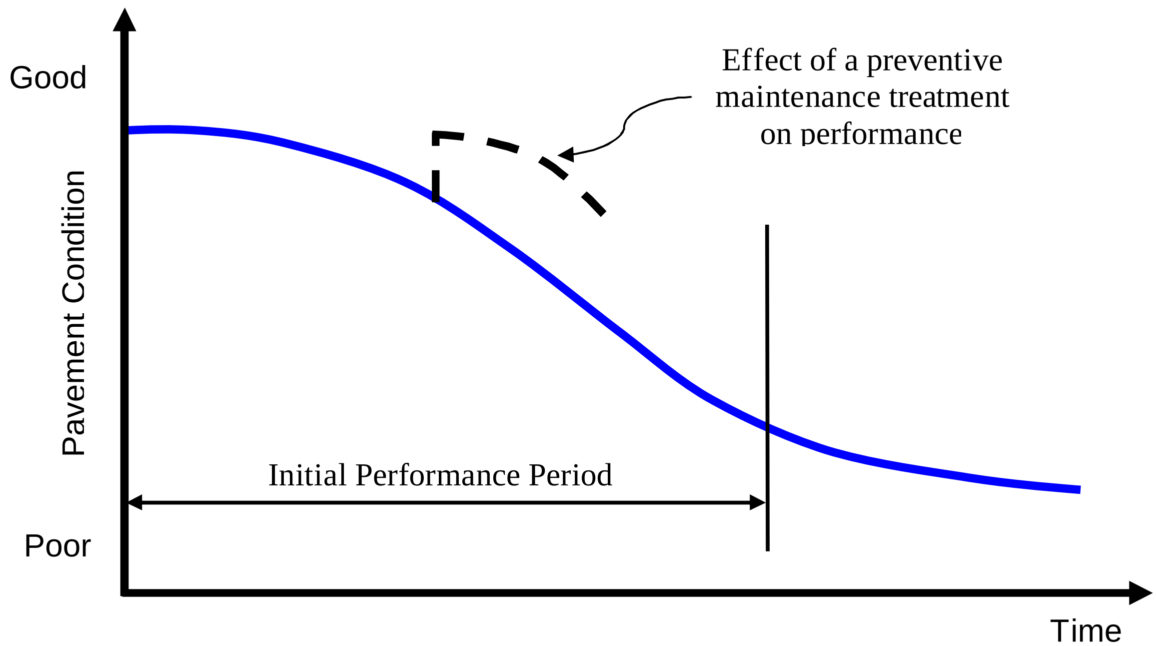

Figure 1. Typical pavement performance over time, including the expected initial effect of preventive maintenance.

- Preventing or slowing down infiltration of moisture and incompressibles. Crack and joint sealant materials, membrane seals applied over a pavement's entire surface, and certain patches will reduce the amount of water that infiltrates the pavement system. Sealing cracks and joints also keep incompressibles from entering into the pavement structure, and impeding the expansion/contraction of the pavement.
- Providing protection against aging and oxidation of bituminous surfaces. In sealing a bituminous surface, the underlying structural layer is protected from some environmental effects (most notably certain types of climate-induced cracking) by the new thin surfacing. That surfacing then ages and wears out, but as long as the overall pavement remains structurally sound and the environmental effects are not too severe, the process can be repeated several times.
- Restoring surface integrity. Deterioration that is limited to the surface of a pavement, that is primarily non-structural in origin, and that is not too severe (this may include distresses such as weathering and raveling, bleeding, loss of friction, roughness, and some rutting, for example) may be corrected by preventive maintenance treatments such as slurry seals, chip seals, and partial-depth repairs.
- Improving surface texture. Preventive maintenance treatments, such as chip seals, thin overlays, and diamond grinding, improve the surface characteristics of the pavement structure by adding aggregate to the pavement surface or restoring the macrotexture of the existing surface. These directly address skid resistance, which is a key functional performance measure.
- Reducing pavement roughness. Keeping moisture and incompressibles out of the pavement structure, reducing environmental effects, restoring surface integrity, and

providing a new riding surface all can contribute to a smoother road. Smoother roads contribute to lower vehicle operating costs and greater user satisfaction.

As long as a pavement is in good overall condition it continues to be a candidate for preventive maintenance. Figure 2 illustrates the successive application of two preventive maintenance treatments. The demonstrated benefits of this are not only improved overall performance in comparison to the expected performance of the pavement without treatment (as shown by the dashed line), but also a delayed need for rehabilitation.

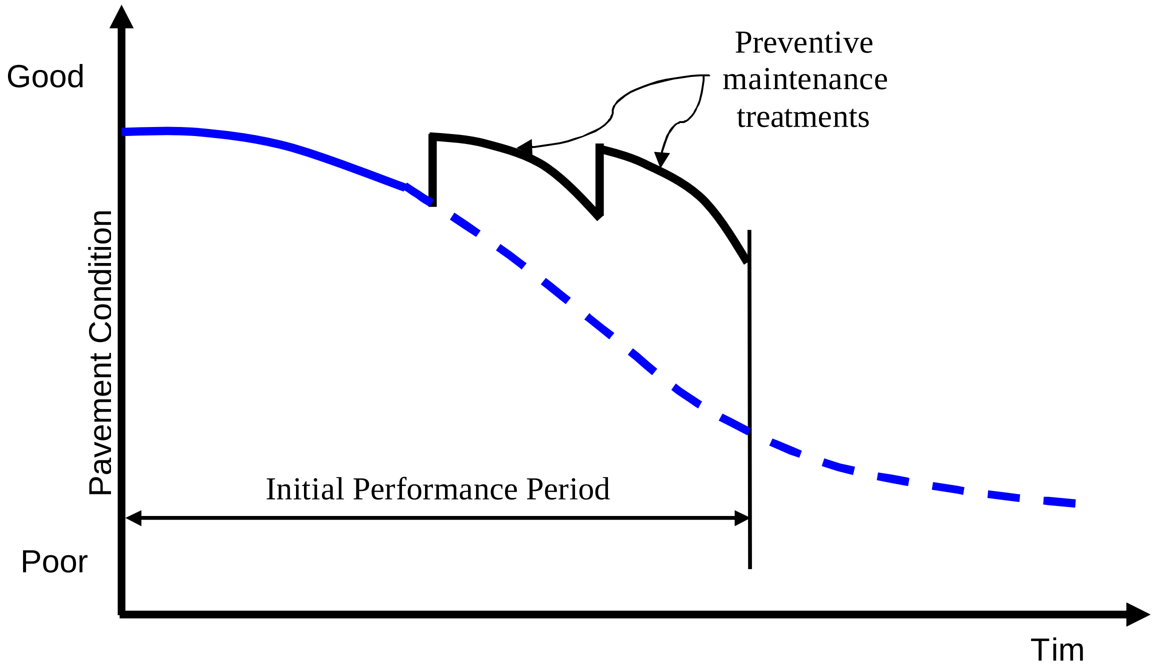

Figure 2. Anticipated effect on pavement performance of multiple preventive maintenance treatments.

Given the beneficial role that preventive maintenance or pavement preservation is believed to play in the life of a pavement, it is useful to further explore how these strategies are addressed in pavement design. In the 1993 design procedure, AASHTO notes that "the emphasis of highway construction has gradually shifted from new design and construction activities to maintenance and rehabilitation" (1993). However, the Guide itself only covers structural overlays and other rehabilitation methods, as partially explained below (AASHTO 1993):

> *In general, one of the least understood areas of state of the art rehabilitation concerns the ability to confidently and accurately predict probable performance (e.g., serviceability-traffic loading/time) for nonoverlay rehabilitation solutions. This is one of the most significant limitations of the rehabilitation guidelines, and user agencies are strongly encouraged to build a continuous and accurate performance data base to increase the overall accuracy and confidence level of performance predictions.*

Without going into great detail on the origins of the AASHTO pavement design procedure, this gap is due in part to the fact that the test sections at the AASHO Road Test were not subjected to a design life's worth of environmental forces nor did they receive preventive maintenance or rehabilitation treatments whose performance was extensively monitored, so that the performance of those strategies was never captured in the subsequent pavement modeling.

Mechanistic-Empirical Pavement Design

For over a decade, AASHTO, in cooperation with the National Cooperative Highway Research Program (NCHRP), have supported the development of a mechanistic-empirical based approach to pavement design. A fundamental underlying goal has been to move the basis of pavement design away from the primarily empirical AASHO Road Test-based models and toward models that reflect the effects on performance of the interactions between in situ conditions, different pavement materials, vehicle loading characteristics, and pavement designs. In 2008 AASHTO released an interim publication describing the resultant approach to pavement design (AASHTO 2008). This new approach to pavement design differs substantially from the one that has been used for almost five decades. In addition to relying more on mechanistic principles, one of the major differences is that the design characteristics of pavements are analyzed in terms of their effects on individual measures of performance (i.e., distress) rather than on a single overall performance index.

