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RESEARCH

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Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements

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Highway agencies have constructed expansive networks of pavements that are vital to the economic prosperity and vitality of the nation. These networks are currently deteriorating at such a rate that most agencies cannot afford to reconstruct them in a timely manner. Consequently, many agencies have employed low-cost preventive maintenance (PM) techniques such as crack and surface treatments in an attempt to slow the deterioration rates of the pavements, thus extending the service life and delaying the time until reconstruction. This study sought to address whether or not recent advances in bituminous mixtures and binder selection through SuperPave necessitated a re-examination of current PM practices. In other words should SuperPave pavements be managed differently, compared to other mixture types in the network. The first project task sought to analyze the effectiveness of PM treatments by using historical pavement management data to develop pavement decay curves with time. The results of the analysis indicated a life extension; however due to data limitations, a life cycle cost analysis (LCCA) as well as a specific life extension value were not conclusively determined. The second project task assembled a pavement owner's manual to provide general guidance on applying PM treatments throughout a pavement's life. The recommendations of applying PM are based primarily on the pavement's age and general surface characteristics. The recommendations of task 2 are based upon experienced engineering judgment, empirical evidence and a literature review; consequently they must be tempered to the local conditions, environment and materials.

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Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements

Final Report

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Executive Summary

Highway agencies have constructed a vast network of pavements that are vital to the economic prosperity and vitality of the nation. Currently very few new pavements are being constructed and the main focus of Highway Agencies is the preservation and maintenance of the current network. However, with limited available funding most agencies cannot afford to reconstruct the network at the current rates of deterioration. In fact the current inventory of badly distressed principle arterial pavements is expected to grow from 2.6% to 7.6% and non-principle arterials are expected to grow from 6.5% to 11.4% by 2011 if current trends continue [1]. Preventive maintenance activities such as crack and surface treatments have been employed in an attempt to slow the deterioration rates of the pavements, extend the service life and delay the time until reconstruction. Although it is commonly accepted by most practitioners that these preventive maintenance treatments extend the service life of the pavement, it is also commonly accepted that for a preventive maintenance program to be successful "the right treatment must be applied to the right road at the right time". This relatively simple sounding statement is very difficult to implement on a network basis, and represents a complicated problem identified by the Federal Highway Administration (FHWA) [3]. Due to the advent of improved bituminous mixes and binder selection through Superpave, the question arose, "Should the new pavements be maintained differently, or at all, when compared to previous bituminous pavements?"

This report will explain the recent efforts of using pavement management data to provide evidence for the benefits of preventive maintenance, and also provide a brief literature review on the current state of the practice in terms of the benefits and timing of preventive maintenance treatments. The different available treatments and associated best practices will form the basis of a pavement "owners manual" that should help practitioners effectively manage their pavements from the time of construction.

The first task developed decay curves using Mn/DOT pavement management data. Performance of bituminous over aggregate base (BAB) and bituminous over bituminous (BOB) sections were analyzed since these two pavement types contained enough data points to provide significant findings. The results of task one indicated a life extension as a result of the treatments. However, the analysis was confounded by the need for a large enough dataset to have meaningful results. This created a dataset that included pavements from the time prior to superpave implementation and dramatic improvements in Preventive Maintenance (PM) treatment specifications that occurred after 1995. Therefore a specific life extension value and life cycle cost analysis were not completed.

The second task of this study developed a user manual for Pavement Preservation methods. The goal of this manual was to give the owner agencies guidance to how and why to start a PM program. It contains descriptions and definitions of the various available treatments, as well as recommendations for the timely application of these treatments based on the pavement's surface condition. The guidelines for applying these preventive maintenance treatments are intended to be implemented as part of a long-term strategy that preserves the life of the pavement and improves the overall condition of the network. These recommendations are primarily based on experienced engineering judgment, extensive literature searches and empirical evidence. These recommendations are general in nature, thus each specific project requires an evaluation and decisions must be tempered to local conditions, materials, and other considerations.

The final section of this report is the conclusions and recommendations.

Chapter 1: Analysis of Pavement Performance with and without Preventive Maintenance

Introduction

This chapter contains the analysis using Minnesota Department of Transportation (Mn/DOT) pavement management data to determine whether a pavement's life is extended by preventive maintenance and if so, by how much. New bituminous over aggregate construction and bituminous overlays of bituminous pavements are used to evaluate the amount of life extension from preventive maintenance activities.

It also includes case studies from Minnesota and around the world that documents examples of preventive maintenance programs.

Preventive Maintenance - Definitions and Goals

Preventive maintenance is defined by AASHTO as "a planned strategy of cost-effective treatments to an existing roadway system that preserves the system, retards future deterioration, and maintains, or improves the functional condition (without adding additional structural capacity)" [2]. A pavement management program is necessary in order to successfully implement a preventive maintenance program [2]. Note that applying a preventive maintenance treatment (i.e. chip seal) as a stop gap measure to hold together a badly distressed pavement until reconstruction funds are available is not considered preventive maintenance, and such treatments will not be considered in terms of life cycle cost effectiveness nor in performance benefits – this does not infer that all stop gap treatments are not cost effective.

Pavement Degradation and Distress Mechanisms

Preventive maintenance treatments have the stated goal of protecting the pavement from the infiltration of water, sealing it from the ultraviolet radiation of the sun and from oxygen which can all lead to oxidative aging, or hardening of the asphalt binder. This hardening can make the pavement more susceptible to cracking and it is believed that the deterioration rate accelerates with increased exposure. Moisture can sometimes lead to stripping and degradation of the asphalt layer, although modern advances have reduced these occurrences. Additionally the infiltration of moisture into the pavement substructure can reduce the bearing capacity of the pavement leading to increased susceptibility to load related distresses.