Much has been written about the revised pavement design procedure, commonly referred to as the mechanistic-empirical pavement design guide or MEPDG, and there is no need to address the procedure and its capabilities in this document. Of specific interest here, however, is how the design methodology addresses preventive maintenance and pavement preservation. It is noted in the overview of the MEPDG design procedure that the MEPDG is used to develop designs for either a new pavement or a rehabilitation strategy. More explicitly, regarding pavement preservation programs, the interim *Manual of Practice* states the following (2008):

> *Pavement preservation programs and strategies are policy decisions which are not considered directly in the distress predictions. Pavement preservation treatments applied to the surface of HMA [hot-mix asphalt] layers early in their life may have an impact on the performance of flexible pavements and HMA overlays. The pavement designer needs to consider the impact of these programs in establishing the local calibration coefficients or develop agency specific values – primarily for load and non-load related cracking. This pavement preservation issue is discussed in more detail in the Calibration Guide (NCHRP 2007), a future AASHTO publication, for determining the regional or agency specific calibration factors. Preservation is considered in JPCP design only in the ability to design a restoration project.*

In short, the beneficial effects of pavement preservation are not recognized in the MEPDG. This omission is important and needs to be addressed. As noted previously, nationwide surveys indicated that many agencies already use pavement preservation as part of an overall approach to managing a pavement network. In addition to these quantitative results, there are many reports documenting the nature of individual state highway agency (SHA) programs.[4] These reports, and others, describe in some cases markedly different programs, but programs that nonetheless share the concepts common to pavement preservation programs. Failure to explicitly consider the benefits of pavement preservation, and in particular the effect of preventive maintenance treatments on pavement performance, not only challenges the management approach of the many agencies actively involved in pavement preservation, but it means that pavement designs developed with the MEPDG may be either over or under-designed.[5]

This report addresses how to incorporate pavement preservation, and specifically the use of preventive maintenance treatments, in pavement design. It specifically addresses the design of pavements that are expected to benefit from the timely application of preventive maintenance treatments using the new MEPDG. In implementing the MEPDG procedure users are urged to adjust or modify various performance models for local conditions. This provides a unique opportunity to consider and account for the impact of preventive maintenance on pavement performance and, ultimately, on pavement design. Illustrating how this can be accomplished is the purpose of this report. The following topics are covered in separate sections in the remainder of this report:

- Preventive maintenance treatments.
- Preventive maintenance and pavement design.
- Incorporating preventive maintenance in the MEPDG.

[4] Examples from across the United States include California (Massey and Pool, 2003), Kansas (Miller 2002 and Testa 2007), and North Carolina (Corley-Lay et al., 2005).

[5] As discussed later, the actual impact is ambiguous for several reasons. The primary reason is that there is not good documentation on the life extension of preventive maintenance treatments applied under different conditions. In general, however, pavements designed without consideration of the subsequent benefits of preventive maintenance will be overly conservative, while locally calibrated models that don't recognize where preventive maintenance has been has been applied will be under-designed.

2. PREVENTIVE MAINTENANCE TREATMENTS

Introduction

Just as design, construction, maintenance, and rehabilitation practices vary from agency to agency, so does the practice of pavement preservation. While many SHAs are moving toward defined preservation programs with dedicated funding, an examination of those individual programs reveals extensive differences.

A key to considering the effects of preventive maintenance on MEPDG-based pavement design is to understand the effects of preventive maintenance treatments on pavement performance. There are many factors that affect preventive maintenance treatment effectiveness. These include the quality of construction, materials and material compatibility, environmental conditions during placement, traffic loadings, environmental conditions after placement, subsequent maintenance, snow removal equipment and procedures, existing pavement distress at the time of construction, and pavement structural capacity. Attempting to account for all of these factors is difficult, if not impossible. However, having a general understanding of the expected effects of the treatment can be helpful in many ways. In the pavement design context, such an understanding can help an agency to both identify what treatments may be appropriate for their particular conditions and determine how those treatments affect the performance of their pavements.

There are many different types of preventive maintenance treatments, and more being developed all the time. This section summarizes key characteristics of the following treatments or treatment groups:

<u>HMA Pavement Treatments</u>

- Crack sealing/filling.
- Fog seal/rejuvenators.
- Slurry seal/microsurfacing.
- Chip seals (bituminous surface treatments).
- Thin hot-mix asphalt (HMA) overlays.
- Ultra-thin friction course.
- In-place surface recycling.
- Drainage preservation (both HMA and portland cement concrete [PCC] pavements).

<u>PCC Pavement Treatments</u>

- Crack sealing/joint resealing.
- Diamond grinding.
- Load transfer restoration.
- Undersealing.
- HMA and PCC pavement patching.

This list, and the following descriptions of each of these treatments, is not intended to be exhaustive. The list can easily be expanded by anyone so interested by considering the content categories and either completing the information from their experience, from the experience of others who have used the treatments in applications similar to theirs, from information provided by the materials suppliers or contractors, from industry organizations, or even from expert opinion as a starting point. In fact, agencies interested in considering the impacts of pavement preservation on their MEPDG-based designs are encouraged to modify and expand upon this information to better address local conditions.

It is noted that these treatments are primarily intended to improve the functional performance of a pavement without increasing structural capacity, which raises the question of how they can affect structural pavement design. While the individual treatments do not increase the structural capacity of a pavement, they can affect the individual analytical models. For example, many of the treatments reduce pavement roughness, meaning a reduction in the International Roughness Index (IRI) value modeled in the MEPDG. As another example, surface seals and crack sealing on HMA pavements help to keep moisture out of a pavement structure, helping to maintain the integrity of subsurface layers and the subgrade. This in turn can slow down the development of fatigue cracking. As can be seen, while the treatments may not increase structural capacity, by slowing the onset or progression of certain performance measures a pavement's life may be extended.

Treatment Characteristics

In this section, each preventive maintenance treatments is described in terms of a set of key characteristics. Those characteristics, which are explained in general below, include information that should help the pavement designer or pavement manager to identify when various treatments might be used (or not used), and how the treatment could be expected to affect pavement performance and hence the pavement design.

- Description. This provides a summary of the nature of the treatment. This may be the same information that is provided in the agency's Pavement Preservation Handbook, or similar documentation of agency practices.
- Conditions addressed. This identifies the types of pavement deterioration which warrant the use of the treatment. These conditions are further divided into functional/other distresses and structural distresses. For the most part, preventive maintenance treatments will not address structural conditions.
- Contraindications. This category can be thought of as the opposite of "conditions addressed;" that is, it identifies when the treatment should not be used. When conditions identified in this section are present, either the treatment will be ineffective or it will create additional safety or performance problems.
- Pavement performance measures affected. The effects of this treatment on specific performance measures used in the MEPDG are identified here. The trend of the effect is identified using symbols as either positive (+) or negative (-), where "positive" suggests either an improvement in performance or an extension in pavement life. These effects are also summarized in table 1 for flexible pavements and table 2 for rigid pavements.
- Expected life. This refers specifically to the time during which the treatment is positively affecting pavement performance and not, for example, how long traces of the treatment are visible. The numbers provided here are national averages and are usually expressed as ranges to reflect that there is enormous variability in these values.
- Additional remarks. A variety of additional comments are collected under this heading, including information about materials, construction, and other factors that may impact the use or performance of the treatment.

<table>
<tr><td colspan="4">CRACK SEALING/FILLING</td></tr>
<tr><td>Description</td><td colspan="3">These treatments are primarily intended to prevent moisture from intruding existing cracks, reducing further crack deterioration, roughness, and rutting. Crack sealing addresses “working” cracks (i.e., those that open and close with temperature changes). Sealing operations typically require good crack preparation and high quality materials (i.e., thermosetting or thermoplastic (bituminous) materials that soften upon heating and harden upon cooling). Crack filling is for cracks that undergo little movement, and is characterized by minimal crack preparation and lower quality materials.</td></tr>
<tr><td colspan="2">Conditions Addressed</td><td>Contraindications</td><td>Pavement Performance Indicators Affected</td></tr>
<tr><td colspan="2">Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Minor block cracking

Structural
Adds no structural benefit and does not address structural deterioration. Does minimize moisture infiltration through cracks to base and subgrade and may slow progression of structural cracking exacerbated by moisture infiltration.</td><td>§ Structural failure (i.e., extensive fatigue cracking or high severity rutting)
§ Extensive pavement deterioration, little remaining life</td><td>+ Non-load-related transverse and longitudinal cracking

+ Reflection cracking in HMA overlays

– Smoothness (filler material may bulge during warmer months)</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">2 to 6 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Material selection requirements to consider: 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-inch wide or larger, expanding cracks (large longitudinal, transverse, and reflective cracks), while cold crack fillers work better in smaller cracks less than 0.5-inch wide.
§ Although treatment can perform well in all climatic conditions, placement should take place during cool, dry weather in order to avoid pulling away during the winter (if placed during hot temperatures) or excessive bulging (if placed during cold temperatures).
§ Sealants perform best in dry, warm environments that do not undergo large daily temperature cycles.
§ Treatment is not significantly affected by ADT or truck levels.
§ Crack cleaning is essential to good bond and maximum performance. Some agencies also use a hot compressed air lance prior to sealing.
§ Undesirable visual impacts may occur, such as tracking of seal or fill material by tire action, which may obscure lane markings and adversely affect skid resistance.
§ Placement of a crack treatment can enhance performance of a subsequent treatment, such as a slurry/microsurfacing or thin HMA overlay. However, the presence of sealant material at the pavement surface can also adversely affect the performance of thin HMA overlays due to bleed through of the sealant. Some agencies require a lag time of several months to one construction season, while others either place a level course or mill the crack treatment prior to overlay construction.</td></tr>
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<table>
<tr><th colspan="3">FOG SEAL/REJUVENATORS</th></tr>
<tr><td>Description</td><td colspan="2">Fog seals are a spray-applied diluted asphalt emulsion applied to the pavement surface (without aggregate) to reduce the rate of aging and environmental degradation of the existing asphalt pavement. They provide some protection of the pavement surface from air and moisture, inhibit raveling, enrich hardened/oxidized asphalt, and provide pavement-shoulder delineation. Rejuvenators include a recycling agent and other additives; they soften and penetrate into the existing binder, thereby slowing the development of raveling, thermal cracking, and roughness. The asphalt emulsions used as rejuvenators typically include polymer latex and other additives, and can be used in fog seal, sand seal, scrub seal, or any other surface seal applied directly to the pavement surface.</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Low and medium block cracking
§ Raveling/weathering
§ Asphalt aging, oxidation, and hardening
§ Moisture infiltration

Structural
Adds no structural benefit, but can reduce moisture infiltration through low severity fatigue cracks.</td><td>§ Structural failure (i.e., extensive fatigue cracking)
§ Medium flushing/bleeding
§ Medium/high friction loss
§ High severity thermal cracking
§ Extensive pavement deterioration, little remaining life
§ Very dense pavement surface
§ Pavement with poor surface friction</td><td>+ Non-load-related transverse and longitudinal cracking

+ Load-related alligator cracking

+ Smoothness (potentially to the detriment of friction)

– Friction</td></tr>
<tr><td>Expected Life</td><td colspan="2">Fog seals: 1 to 2 years
Rejuvenators: 3 to 5 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ Special consideration should be given to raised pavement markers and bump grinding prior to treatment placement.
§ Although treatment can perform well in all climatic conditions, actual performance will vary according to factors affecting pavement weathering/raveling.
§ Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants.
§ Increased ADT or truck levels can increase surface wear, particularly where studded tires are permitted.
§ Slow-setting emulsions require time to “break,” sometimes necessitating closing the pavement to traffic for curing (typically for up to 2 hours).
§ Traffic should not be allowed back on the surface until adequate friction is restored (e.g., spreading manufactured sand over the treated area).
§ Typical application rates for fog seals range from 0.05 to 0.10 gal per yd^2, while testing is needed to determine application rates for rejuvenators.
§ Will temporarily reduce skid resistance and may increase road spray</td></tr>
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<table>
<tr><td colspan="3">SLURRY SEAL/MICROSURFACING</td></tr>
<tr><td>Description</td><td colspan="2">Slurry seals are a mixture of crushed well-graded aggregate, mineral filler (portland cement), and asphalt emulsion spread over the full width of pavement with either a squeegee or spreader box. Slurry seals are effective at sealing low-severity surface cracks, waterproofing the pavement surface, and restoring surface friction. Microsurfacing is applied in a process similar to slurry seals, and 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).</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Raveling/weathering
§ Friction loss
§ Moisture infiltration
§ Bleeding
§ Roughness
§ Asphalt aging, oxidation, and hardening
§ Rutting (microsurfacing)

Structural
Neither microsurfacing nor slurry seals add structural capacity. Both treatments can seal low severity cracks (including initial fatigue cracks)</td><td>§ Structural failure (i.e., extensive fatigue cracking)
§ High severity thermal cracking
§ Stripping-susceptible HMA pavements
§ Extensive pavement deterioration, little remaining life</td><td>+ Non-load-related transverse, longitudinal cracking

+ Load-related alligator cracking until they reflect through

+ HMA rutting (microsurfacing)

+ Friction

§ Can accelerate the development of stripping in susceptible pavements, negatively affecting cracking, rutting.
§ If placed over working cracks (e.g., fatigue cracks and wide thermal cracks), cracks will reflect through and may cause localized delamination (roughness).</td></tr>
<tr><td>Expected Life</td><td colspan="2">Slurry seals: 3 to 5 years
Microsurfacing: 4 to 7 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ Special consideration should be given to raised pavement markers and bump grinding prior to treatment placement.
§ 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. Aggregate should also be chemically compatible with emulsion system.
§ 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; placement in cool weather can result in early raveling.
§ Although treatments can perform well in all climatic conditions, they perform best in warm environments that do not undergo large daily temperature cycles.
§ Avoid opening to traffic prematurely; microsurfacing can typically carry traffic 1 hour after placement, whereas slurry seal emulsions may require 2 to 4 hours to “break,” depending on environmental conditions.
§ Allow minimum 7 days before applying permanent pavement markers and striping.
§ Increased ADT or truck levels can increase surface wear.
§ Early damage can occur at down grade locations or where there is heavy truck turning; in such areas, rolling may improve durability.
§ Delaminated layers or areas should be removed prior to placement of subsequent treatments.</td></tr>
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<table>
<tr><td colspan="3">CHIP SEALS (BITUMINOUS SURFACE TREATMENTS)</td></tr>
<tr><td colspan="3">Description
Chip seals consist of an application of asphalt (commonly an emulsion) 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 (50 to 70 percent 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 (double chip seal), and in combination with other treatments, such as microsurfacing, which is called a cape seal and reduces the hazards associated with loose chips.</td></tr>
<tr><td>Conditions Addressed</td><td>Contraindications</td><td>Pavement Performance Indicators Affected</td></tr>
<tr><td>Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Block cracking
§ Friction loss
§ Bleeding
§ Roughness
§ Moisture infiltration

Structural
Adds no structural benefit, but can be effective at sealing medium severity fatigue cracks in comparison with other treatments.</td><td>§ Structural failure (i.e., extensive fatigue cracking)
§ High severity thermal cracking
§ Extensive pavement deterioration, little remaining life
§ Pavement susceptible to stripping</td><td>+ Load-related alligator cracking

– Smoothness

+ Friction

– Can accelerate the development of stripping in susceptible pavements, negatively affecting cracking, rutting.</td></tr>
<tr><td>Expected Life</td><td colspan="2">4 to 7 years</td></tr>
<tr><td colspan="3">Additional Remarks
§ Application rates depend upon aggregate gradation and maximum size.
§ 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.
§ Although treatment can perform well in all climatic conditions, placement should take place during warm when the temperature in the shade is above 55 °F. Placement should avoid cold and/or wet weather conditions.
§ Treatment should be placed with chip spreader immediately behind asphalt distributor and rollers close behind spreader.
§ Normal traffic speeds should not commence until after curing (typically 2 hours); pilot cars can be used to minimize damage to the fresh surface as well as windshield/vehicle damage.
§ 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.
§ With special design and placement considerations, the treatment can perform well on high-volume roads; however, due to risk of windshield/vehicle damage, its use is often limited to low-speed, low-volume roads.</td></tr>
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<tr><th colspan="4">THIN HOT-MIX ASPHALT (HMA) OVERLAYS</th></tr>
<tr><td>Description</td><td colspan="3">Thin HMA overlays are composed of asphalt binder and aggregate combined in a central mixing plant and placed with a paving machine in thicknesses between 0.75 and 1.50 in.
Dense-graded—a well-graded, relatively impermeable mix, intended for general use.
Open-graded—an open-graded, permeable mix designed using only crushed stone (or gravel) and a small percentage of manufactured sands. Effective at reducing tire-road noise, tire splash/spray in wet weather, and 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.</td></tr>
<tr><th colspan="2">Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td colspan="2">Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Raveling/weathering
§ Block cracking
§ Friction loss
§ Bleeding
§ Roughness

Structural
Rutting (requires separate rut-fill treatment). Also, although intended as a functional treatment, load-carrying capability may be improved, depending on thickness.</td><td>§ Structural failure (i.e., extensive fatigue cracking)
§ High severity thermal cracking
§ Extensive pavement deterioration, little remaining life</td><td>+ Non-load-related transverse and longitudinal cracking