Although there are treatments that can be used to fill in ruts, preventive maintenance treatments are by nature not designed to add significant structural capacity to the pavement. Pavements with load related distresses due to insufficient support, or are under designed for the current traffic, should not be considered as candidates to receive preventive maintenance treatments.

Performance Data

The Mn/DOT Pavement Management Unit in the Office of Materials and Road Research monitors the condition of the trunk highway system (including interstates). Monitoring includes annual inspection of the pavements using specially equipped vans that measure the pavement roughness and rutting, and collects digital images of the surface for condition ratings. This information is collected on the entire system every year. Roughness and rutting results are available for each year, but condition survey results from the digital images are generally determined every other year. In years past, this data was collected directly in the field by a manual rating process. The result of this monitoring is a database that describes the pavement performance. This data has been consistently collected since 1960's.

Pavement distresses such as cracks, patches and ruts are those defects visible on the pavement surface. They are symptoms, indicating some problem or result of pavement deterioration. The type and severity of distress a pavement has can provide great insight into what the future maintenance and/or rehabilitation needs will be.

Mn/DOT uses the Surface Rating, or SR, to quantify pavement distress. Since preventive maintenance is directed more at slowing deterioration than improving ride, the surface rating data from the pavement management system was used to compare roads with and without preventive maintenance. Although Pavement Management Systems are excellent tools for monitoring and managing at the network level, the present Mn/DOT system does not effectively capture raveling. Raveling is an indication of surface aging. Also the images do not have sufficient resolution to capture the initial formation of cracks.

Ride is also used as a measure of a pavement's performance. Ride importance increases with the posted speed limits and the length of the trip. Ride on urban city streets often does not reflect the pavement condition because of the high number of manholes and other structures in the pavement. Therefore, surface ratings are a better measure of preventive maintenance's effectiveness on city streets.

Preventive maintenance is used to slow the rate of pavement deterioration. Weathering raveling and minor cracking of bituminous surfaces are controlled by surface treatments. Surface treatments and crack treatments are thought to slow the deterioration of the bituminous adjacent to cracks. Crack treatments and surface treatments are also thought to reduce the amount of precipitation that can enter the lower pavement layers. Crack treatments have minimal effect on ride and chip seals have very little effect on ride. Thin overlays (non-structural) micro surfacing and slurry seals can result in small improvements in ride particularly if the pavement has small localized dips or the transverse cracks have cupped. Micro surfacing also is often used as a method of rut filling, another documented pavement distress.

Pavement Design and Preventive Maintenance in Minnesota

The scope of this study is to determine the effectiveness of pavement preservation. In addition it is noteworthy to determine the effectiveness of pavement preservation in the advent of improved hot mix asphalt pavements with the implementation of superpave specifications in particular. Mn/DOT developed a quality management program in 1987, which addressed some of the issues with pavement performance. The first superpave sections were placed in 1995 and fully implemented in 2000. The superpave specifications include enhanced binder properties with the PG grading system which has helped to address the rutting and cracking issues. Since the network of superpave pavements at the State and local level are relatively young, there is limited performance data available.

In addition the quality and usage of preventive maintenance treatments has also changed since 1987, with the evolution of better crack sealants and improved surface treatments. The Seal Coat Handbook published in 1999 was the tool for implementing a rational design and higher quality standards for chip seals. Micro-surfacing was introduced into the State in 1999 with a State-wide project. Overlays used as pavement preservation treatments have also been improved with the superpave technology. The pavement performance is influenced by the preventive maintenance treatments, which in turn can be enhanced by better performing treatments.

New Bituminous with Aggregate Base Pavements

The Mn/DOT pavement management data was used to evaluate the effect of preventive maintenance (PM) on new Bituminous Aggregate Base (BAB) sections. In order to have a large enough data set to draw conclusions, an analysis of non-interstate BAB pavements built since 1987. (Figure 1) The performance of pavements that had received one or more PM treatments since construction was compared to those that had never received any PM. The average SR of these two groups in the following chart shows a significant difference in performance.