+ Load-related alligator cracking

+ Smoothness

+ Friction

+ Total rut depth (requires separate rut-fill treatment)</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">5 to 10 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Relationship between maximum aggregate size and lift thickness should be confirmed.
§ 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.
§ Although treatment can perform well in all climatic conditions, actual performance will vary according to factors affecting pavement weathering/raveling.
§ Because thin HMA overlays dissipate heat rapidly, it is important to specify minimum placement temperatures and timely compaction.
§ Treatment is not significantly affected by ADT or truck levels; however, certain combinations of loadings, environmental conditions, and pavement structure can initiate top-down cracking.
§ When placed on a surface with crack sealant, measures may need to be taken to control bleed through of the sealant.</td></tr>
</table>

ULTRA-THIN FRICTION COURSE

<table>
<tr><td>Description</td><td colspan="3">An alternative treatment to bituminous surface treatments (chip seal), microsurfacing, or thin HMA overlays, consisting of a gap-graded, polymer-modified HMA layer (0.4- to 0.8-in thick) placed on a tack coat (heavy, polymer-modified asphalt emulsion). Effective at treating minor surface distresses and increasing surface friction.</td></tr>
<tr><th colspan="2">Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td colspan="2">Functional/Other
§ Longitudinal cracking*
§ Transverse cracking*
§ Block cracking*
§ Raveling/weathering
§ Friction loss
§ Bleeding
§ Roughness

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

Structural
Multiple applications may add structural benefit, and retard fatigue cracking.</td><td>§ Structural failure (i.e., extensive fatigue cracking and deep rutting)
§ High severity thermal cracking
§ Extensive pavement deterioration, little remaining life
§ Not suited for deeply rutted pavements.</td><td>+ Non-load-related transverse and longitudinal cracking

+ Load-related alligator cracking

+ Smoothness

+ Friction</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">7 to 10 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Performs similarly to thin HMA overlays, but does not create the same overhead clearance issues or loss of curb height/drainage capacity.
§ Requires special paving equipment and a license to place.
§ Special consideration should be given to bump grinding prior to treatment 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.
§ Treatment can perform well in all climatic conditions.
§ Capable of withstanding high ADT and truck levels.</td></tr>
</table>

<table>
<tr><th colspan="4">IN-PLACE SURFACE RECYCLING</th></tr>
<tr><td>Description</td><td colspan="3">In-place surface recycling includes hot in-place recycling (HIR) and cold in-place recycling (CIR) practices. Hot in-place recycling 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, or virgin asphalt; includessurface recycling, repaving (simultaneous overlay of new HMA), and remixing (milled material is mixed with new HMA in a pugmill) methods. CIR is also an in situ process, but does not use heat and is effective at correcting surface distresses within the top 4 inches of a bituminous pavement.</td></tr>
<tr><th colspan="2">Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td colspan="2">Functional/Other
§ Alligator, thermal, and surface cracking
§ Raveling/weathering
§ Friction loss
§ Bleeding
§ Roughness
§ Corrugation
§ Rutting

Structural
Adds some structural benefit.</td><td>§ Structural failure (i.e., extensive fatigue cracking and/or structural rutting)
§ Distresses deeper than range of treatment effectiveness
§ High traffic volumes (CIR)
§ Urban road sections (HIR)</td><td>+ Non-load-related transverse cracking

+ Load-related alligator cracking

+ Load-related, surface initiated cracking

+ HMA rutting

+ Smoothness

+ Friction</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">5 to 15 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Crack sealant should be removed prior to placement to reduce risk of flash fires or excessive blue smoke.
§ Recommended to repair localized structural problems prior to placement.
§ Presence of rubber in the surface lift (rubberized seals, some crack fillers, and similar sources) requires special attention during the mix design process.
§ Pavement surface must be dry and swept clean of dirt, sand, gravel, and other surface contaminants.
§ Although treatment can perform well in all climatic conditions, placement should not occur when temperature is below 50 °F, or when it is raining.
§ HIR is appropriate for all traffic volumes; however, the heat scarification process should be used for only low-volume roads. Due to the length of the recycling equipment train, short road sections, particularly in urban settings, are not suitable.
§ CIR is most often used on secondary or low-volume roads, avoiding steep grades, sections with tightly curved roads, or those with many utility appurtenances. May be used on higher volume roads if recycling process is used to stabilize the road base prior to overlay. CIR requires placement of a final wearing course, such as a chip seal or HMA overlay.
§ HIR processes require mix design to determine quantities of new materials, additives.
§ Characterization of in place materials should consider material variability and adequacy of lift thicknesses.</td></tr>
</table>

<table>
<tr><th colspan="3">CRACK SEALING/JOINT RESEALING</th></tr>
<tr><td>Description</td><td colspan="2">Sealing cracks and resealing transverse joints in PCC pavements minimizes surface water infiltrating the underlying pavement structure, retards crack deterioration and associated roughness, and prevents the intrusion of incompressible material into joints, thereby reducing faulting, pumping, and spalling. A range of materials from bituminous-based to silicone to neoprene are used in various joint resealing configurations; thermosetting bituminous materials are typically used for crack sealing.</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Unsealed/partially sealed joints

Structural
Adds no structural benefit, but may reduce rate of structural deterioration. May also post-pone time until rehabilitation. Crack sealing is not intended to <u>repair</u>, but instead prevent further deterioration of, cracked slabs.</td><td>§ Extensive structural failure (i.e., significant faulting or spalling)

Different sealant materials can be expected to have different performance lives; thus, material selection should be based on expected time until next treatment.</td><td>+ Mean joint faulting

+ Load-related transverse slab cracking

+ Joint spalling

– Smoothness (if sealed in an overband configuration; also, material may bulge during warmer months)</td></tr>
<tr><td>Expected Life</td><td colspan="2">4 to 8 years for hot pour; 6 to 10 years for silicone sealant</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ Performance is dependent on many construction factors, including sealant type, placement geometry, and application in a clean and dry environment.
§ Although treatment can perform well in all climatic conditions, performance varies within environmental regions.
§ Treatment is not significantly affected by ADT or truck levels; however, curing before opening to traffic may be required.
§ Silicone sealants improperly recessed are more likely to fail in the wheel path.
§ Thorough crack preparation is essential to good bond and maximum performance; sealant reservoir should be clean and dry.
§ Undesirable visual impacts may occur, such as tracking of sealant material by tire action, which may obscure lane markings and adversely affect skid resistance.</td></tr>
</table>

<table>
<tr><th colspan="4">DIAMOND GRINDING</th></tr>
<tr><td>Description</td><td colspan="3">Diamond grinding is the removal of a thin layer of concrete (generally up to about 0.25 inches) from the pavement surface, using special equipment outfitted with a series of closely spaced diamond blades. Diamond grinding removes surface irregularities (most commonly joint faulting), restores smoothness, and increases pavement surface friction. It is often used in conjunction with other pavement preservation treatments, such as after the completion of load transfer restoration.</td></tr>
<tr><th colspan="2">Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td colspan="2">Functional/Other
§ Roughness
§ Friction loss

Structural
§ Faulting (although if the cause of the faulting is not addressed, diamond grinding may be needed again)</td><td>§ Significant faulting or other structural failure (e.g., pumping or corner breaks)
§ Materials-related distresses
§ Soft aggregate will wear quicker, requiring more frequent grinding</td><td>+ Mean joint faulting

+ Smoothness

+ Friction</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">8 to 10 years (against faulting); ≥ 5 years (against roughness)</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Special consideration should be given during project development to slurry disposal.
§ Although treatment can perform well in all climatic conditions, environments where studded tires or chains are used may require more frequent grinding.
§ The cause of surface roughness should be identified before beginning a grinding project. In some cases grinding alone may address the symptom of a problem but not correct the cause.
§ High ADT or continued application of heavy truck traffic can increase surface wear or cause faulting to reoccur, requiring more frequent grinding.
§ Diamond grinding is a surface repair method; it does not correct pavement distress mechanisms, which must be addressed using other techniques.
§ Numerous sections have been successfully diamond ground multiple times.
§ Diamond grooving is often linked with diamond grinding. This technique is the creation of parallel shallow grooves on a pavement surface to improve tire-pavement interaction during wet weather. It uses the same equipment that is used in diamond grinding, but a greater spacing between the saw blades.</td></tr>
</table>

<table>
<tr><td colspan="4">LOAD TRANSFER RESTORATION</td></tr>
<tr><td>Description</td><td colspan="3">Load transfer restoration (sometimes referred to as “dowel bar retrofit”) is the placement of load transfer devices across joints or cracks in a jointed PCC pavement in an effort to prevent pumping, joint faulting, and corner breaks. It is most effective on pavements having significant remaining structural life. It is often used in conjunction with diamond grinding.</td></tr>
<tr><td colspan="2">Conditions Addressed</td><td>Contraindications</td><td>Pavement Performance Indicators Affected</td></tr>
<tr><td colspan="2">Functional/Other
§ Faulting-related roughness

Structural
Best applied when the pavement is just beginning to show signs of structural distress (e.g., pumping, onset of faulting). Repeated applications will provide some structural benefit in load-carrying capability.</td><td>§ Significant faulting or other structural failure (e.g., pumping or corner breaks)
§ Materials-related distresses
§ Extensive pavement deterioration, little remaining life</td><td>+ Mean joint faulting

+ Joint load transfer efficiency

+ Joint spalling

+ Smoothness, when used in conjunction with diamond grinding</td></tr>
<tr><td colspan="2">Expected Life</td><td colspan="2">minimum 10 to 15 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="3">§ Special consideration should be given to isolation of the joint and selection of patch material.
§ Treatment can perform well in all climatic conditions.
§ The higher the ADT or truck levels, the greater the potential need for load transfer restoration; may not be necessary on low-volume jointed PCC pavements that are not doweled.
§ Highway agencies have experimented with different dowel bar retrofit configurations; three to four bars per wheel path is typical.</td></tr>
</table>

<table>
<tr><th colspan="3">UNDERSEALING (PAVEMENT SUBSEALING)</th></tr>
<tr><td>Description</td><td colspan="2">Undersealing is the pressure insertion of a flowable material beneath a PCC slab to fill voids (generally < 0.12 inches thick) between the slab and base, thereby reducing deflections and related distresses, such as pumping or faulting. It is most often performed at areas where pumping and loss of support occur, such as beneath transverse joints and deteriorated cracks.</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Functional/Other
§ Faulting-related roughness

Structural
Fills voids that, if left unfilled, will lead to faulting and other structural deterioration; however, overfilling can contribute to worse problems than leaving them unfilled. Most effective when applied before faulting develops.</td><td>§ Significant faulting or other structural failure (e.g., pumping or corner breaks)
§ For pavements without load transfer, additional treatments (e.g., dowel bar retrofit) may be necessary</td><td>+ Mean joint faulting

+ Joint load transfer efficiency</td></tr>
<tr><td>Expected Life</td><td colspan="2">Varies</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ There are no known studies differentiating the performance of undersealing in various environmental conditions.
§ Performance is not known to be affected by ADT or truck levels.
§ Cement-fly ash grout is commonly used, as are polyurethane materials. Roofing grade asphalt cement has also been used.
§ Operation must be closely monitored to avoid damaging slab(s).
§ Voids must be identifiable and contained for treatment to work.</td></tr>
</table>

<table>
<tr><th colspan="3">PCC PAVEMENT PATCHING</th></tr>
<tr><td>Description</td><td colspan="2">PCC pavement patching includes both full-depth and partial-depth repairs. Full-depth repairs are cast-in-place concrete repairs extending the full thickness of the existing PCC pavement. Such repairs involve the full-depth removal and replacement of full or half lane-width areas of deteriorated pavement. Partial-depth repairs are defined as the removal and replacement of small, shallow areas—limited to the top one-third of slab thickness—of deteriorated PCC pavement. These repairs restore structural integrity and improve ride quality, thereby extending the service life of pavements having spalled or distressed joints.</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Functional/Other
§ Longitudinal cracking
§ Transverse cracking
§ Corner breaks
§ Joint spalling

Structural
Adds some localized structural benefit.</td><td>§ Significant structural failure
§ Materials-related distress (i.e., D-cracking or ASR)
§ Extensive pavement deterioration, little remaining life

Additionally for partial-depth repairs:
§ Compressive stress buildup in long-jointed pavements
§ Dowel bar misalignment or lockup
§ Improper joint construction
§ Working cracks caused by shrinkage, fatigue, or foundation movement</td><td>+ Joint load transfer efficiency (full-depth repairs only)

+ Load-related transverse slab cracking

+ Joint spalling

+ Punchouts

+/– Smoothness</td></tr>
<tr><td>Expected Life</td><td colspan="2">Full-depth: 10 to 15⁺ years
Partial-depth: 5 to 15 years</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ For jointed pavements, in many cases it may be more cost effective and reliable to forgo full-depth repair for slab replacement.
§ Special consideration should be given to defining repair boundaries, preparing the base, restoring joint load-transfer (full-depth repairs only), and finishing, texturing, and curing the patch.
§ High early-strength concrete mixes may be an option when curing time is an issue.
§ It is not desirable to create a large number of closely spaced joints in pavement such as would result from placing a number of closely spaced patches.
§ Treatment can perform well in all climatic conditions.
§ Capable of performing under all traffic conditions.
§ Partial-depth repair performance is closely related to bonding conditions: poorly bonded repairs have an extremely short life.</td></tr>
</table>

<table>
<tr><th colspan="3">DRAINAGE PRESERVATION</th></tr>
<tr><td>Description</td><td colspan="2">Any of the following strategies used to improve or enhance drainage capabilities of an existing pavement structure, thereby significantly increasing the pavement's serviceability and life:
§ Install/maintain reference markers at outlet locations
§ Clear debris and vegetation at outlets and culverts
§ Video-inspect outlets and longitudinal edge drain collector pipe
§ Flush/rod edge drain system with high-pressure equipment
§ Clean ditches and reestablish depths and grades
§ Milling or surface leveling to restore cross slopes (HMA pavements only)
§ Re-grade shoulder to remove buildup of dirt and debris
§ Cleaning closed drainage systems (drainage inlets, catch basins, and manholes)</td></tr>
<tr><th>Conditions Addressed</th><th>Contraindications</th><th>Pavement Performance Indicators Affected</th></tr>
<tr><td>Does not address any specific pavement condition; however, does help to prevent development of more serious deterioration, such as stripping and structural distresses related to loss of support that can occur in any pavement layer susceptible to weakening from saturated conditions. May also improve load-carrying capacity by enhancing base and subgrade stability.</td><td>Only helpful if pavement has a horizontally drainable layer.</td><td></td></tr>
<tr><td>Expected Life</td><td colspan="2">Varies</td></tr>
<tr><td>Additional Remarks</td><td colspan="2">§ Generally performed entirely off of roadway (i.e., few site restrictions).
§ Should be done on a regular basis or when conditions warrant.
§ Maintenance of drainage features provides the greatest value if performed as a programmed activity.
§ Underdrain installation should occur prior to patching, unless there is a valid reason to do otherwise.</td></tr>
</table>

Table 1. Summary of possible preventive maintenance treatment effects on MEPDG performance indicators for HMA-surfaced pavements.

	Treatment	**PERFORMANCE INDICATORS** Rutting	Non-load-related transverse cracking	Load-related fatigue cracking	Load-related longitudinal cracking	Reflection cracking	Smoothness (IRI)
Hot-Mix Asphalt Surfaced Pavements	Crack Sealing/ Crack Filling		+			+	–
	Fog Seal/ Rejuvenators		+	+			+
	Slurry Seal/ Microsurfacing	+	+	+		–	
	Chip Seals			+			–
	Thin HMA Overlays	+	+	+			+
	Ultra-thin Friction Course		+	+			
	In-Place Surface Recycling	+	+	+	+		+

Table 2. Summary of possible preventive maintenance treatment effects on MEPDG performance indicators for PCC-surfaced pavements.

		PERFORMANCE INDICATORS							
		Jointed Plain Concrete Pavement				**Continuously Reinforced Concrete Pavement**			
	Treatment	Joint faulting	Load transfer efficiency	Load-related transverse cracking	Joint spalling	Crack spacing/width	Load transfer efficiency	Punchouts	Smoothness (IRI)
Portland Cement Concrete Pavements	Crack Sealing/ Joint Resealing	+		+	+				–
	Diamond Grinding	+							+
	Load Transfer Restoration	+	+						+
	Undersealing	+	+						
	Pavement Patching		+	+	+			+	+/–

3. PAVEMENT DESIGN BASED ON THE MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE

The premise behind the development of AASHTO's MEPDG was to create a pavement thickness design procedure that would use existing mechanistic-empirical based models and data that reflect the state-of-the-practice in pavement design (i.e. no new models were to be developed and no new test sections were to be constructed or monitored). SHAs, researchers, and others have long sought to move toward a mechanistic approach to pavement design for the following reasons:

- Improved ability to model the response/behavior of virtually any pavement design in any climatic region and constructed with different pavement materials.
- More realistic characterization of in-service pavement performance.

While the interest, if not also the intent, has been around for a long time, the capabilities to conduct pavement designs in this manner have not. Over time, however, the ability to implement mechanistic-empirical based procedures has been enhanced by improved analytical methods, the low cost and widespread availability of high-level computing capabilities, and the increased familiarity of SHAs with mechanistic-empirical based design procedures.