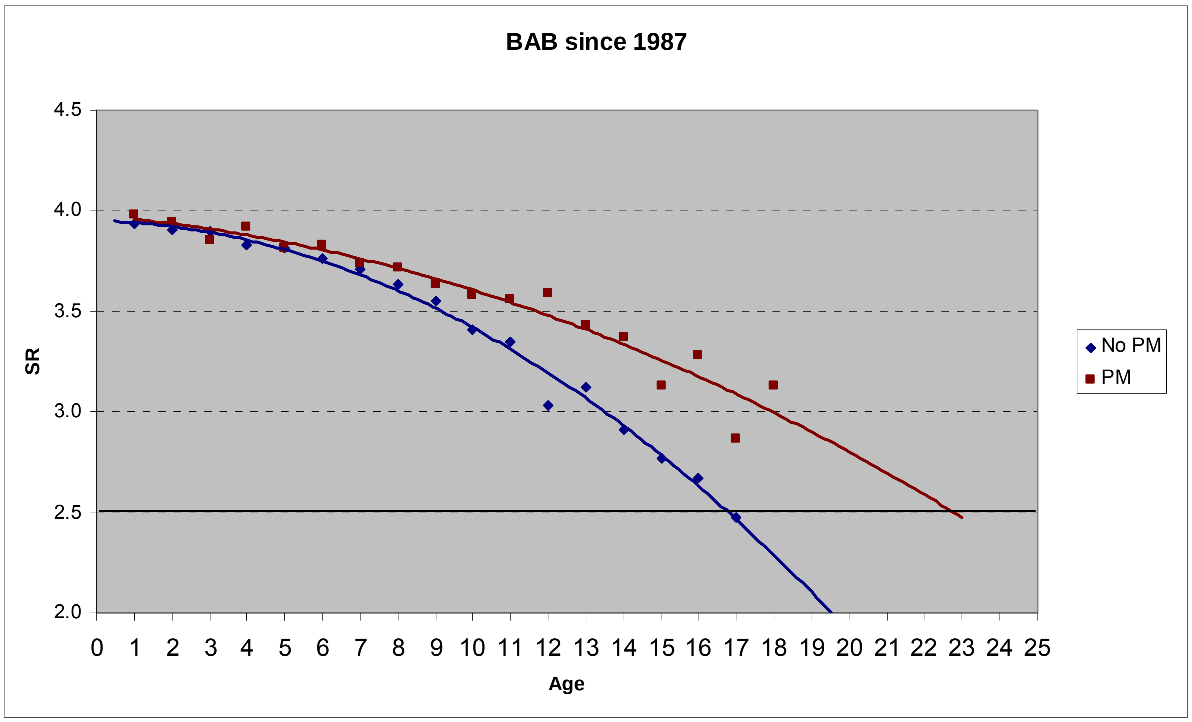

Figure 1: Bituminous Aggregate Base Pavements with and without PM

Rehabilitated Bituminous with Aggregate Base Pavements

A similar analysis of Mn/DOT US and MN roadways that were originally bituminous with aggregate base but have been overlaid or milled and overlaid. Bituminous over Bituminous (BOB) are shown below. (Figure 2) The date of the last overlay is 1987 or later. This data also shows that pavements that receive preventive maintenance treatments have an extended life.

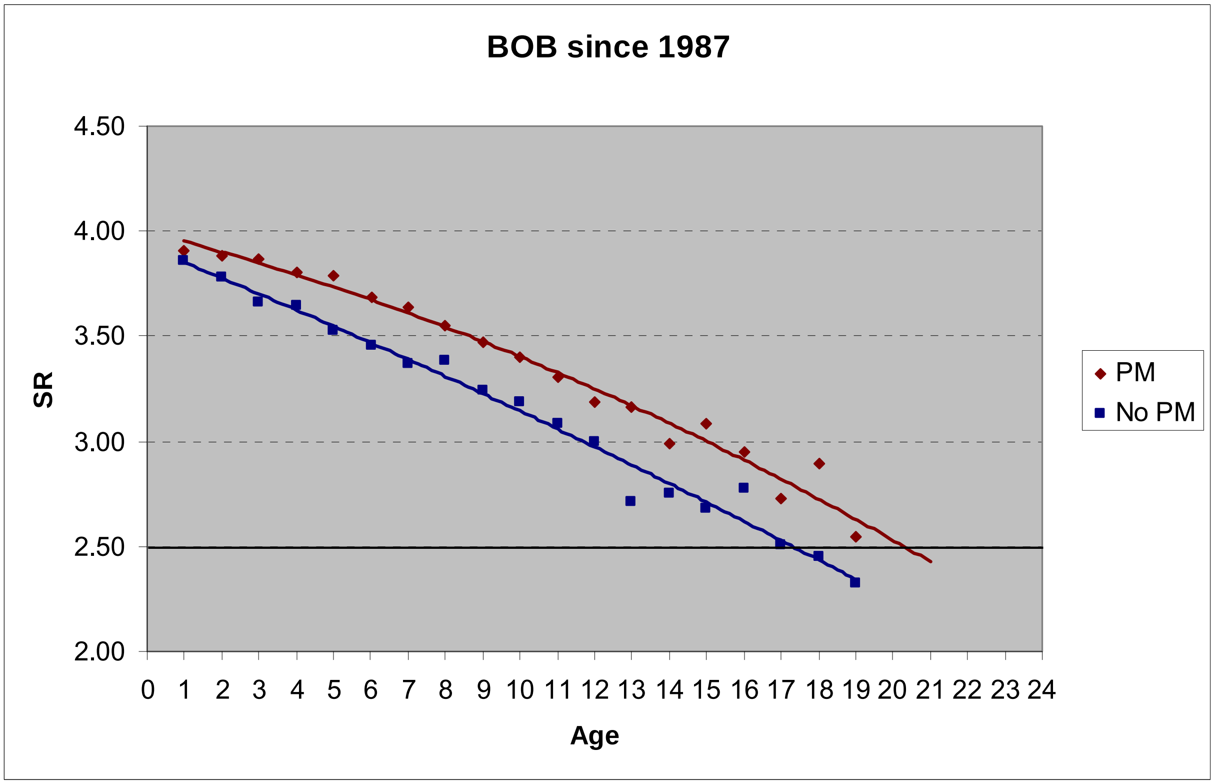

Figure 2: Bituminous over Bituminous Pavements with and without PM

Case Study: City of Eagan

The above tables are based on Mn/DOT PM data, which is based on the trunk highway system at the network level. As an example of a local agency program, the City of Eagan was contacted and supplied the following information:

The City of Eagan began doing pavement management in 1989 and had monitored the condition of city streets on a nominal three year cycle ever since. The distress rating process of their pavement management system is based on the Pavement Condition Index as defined in ASTM D6433-03 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. The Pavement Condition Index (PCI) is a composite index that is based on the extent (percentage of total area) and severity of pavement distresses. The City's pavement management data is used to describe the PCI deterioration, as shown in Figure 3.