The mechanistic-empirical approach to pavement design can be briefly explained as follows: the mechanistic portion addresses the relationship between the existing pavement condition, materials, climate, and traffic loads and the resulting stresses, strains and deflections, while the empirical portion relates calculated stresses, strains and deflections to some measure of pavement performance (and the resultant definition of pavement failure based on that performance measure). In the MEPDG, the stresses, strains, and deflections are used to calculate incremental damage over time, which is then empirically related to observed pavement distress. As such, the outputs of the MEPDG are pavement distresses and not layer thicknesses.[6]

The general process for conducting a pavement design with the MEPDG follows these steps:

1. Select a trial design, which can be based on agency practices, design catalogs, or other pavement design programs. This trial design may include establishing a pavement cross section (layer types and thicknesses), defining material characteristics and properties, defining joint spacing, addressing drainage needs, and so on.
2. Select pavement performance criteria and design reliability level. Examples of pavement performance criteria include the acceptable amount of cracking, acceptable rut depth or the roughness level at the end of the pavement design life.
3. Obtain all needed inputs (material characterization, traffic, climate, and so on).
4. Run the MEPDG software.

If the trial design fails to meet the specified performance criteria, the pavement designer will need to modify the trial pavement design (e.g. select a different grade asphalt binder, increase pavement layer thicknesses, decrease joint spacing, or otherwise alter one or more inputs to the

[6] In 2008, AASHTO initiated a solicitation to State Departments of Transportation for the development of the next generation of the MEPDG software, one of the proposed modifications would include the ability of the MEPDG software (which has been renamed DARWin-ME by AASHTO) to iterate for pavement thickness.

design) and rerun the analysis to determine if the new pavement section satisfies the specified performance criteria. In this procedure, the above process is repeated until a satisfactory pavement section is determined, where “satisfactory” is defined as not exceeding selected pavement performance criteria. This entire process is represented graphically in figure 3.

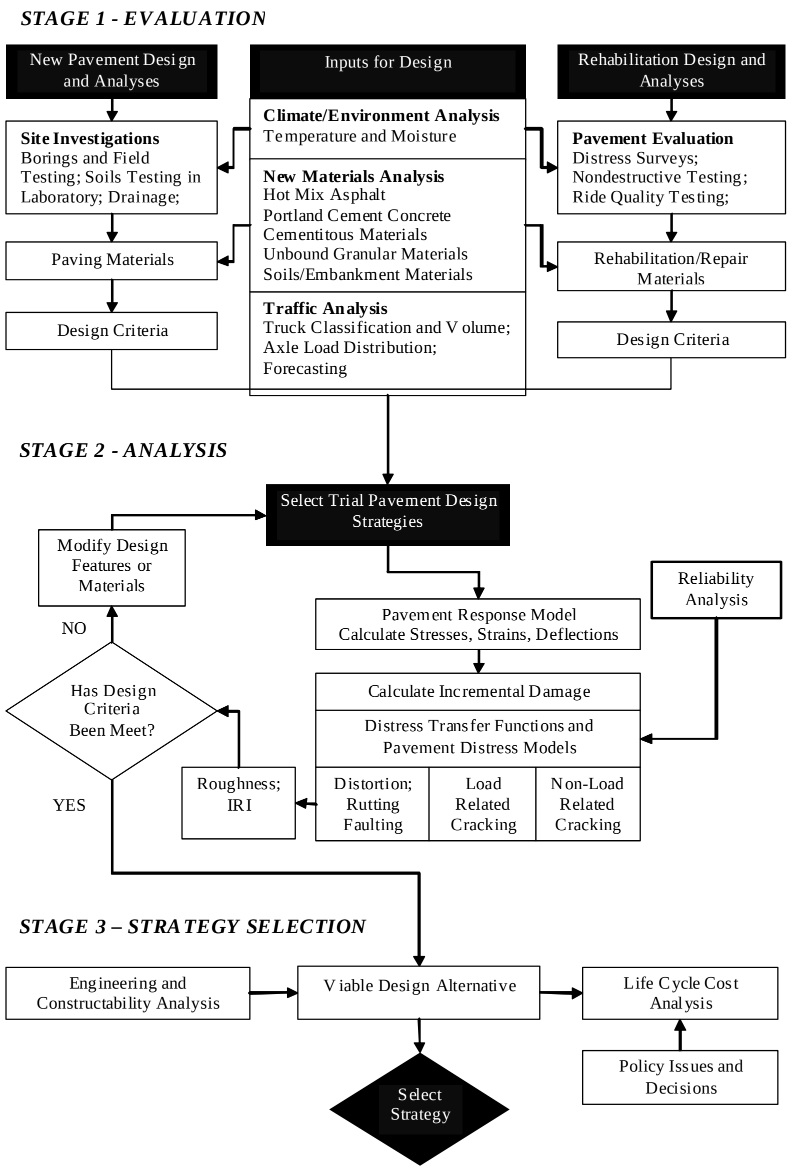

Figure 3. MEPDG conceptual flow chart (AASHTO 2008).

The MEPDG is by no means a finished product. In fact, AASHTO’s adoption of the MEPDG (guide and software) is referred to as an Interim Edition. The NCHRP, Federal Highway Administration (FHWA), universities, and numerous SHAs continue to evaluate the MEPDG and provide recommendations for enhancement. For example, NCHRP has the following active projects related to the MEPDG:

- NCHRP 1-41: Models for Predicting Reflection Cracking of Hot-Mix Asphalt Overlays.

- NCHRP 1-47: Sensitivity Analysis of MEPDG.
- NCHRP 4-36: Characterization of Cementitious Stabilized Layers for the New Mechanistic-Empirical Pavement Design Guide (MEPDG).
- NCHRP 9-29: Simple Performance Tester for Superpave Mix Design.
- NCHRP 9-30A: Calibration of Rutting Models for HMA Structural and Mix Design.
- NCHRP 9-38: Endurance Limit of Hot Mix Asphalt Mixtures to Prevent Fatigue Cracking in Flexible Pavements.
- NCHRP 9-44: Developing a Plan for Validating an Endurance Limit for HMA Pavements.
- NCHRP 9-44A: Validating an Endurance Limit for HMA Pavements.

The current capabilities of the MEPDG to analyze anything other than a new pavement design are limited to only load transfer restoration of PCC pavements and thick HMA and PCC overlays. As is noted previously, while the impacts of other pavement preservation treatments (such as fog seals, chip seals, crack sealing, diamond grinding, thin HMA overlays and so on) are considered by many to have a positive effect in extending pavement life, it is not possible to directly account for that effect within an MEPDG design analysis. One of the more challenging issues associated with these types of pavement preservation treatments is the ability to quantify the treatment performance according to mechanistic-empirical principles, such as existing pavement conditions, material type, traffic loads, climate conditions, and so on. This is because the application of these treatments may not result in a measureable change in stress, strain, or deflection. However, since an extension of pavement performance life is noted, there needs to be some way of capturing that benefit.

4. RECOMMENDATIONS FOR INCORPORATING PAVEMENT PRESERVATION INTO THE MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE

It has previously been stated that pavement preservation has a positive effect on pavement performance and that the Interim Edition of the MEPDG manual of practice does not account for the effects of pavement preservation on pavement performance. As such, designs developed for both new and rehabilitated pavements have the potential to be either overdesigned, if applied by an agency with a pavement preservation program using models not calibrated to account for local preservation practices, or under designed if the agency's preservation practices are less extensive than those represented in the models.

Incorporating Preservation without Detailed Data

Within the existing framework of pavement design using the MEPDG (see figure 3) there are at least three approaches that can be used to incorporate pavement preservation within the pavement design process. These approaches can be distinguished by where in the design process the effects of pavement preservation are considered or incorporated. In the first approach (referring to figure 3), the impact of pavement preservation on pavement design is considered in "Stage 3—Strategy Selection." As shown in figure 3, the first step in this stage is the application of engineering and constructability analyses to a viable design alternative, followed by the calculation of life cycle costs, tempered by policy issues, and then the final selection of a design strategy. To incorporate pavement preservation at this level, a new step is introduced between the viable design alternative and the life cycle cost analysis. This step is labeled "Pavement Preservation Analysis," and consists of the consideration of the effects of pavement preservation on the viable design alternative. In this new step, a preventive maintenance treatment or series of treatments is selected and the effect on performance is defined in terms of improvements in pavement performance or extensions in pavement life. A life cycle cost analysis is then performed on the viable design, modified by the preventive maintenance, prior to the selection of a final strategy. This revised strategy can be modeled as shown in figure 4, with the various substeps described in more detail as follows:

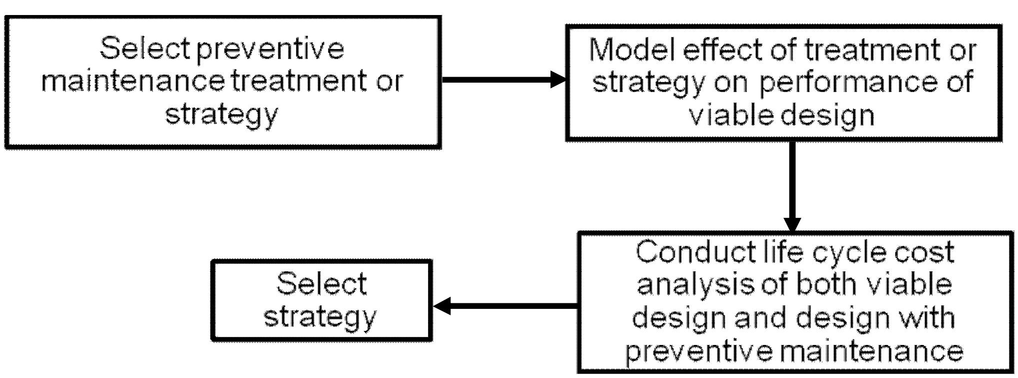

Figure 4. Expansion of "pavement preservation analysis" step in the MEPDG design process.