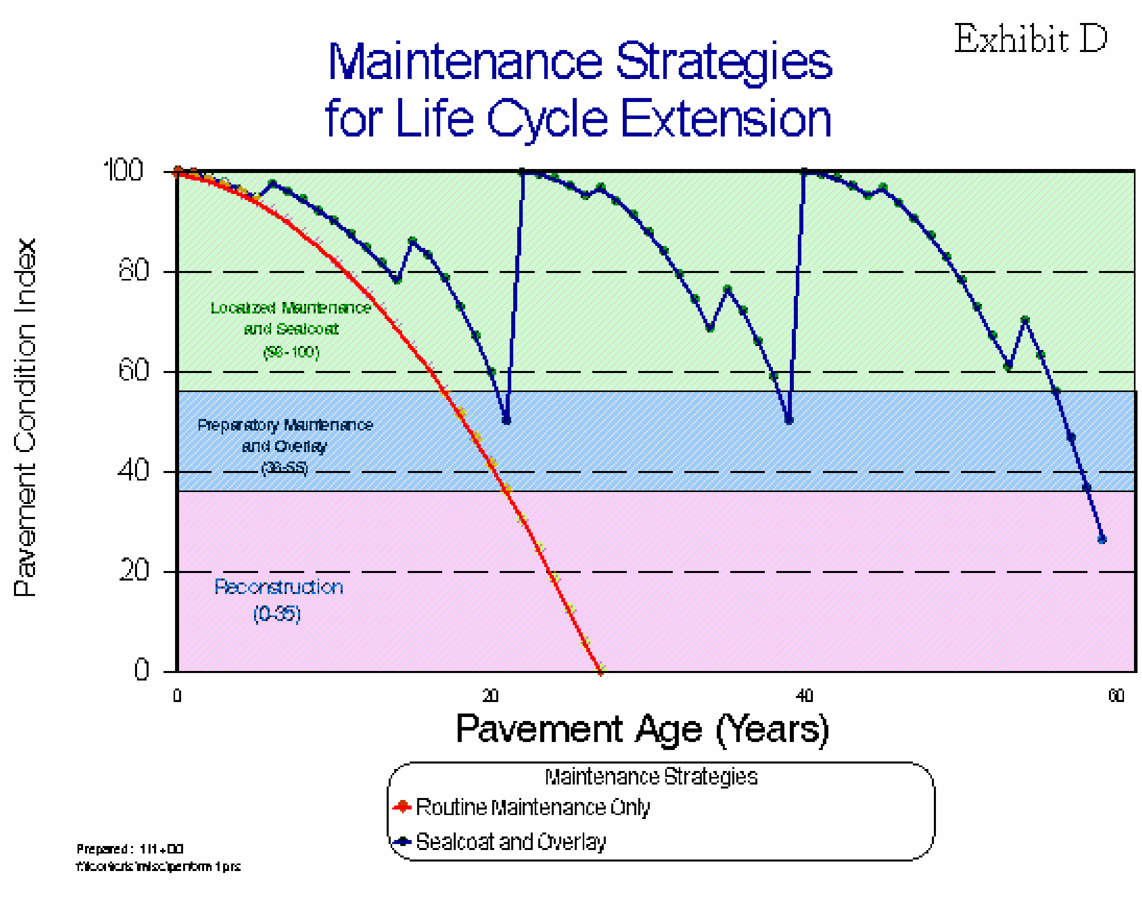

Figure 3: Pavement Deterioration for the City of Eagan

The figure shows two condition trends. The 'Routine Maintenance Only' trend line describes the deterioration of city streets based on typical PCI loss per year, which is age dependent. The 'Sealcoat and Overlay' trend line shows small PCI improvements that correspond with seal coats and the larger PCI improvements are results of overlays. The PCI improvements are a result of local repairs followed by a seal coat. Transverse cracks, for example, do not go away but their severity level is reduced to low severity. Pot holes turn into patches, alligator cracking is repaired and turns into a patch – patches have a much lower deduct. The increases for the seal coat events are calculated from actual city distress data. The 'routine maintenance only' trend line is an inferred line since the City does not have any streets that did not receive surface treatments and is based on the typical PCI deterioration rates for streets in the years no preventive maintenance was done.

Case Study: Ontario Crack Sealing

In 1992 the Ontario Ministry of Transportation (MTO) published a study titled CRACK SEALING IN FLEXIBLE PAVEMENTS: A LIFE-CYCLE COST ANALYSIS. Ontario typically sealed pavement cracks to prevent water from entering into base course layers. Experience suggests that water, present in pavement layers, hastens pavement deterioration and increases rehabilitation costs. Initially, the MTO experienced only limited success in sealing cracks because of the use of inappropriate materials and installation procedures. This setback, at the initial stages of development in crack sealing, raised questions concerning the effectiveness of crack sealing in reducing the rate of pavement deterioration. In the 1970s and 1980s, MTO carried out several field studies to develop an effective crack sealing procedure and to study the influence of crack sealing on pavement distress and performance. As well, the cost-effectiveness of this treatment was investigated. The results of the studies indicate that sealing cracks is a viable and cost-effective preventive maintenance treatment which can extend the service life of asphalt pavements by 2-5 years. However, for optimum benefits, the crack sealing program must be implemented according to the guidelines proposed in the paper. The guidelines provide a basis for the selection of suitable pavements and cracks, sealant materials, and application procedures.