1. Select preventive maintenance treatment or strategy. Starting with the viable design alternative identified in Stage 2, generate a preventive maintenance treatment or, as is more likely, a preventive maintenance strategy[7]. As an example, consider a viable design consisting of a total of 9 inches of HMA materials over a 6-inch aggregate base. If the expected life of this pavement for the given conditions is 19 years, an agency could develop a preventive maintenance strategy consisting of crack sealing at 4 and 8 years, and a microsurfacing treatment at 9 years.

2. Model effect of treatment or strategy on performance of viable design. The effect of this preventive maintenance strategy is expected to be a delay in the need for structural rehabilitation, as represented by the performance measures of interest to the agency. This effect can be represented by a life extension in years, where data for this might come from agency experience, the experience of other agencies, or other objective sources (or even subjective ones, such as "expert opinion").

3. Conduct life cycle cost analysis of both viable design and design with preventive maintenance. The design process is not complete until a life cycle cost analysis is used to evaluate whether the beneficial effects of the preventive maintenance strategy outweigh its costs. In this step, the analysis should include a comparison of the life cycle costs of the design without preventive maintenance as well as the costs of the preventive maintenance strategy. Incidentally, there is nothing to preclude the analysis of a number of alternative preventive maintenance strategies.

4. Select strategy. The selection of a final pavement design is made in the final step, and now has the potential to include a design and preventive maintenance strategy. Strategy selection might be made based on the lowest life cycle costs, but it is recognized that other considerations could affect this decision. For example, a treatment or strategy that improves surface friction but does not extend pavement life would probably have higher life cycle costs than the strategy without that treatment, but still be desirable for other, strategic reasons.

Because of where and how in the design process preventive maintenance is being considered, this first approach can be undertaken at the same time that agencies begin implementation of the MEPDG.

The second approach to incorporating pavement preservation into the MEPDG involves addressing pavement preservation in the analysis stage of the design process, Stage 2. Recall

[7] A preventive maintenance treatment is one that preserves the pavement, slows deterioration, and maintains or improves the pavement's functional condition without significantly increasing its structural capacity. The treatments described in section 2 of this report are considered preventive maintenance treatments when those benefits are the result of the treatment's application. Sealing cracks in a 2-year old bituminous-surfaced pavement is an example of a preventive maintenance treatment application. Rarely does an agency's preventive maintenance practice consist of the single application of a preventive maintenance treatment, however. It is far more common to employ a preventive maintenance strategy, in which a series of treatments are applied at different appropriate times in the life of the pavement. An example of a preventive maintenance strategy is sealing cracks, followed by the application of a chip seal 1 to 2 years later, and the placement of a thin overlay 8 years after that.

from figure 3 that this is the stage in which the performance of the trial design is evaluated against established design criteria by considering pavement responses and the development of pavement distress (e.g., roughness, distortion, load-related cracking, and non-load related cracking. This second approach involves making modifications to the distress transfer functions and pavement distress models, based on the effect of preventive maintenance treatments.

Incorporating Preservation with Data

This second approach is based on actual data being used to modify pavement performance modeling. It assumes that the default models in the MEPDG do not reflect the benefits of pavement preservation, but that those benefits can be reflected in revised models. As described below, there are two ways to develop these revised models: by analyzing existing data and by generating new data through the construction and monitoring of appropriate test sections.

Analysis of Existing Data

Within the MEPDG framework, the adjustment of existing analytical models to local conditions is referred to as "local calibration." This process is applied to improve the applicability of the general models to locally observed performance, and should account for many of the factors that affect the variable performance of pavements in different environments, constructed to varying levels of quality, and maintained to different standards. In the specific case where the agency wishes to consider the effect of pavement preservation on pavement performance (and thus its effect on pavement design), the agency must have access to relevant performance data from pavements that have received preventive maintenance treatments. The analysis of existing data would then proceed along the following lines:

- Identify agency preventive maintenance treatments or strategies.
- Identify pavements where treatment or strategy has and has not been (control section) applied.
- Analyze pavement condition data (rutting, cracking, roughness) associated with each treatment or strategy. This requires that sufficient condition data exists over the full life of the treatment).
- Determine impact on pavement performance prediction models by comparing the performance of the treated sections to the control sections.
- Calibrate models.

The agency may wish to develop calibrations for two categories of pavements: those that benefited from pavement preservation and those that did not. Conducting a dual analysis would permit comparisons of the cost effectiveness of different approaches to pavement design and preservation. Guidance on conducting local calibrations is available in a forthcoming NCHRP report.

Generation of New Data

Ideally an agency would have performance data reflecting the use of either a preventive maintenance treatment or strategy. In that case, the incorporation of pavement preservation in the MEPDG process would simply involve the calibration of models using such data, as described above. Where this is not the case, the recommended approach involves the construction of test sections and the monitoring and analysis of performance results. Test sections should reflect the ranges of material types, traffic loadings, and climates experienced by the agency, as well as a range of treatments, strategies, and their respective application timings. Furthermore, test sections should include pavements that receive no treatments between construction and rehabilitation to serve as the control. It is anticipated that a large database of pavement preservation treatments, site conditions, pavement performance measures, and so on would be established to provide valuable data for the development of new models to be incorporated into the MEPDG. It is worth repeating that there is a difference between preventive maintenance treatments and strategies, and that over time if it is the effects of strategies that are being modeled then test sections need to be treated with those strategies.

The steps involved in incorporating pavement preservation into the pavement design process through the establishment of test sections include the following:

- Select treatments and strategies of interest to the agency.
- Design experiment to cover the range of variables appropriate to the agency (including pavement type, treatment and strategy types, traffic, environment, treatment timings, and so on).
- Construct test sections or use a combination of existing pavements and new sections that fit the experimental design.
- Generate performance model inputs from the construction process and monitor performance according to MEPDG.

Appendix D of NCHRP Report 523, *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (Peshkin et al. 2004), provides detail on designing and monitoring preventive maintenance test sections. While the potential knowledge gleaned from such test sections would have a significant impact on improved pavement designs, test sections are costly to design, maintain, and monitor. Agencies that are considering generating their own data in this manner are encouraged to use that publication, or other reasonable guidance, to plan and design useful preventive maintenance experiments.

As noted previously, in the absence of existing data or test section results, the anticipated benefits of preventive maintenance may be estimated. Such an estimation could be based on the experience of others or expert opinion, for example. This approach is potentially more subjective than others that have been proposed, but has the advantage of being comparatively quick and simple to implement.

Incorporating Preservation Considering Effects on Material Inputs

The third approach recognizes that preventive maintenance treatments affect material properties, for example by retarding aging in bituminous materials or by keeping unbound layers from becoming saturated. This approach is the most mechanistic of the three, as it directly considers the effect of preventive maintenance on material inputs in either Stage 1 – Evaluation (new materials analysis providing inputs for design) or in Stage 2 – Analysis (modify design materials). It is believed, however, that little to no guidance is available to help designers model material inputs to reflect the benefit of timely preventive maintenance. As noted later, additional research is needed to determine these effects.

One caveat that applies to any approach to alter how the MEPDG accounts for preservation is that it assumes that preventive maintenance benefits have not already been accounted for. It is acknowledged that agencies routinely apply maintenance treatments to the pavements that they manage. This may include routine and corrective maintenance as well as preventive maintenance. As such, to the extent that pavements included in the development of models used for the MEPDG received such maintenance, the models themselves may already reflect the effects of preventive maintenance. Taking additional steps to account for the benefits of preventive maintenance would, in effect, constitute "double counting" of those benefits. However, given that proactive preventive maintenance has historically been more of an exception than the rule, and recognizing that the pavement sections used both to develop and validate models for the MEPDG are not distinguished by whether preventive maintenance was applied to them, it is still more likely that the models were developed from pavements that did not receive preventive maintenance. Therefore, the potential for double counting the positive effects of preventive maintenance is minimal.

5. CONCLUSIONS AND SUGGESTED RESEARCH

Pavement preservation is rapidly becoming a common component of how public and private agencies maintain their pavement networks. However, it is not only the increasing prevalence of preservation programs, but also the beneficial impact that pavement preservation has on pavement performance and pavement life, that suggest that pavement preservation should be considered as part of the pavement design process.

With the introduction of the MEPDG, there is an opportunity to consider pavement preservation in the overall analysis and design process. For any agency with a viable pavement preservation program, in which the conventional timing of rehabilitation and reconstruction is being delayed through the effective use of preventive maintenance treatments, this should be a priority. This report describes how this can be done, both early on in the process (i.e., currently) and over time.

It is recognized that one of the greatest obstacles to greater integration between the pavement design process and all types of non-structural treatments is the lack of well-documented benefits. Accordingly, the following recommendations are made for further research.

- Identify opportunities for lab-based work to adjust mechanistic models (calibration to field conditions to account for climatic and truck loading impacts will still be necessary, and laboratory testing to quantify material properties will be critical).
- Analyze the effects of preventive maintenance treatments on material inputs used in generating inputs for design or analysis.
- Better quantify the effects of preventive maintenance treatments on pavement materials over time in order to modify MEPDG calculations of incremental damage over time.
- Analyze existing data from agencies with documented pavement preservation experience to determine the feasibility of refining global models for select treatments.
- Refine and better quantify the impacts of pavement preservation on performance models.
- Better quantify the effects of preventive maintenance (both individual treatments and strategies) on reducing roughness and thereby extending pavement life (i.e., objectively quantifying the observation that “smoother roads last longer”).
- Investigate the feasibility of a national experiment to develop global models that reflect the effect of pavement preservation on pavement performance and, therefore, on pavement design.

Some of these recommendations call for new research to be performed. However, some simply call for better tracking of where preventive maintenance is being performed, and better differentiation between the performance of pavements that have and have not received preventive maintenance. That could be accomplished through the application of sound pavement management principles.

The need for further research notwithstanding, for those agencies starting to use the MEPDG it is still possible today to begin to address the effects of preservation on their pavement designs.

6. REFERENCES

AASHTO. 1993. *Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C.

AASHTO. 1999. "Pavement Preservation in the United States: Survey by the Lead States Team on Pavement Preservation." Web document available at: http://leadstates.transportation.org/pp/survey/survey_report.pdf (document accessed and reviewed March 18, 2009).

AASHTO. 2008. Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice. American Association of State Highway and Transportation Officials, Washington, D.C.

Corley-Lay, J., N. Mastin, and E. McGraw. 2005. Changing our way of thinking: have we succeeded? Transportation Research Circular E-C078, First National Conference on Pavement Preservation, Transportation Research Board, Washington, D.C.

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

Massey, S. and P. Pool. 2003. Preserving Pavements and Budgets: California's Strategies Leverage Limited Funds, TR News Number 228, September-October 2003. Transportation Research Board, Washington, D.C.

Miller, R. W. 2002. "Why (Not How) Kansas DOT's Pavement Management System Works and How Preventive Maintenance Actions are Integrated." Paper No. 02-3266 on the TRB 2002 81st Annual Meeting CD-ROM, Transportation Research Board, Washington, D.C.

Peshkin, D. and T. Hoerner. 2005. Pavement Preservation: Practices, Research Plans, and Initiatives. National Cooperative Highway Research Program Project No. 20-07, Task 184, Washington, D.C.

Peshkin, D., T. Hoerner, and K. Zimmerman. 2004. "Guide for Optimal Timing of Pavement Preventive Maintenance Treatment Applications." *NCHRP Report 523*, National Cooperative Highway Research Program, Washington, D.C.

Testa, D. 2006. The Road to Pavement Preservation: The Kansas Department of Transportation Way. TR News Number 247, November-December 2006, Transportation Research Board, Washington, D.C.

APPENDIX A. DEFINITIONS

Pavement preservation, preventive maintenance, and other maintenance-related terms refer to a broad set of approaches to manage pavements throughout their lives. The FHWA has provided generally accepted definitions of these key concepts and they are reprinted below (FHWA 2005):

Pavement Preservation

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

Preventive Maintenance

A planned strategy of cost-effective treatments 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).

Minor Rehabilitation

Non-structural enhancements made to an existing pavement section to eliminate age-related, top-down surface cracking that develop in flexible pavements due to environmental exposure. The most common form of minor rehabilitation is a thin HMA overlay.

Routine Maintenance

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

Routine maintenance consists of day-to-day activities that are scheduled by maintenance personnel to maintain and preserve the condition of the highway system at a satisfactory level of service. Examples of pavement-related routine maintenance activities include cleaning of roadside ditches and structures, maintenance of pavement markings and crack filling, pothole patching and isolated overlays. Crack filling is another routine maintenance activity which consists of placing a generally, bituminous material into “non-working” cracks to substantially reduce water infiltration and reinforce adjacent top-down cracks. Depending on the timing of application, the nature of the distress, and the type of activity, certain routine maintenance activities may be classified as preservation. Routine Maintenance activities are often “in-house” or agency-performed and are not normally eligible for Federal-aid funding.

Corrective Maintenance

Activities performed in response to the development of a deficiency or deficiencies that negatively impact the safe, efficient operations of the facility and future integrity of the pavement section. Corrective maintenance activities are generally reactive and performed to restore a pavement to an acceptable level of service due to unforeseen conditions. Activities such as pothole repair and patching of localized pavement deterioration (e.g., edge failures and/or grade separations along the shoulders) are considered examples of corrective maintenance of flexible pavements. Examples for rigid pavements might consist of joint replacement or full width and depth slab replacement at isolated locations.

The relationship between the relative timing of these various activities and pavement performance is illustrated in figure 5, in which these approaches to managing a pavement are illustrated against the backdrop of a generic pavement performance curve.

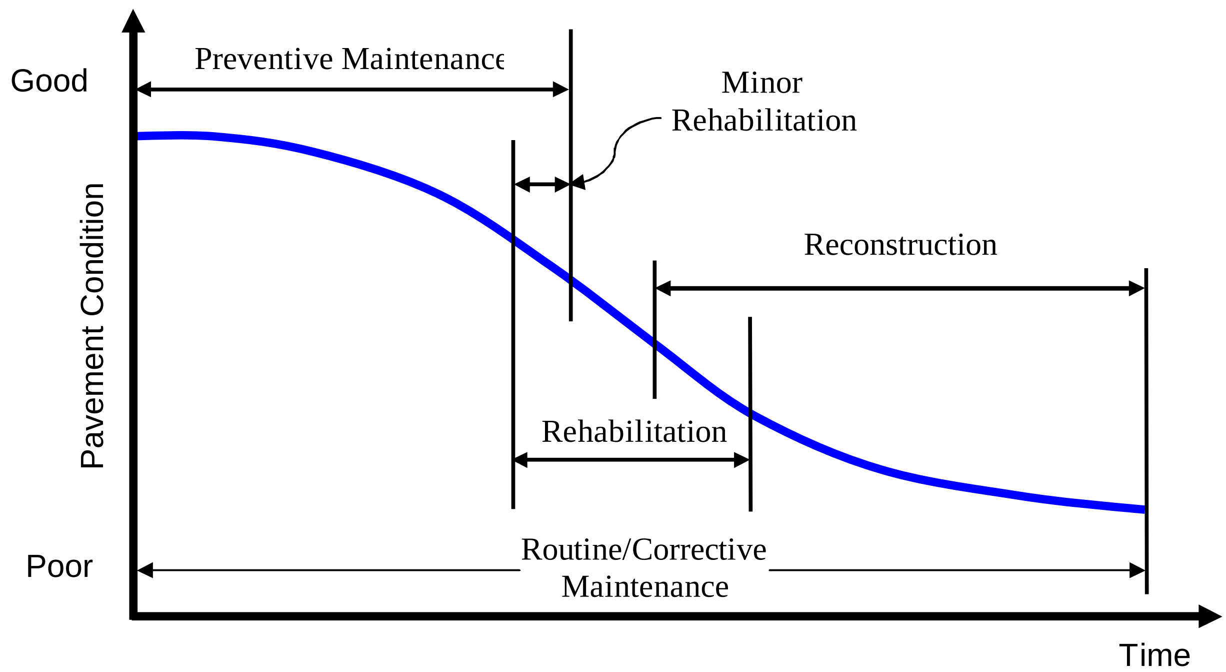

Figure 5. Typical pavement performance curve indicating the relative timing of various pavement treatments.

Key aspects of this diagram are that preventive maintenance treatments are applied to a pavement that is in comparatively good condition, that routine and corrective maintenance actions may be taken during a period in which a pavement is also a good candidate for preventive maintenance, but they continue throughout the life of the pavement, and that minor rehabilitation overlaps both the preventive maintenance and rehabilitation categories. In applying the preceding definition of pavement preservation as a program, it can be thought of as a systems approach to managing pavements earlier in their life, where in the past benign neglect may have left such pavements untreated.