NCHRP Report 523

Under NCHRP Project 14-14, "Guide for Optimal Timing of Pavement Preventive Maintenance Treatment Applications," Applied Pavement Technology, Inc., of Downers Grove, Illinois, was assigned the objectives of (1) developing a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements; (2) presenting the methodology in the form of a user-oriented computational process to facilitate its use for the variety of pavement maintenance situations encountered by highway agencies; and (3) developing a plan, for use by highway agencies, to collect the data needed to support the proposed methodology. In this project, preventive maintenance referred to any planned strategy of cost effective treatments to an existing roadway system that preserves the system, retards future deterioration, and maintains and improves the functional condition of the system (without substantially increasing structural capacity).

The findings of this research pointed out the importance of preventive maintenance programs and the need for developing a guide for determining the optimal timing of maintenance treatment applications. However, because of the lack of sufficient data to develop such a guide, the research identified the need for establishing a database of the performance of preventive maintenance treatments and developed a plan for constructing and monitoring test sections to collect the relevant data. The primary product of this research—a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements—provides a viable approach for comparing the performance and costs associated with application of treatments at different ages. When combined with performance data obtained from in-service projects or otherwise estimated, this approach can be used to select an optimal application age. Such information should be useful to highway agencies and contracting firms involved in preventive maintenance and preservation activities.

Case Study: Kansas DOT Pavement Preservation Program

In the early 1980s, Kansas DOT was investing little in maintenance or pavement preservation projects. Kansas DOT decided that a thin overlay would be a better investment of department funds rather than seal coats or other preservation treatments. Yet with a limited amount of funds available, few maintenance and overlay projects were undertaken. Kansas DOT was spending the little contract funding available on locations with the worst surface conditions—a worst-first approach. In addition to routine patching, the maintenance budget paid for some cold-mix overlays, approximately 1/2 inch thick. Kansas DOT personnel knew—and public comments verified that the system was in poor condition and was continuing to deteriorate.

The 1983 Kansas DOT implemented a Pavement Management System. The initial results indicated that 49 percent of the Interstate system was in good condition and 13 percent in poor condition; 43 percent of the non-Interstate system was in good condition and 19 percent in poor condition. The department's director of operations, the chief of the Bureau of Construction and Maintenance, used this information to convince managers that a dedicated fund for pavement maintenance was needed. At the same time system-wide targets for pavement conditions were set.

Initially the funds were used for thin (3/4-inch) overlays. This generated some minor improvements in the measures but was not enough to make substantial improvements. In 1989, the state legislature specified funding for pavement preservation at a higher level than originally set by the DOT executive staff. This allowed them to develop a full program of preventive maintenance including crack sealing, chip seals, slurry seals and thin micro surfacing.

The Kansas DOT's pavement preservation program exceeded the original goals for system performance. In 1999, a 10-year Comprehensive Transportation Program was passed and it continued the funding of pavement preservation. The results of the Kansas DOT implementation of a Pavement Preservation program is shown in Figure 4.

The results of this program were documented in a TRNews article by Dean Testa, retired Chief, Bureau of Construction and Maintenance, Kansas Department of Transportation.

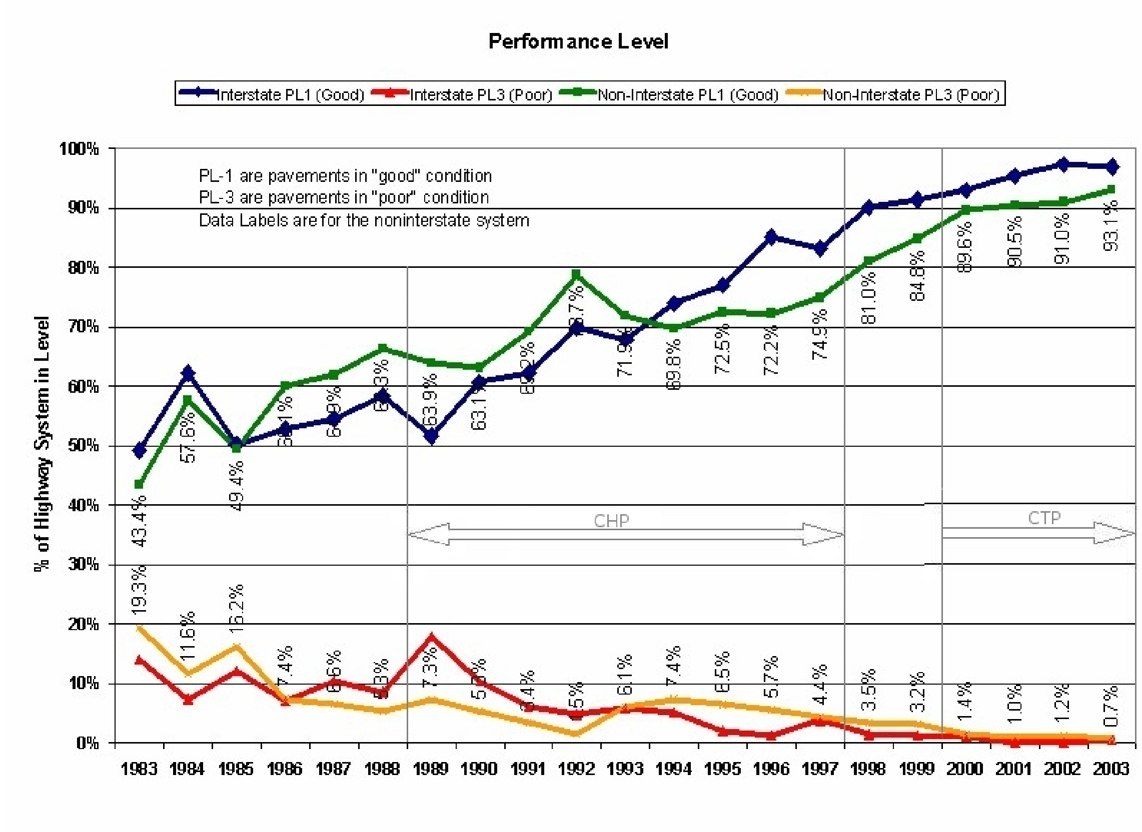

Figure 4: Kansas DOT Pavement Performance

Chapter 2: Timing of Preventive Maintenance Activities – Surface Treatments

The literature review, included in the final report, demonstrated that success of a preventive maintenance treatment is dependant upon not only the quality of the treatment's materials and construction, but also on the application timing with respect to the existing pavement's condition [3]. There are, however, no clear guidelines on the proper time to apply these treatments; only a general consensus that too late will yield little or no preservation benefit. The Federal Highway Administration (FHWA) [3] has recently identified that there is a great need for a comprehensive model that predicts the performance of the treatment, the life extension of the existing pavement and the related cost savings based upon the treatment type, the existing pavement condition, and the environmental and traffic conditions [3]. Such a model would prove invaluable as its goal would be to facilitate network level programming of the right preventive maintenance treatment on the right pavement, at the right time. In addition the cost savings and life extension models would be a useful tool for examining where the biggest opportunities for improvement are and for educating the public and lawmakers on the benefits and necessity of a preventive maintenance program.

In general the best time for preventive maintenance is any time before the condition of the pavement deteriorates to a state that it must be rehabilitated, or reconstructed. Sealing cracks, joints and surfaces as early as possible to prevent water infiltration, and limit the exposure to ultraviolet radiation is recommended. Chip seals and fog seals are cheaper to apply earlier in the pavements life because as the pavement ages its' surface becomes more pocked, porous and oxidized which requires a greater amount of emulsion to seal the surface. In the Local Road Research Board (LRRB) study by Marasteneau and Stephan [*] on the timing of maintenance treatments, results show that applying the chip seal earlier is less costly. The one mile of chip seal was applied to two concurrent segments of on TH 56; one that was one year old and the other that was six years old. The aggregate, crew, and day were the same on both sections. To achieve the same amount of embedment of the aggregate on the six (6) years old segment 670 gallons more emulsion was required due to the aging of the HMA. If the average 2008 costs of emulsion are assumed, this would equal a cost increase of $1233 per mile. Both segments are performing similarly.

Programming Preventive Maintenance Treatments: Selecting the Proper Candidate and Treatment

Network Level Analysis - Decision Trees

Network analysis refers to analysis of a pavement system, or at least some significant subset, such as all bituminous pavements. Network analysis is not intended to provide the final decision on pavement segment by segment basis, but is set up to estimate network funding needs and the projected network condition. Therefore, if a pavement section meets the criteria for one of the preventive maintenance categories, a more in-depth evaluation of the actual project condition is needed.

The pavement management software (HPMA: Highway Pavement Management Application) used by the Minnesota Department of Transportation utilizes a decision tree to identify the appropriate action for each of the pavement segments in the Trunk Highway system. A condensed version of the decision tree for bituminous pavements is shown below Figure 5.

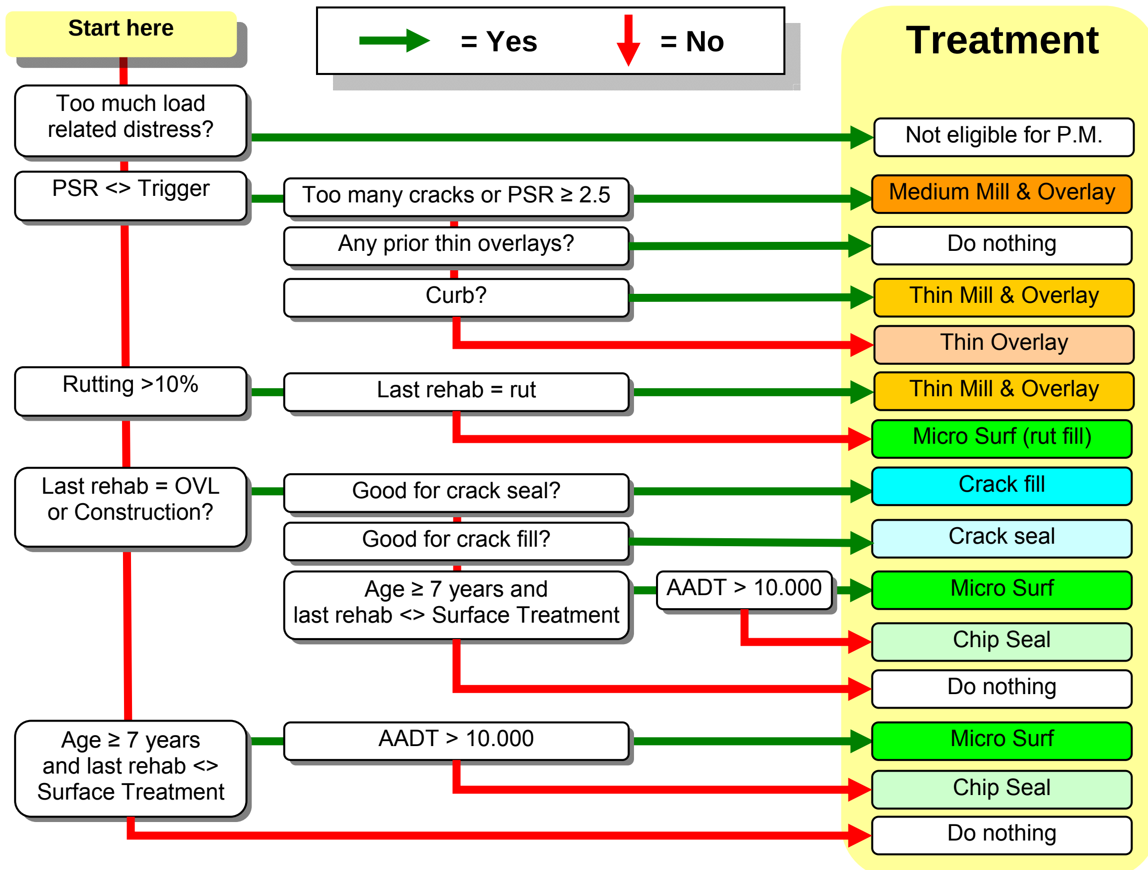

Figure 5: Condensed Version of Pavement Management Decision Tree

It is important to identify the factors that make the pavement more receptive to preventive maintenance treatments, and those which leave little choice except for rehabilitation, or reconstruction. The decision tree shows that if there is not “too much load related distress” and the ride quality index (RQI formerly PSR) of the pavement section is less than the rehab trigger then it is eligible for a number of preventive maintenance treatments.

The PQI is the pavement quality index, which is a composite index of both a ride quality, or roughness (IRI) and a surface rating of distress (SR) measurement. The PQI is a reflection of how the roadway “feels” to the average user [4]. Thus the condition of the pavement must be monitored closely, yearly if possible, to ensure that the opportunity to apply preventive maintenance treatments is not lost; as it is generally accepted that applying preventive maintenance treatments to badly distressed pavements is not a long term cost effective strategy. The amount of traffic, the presence of rutting, and the time since the last rehab activity are other factors that aid in the decision of what specific treatment to apply.

Project Level Analysis – Engineering Experience

Once a list of eligible sections has been provided by pavement management software such as HPMA, it is up to the engineer to decide which sections will be treated. The pavement engineer must also decide if the preventive maintenance category identified by the selection criteria is the best choice. Currently the timely application of preventive maintenance treatments still remains largely dependant upon experienced engineering judgment, empirical evidence and historical agency practices. There is no formalized mechanistic model which accurately predicts the effect of surface treatments (including timing) on the overall performance and service life of the pavement. The decision to apply a surface treatment depends upon other agency factors such as pavement markings, availability of resources and even public perceptions. It is possible that timing may not be as important as selecting a high quality pavement in relatively good condition with no load related distresses and applying a good quality preventive maintenance product (ie proper materials selection and construction practices).

As most counties and municipalities do not monitor the condition of their pavements with a pavement management system on a yearly basis, this owner's manual will not focus on using a pavement management system as the basis for selecting preventive maintenance treatments and application times. This manual will instead provide guidance based upon qualitative evaluations of the pavements surface condition and appearance. The general recommendations provided by this manual are supported by a large body of empirical evidence. Ultimately these recommendations must be adjusted to local conditions, materials, traffic and other considerations as determined by the engineer.

Preventive Maintenance Treatments:
Preventive Maintenance Toolbox: Available Treatments

There are many surface and crack treatments that are available for the pavement engineer to choose from in order to effectively manage and preserve the pavement network. There are also treatments available that are proprietary in nature; however an exhaustive list and description of these products will not be provided. The proprietary products can usually be grouped into the general treatment categories described below.

As mentioned previously not all pavements react in the same manner to the same treatment; and different treatments of the same type yield different results on the same pavement. Thus experienced engineering judgment must be utilized in the treatment and pavement selection and in the subsequent evaluation of the treatment's and pavement's performance. There currently is no "one size fits all" approach that can be applied to select the right treatment for the right pavement at the right time. A major reason for the lack of a uniform mechanistic approach to preventive maintenance is the lack understanding of how pavements deteriorate and what affect the various preventive maintenance treatments have on this deterioration.

The available surface and crack treatments work best when viewed as part of a long term preservation strategy, as opposed to temporary fixes that are part of a reactive maintenance strategy. The cost effectiveness, and subsequent preservation benefits, of these short lived treatments are only fully realized when the whole life of the pavement is considered. Special care must be given to treatment design as poorly designed treatments provide little preservation benefit and are often costly to repair. In addition there may be costly property damage, and safety issues that result from poorly designed treatments.

Fog Seal and Rejuvenator Treatments

(Mn/DOT Special Provision 2356 S-145.I and Mn/DOT Specification 3151.E, Page 28)

Preventive Maintenance Benefits

Fog seals are defined by the Asphalt Emulsion Manufacturer's Association (AEMA) as a light application of dilute asphalt emulsion without the use of an aggregate cover [5-6]. Fog Seals are used primarily to seal an existing asphalt surface against water, and UV radiation, reduce raveling, lock in chips from a chip seal (increase embedment depth important in resisting snow plow damage) and enrich dry and weathered surfaces [5-9]. A fog seal should theoretically slow down the deterioration rate by limiting the pavements exposure to the elements which can lead to oxidative aging that stiffens the asphalt binder making the pavement more susceptible to cracking. Water infiltration can also damage the existing pavement and the supporting structure which also shortens the life of the pavement; however modern Super Pave mixes are more resistant to stripping than previous mixes. Fog seals generally have a relatively short service life and can present friction problems that are not associated with other surface treatments.

Rejuvenators are defined as asphalt emulsions (or emulsions of the non-asphalt components of bituminous binders) that have oils that reduce the viscosity and soften the existing binder by restoring maltenes lost to the oxidative aging process which reduces its viscosity [5]. This reduced viscosity improves flexibility, which reduces the chance of cohesive failure [5]. Thus rejuvenators claim to prevent further damage by repairing damage that has already been done.

Pavement Selection and Timing

Fog seal and rejuvenator treatments are not found on the bituminous pavement decision tree (Figure 5) discussed earlier, but are still categorized as preventive maintenance treatments. Table 1 below discusses the suggested application of three common fog seal products, cationic slow set diluted 1:1 (Css-1h(d)), cationic rapid set diluted 3 parts emulsion to 1 part water (CRS-2pd), and generic rejuvenators based upon either the pavements surface condition or appearance. Note that as the surface condition and appearance degrades there are fewer restrictions on the products that can be applied.

Fog seals can be applied at the time of construction which allows use of construction funds and provides an initially sealed surface. Fog seals and rejuvenators can be applied as light to moderate raveling and/or oxidation develop in the pavement, but are not recommended when structural distresses are present [7]. Mn/DOT normally does not fog seal mainline highway pavement surfaces except over chip seals, due to friction concerns. When applied over chip seals to increase aggregate embedment depth which helps to prevent windshield damage [8]. The amount of friction lost due to the fog seal placed on a new chip seal is considered small when compared to the amount of friction gained from the chip seal [8]. There are other agencies that do perform fog seal operations on mainline pavement, such as the Nebraska Department of Roads (NDOR) which recently applied a fog seal treatment (Gilsonite) on Interstate 80. Bituminous shoulders and recreational trails are pavement surfaces that are often overlooked by the pavement engineer, but these surfaces are ideal candidates for fog seal and rejuvenator surface treatments, generally due to less stringent friction and traffic control requirements. Mn/DOT does apply fog seals to mainline shoulders, including those with rumble strips, and was recently involved with a Local Road Research Board investigation (LRRB 876) which applied fog seal and rejuvenator treatments to recreational trails, all as part of a preventive maintenance strategy. The longitudinal joint between the pavement and the shoulder can be treated with fog seal, in addition to a crack seal, to help prevent water infiltration, however special care must be exercised to ensure that the pavement markings are not covered. The resulting blackened surface of the shoulder caused by applying a fog seal increases the contrast with pavement markings. Consequently fog seal treatments could be marketed as a safety treatment as well as a preventive maintenance treatment.

Fog Seals that penetrate into the surface such as a diluted cationic slow set (CSS-1h) tend to have shorter visual service lives than those that stay near the surface such as cationic rapid set polymer modified asphalt emulsion diluted (CRS-2pd).

The effectiveness of the various rejuvenators' ability to reduce viscosity and improve flexibility in the upper layer of the pavement is dependant upon how much of the product is absorbed into the pavement and the nature of the product itself.

Table 1. Application of Spray Applied Fog Seal and Rejuvenator Surface Treatments by Surface Condition and Appearance

Pavement Surface Condition and Appearance[1]	Emulsion Type	Application Rate (gal/sy)	Functional Application Cycle (years)	Visual Application Cycle (years)	Max. Allowable Volume (ADT) on Mainline
New - Black, Flushed	Css-1h (d)	Not Recommended			
	CRS-2p(d)				
	Rejuvenator				
On a New Chip Seal	Css-1h (d)	0.06 to 0.12	5 to 7	2 to 3	Medium (<10,000)
	CRS-2p(d)	Not Recommended			
	Rejuvenator				
Smooth, non-porous	Css-1h (d)	0.03 – 0.06	3 to 5	2 to 3	Low (<1,000)
	CRS-2p(d)	Not Recommended			
	Rejuvenator				
Slightly Porous & Oxidized	Css-1h (d)	0.03 to 0.06	2 to 5	2 to 3	Low (<1,000)
	CRS-2p(d)	0.02 to 0.04	2 to 5	3 to 6	Low (<1,000)
	Rejuvenator	0.03 to 0.06	2 to 5	2 to 3	Low (<1,000)
Slightly Pocked, Porous & Oxidized	Css-1h (d)	0.05 to 0.08	2 to 5	2 to 3	Low (<1,000)
	CRS-2p(d)	0.03 to 0.06	2 to 5	3 to 6	Low (<1,000)
	Rejuvenator	0.03 to 0.08	2 to 5	2 to 3	Low (<1,000)
Badly Pocked, Porous & Oxidized	Css-1h (d)	0.08 - 0.12	1 to 5	2 to 3	Low (<1,000)
	CRS-2p(d)	0.05 to 0.08	1 to 5	3 to 6	Low (<1,000)
	Rejuvenator	0.05 to 0.08	1 to 5	2 to 3	Low (<1,000)

Note: Shoulders, Rumble Strips, and Recreational Trails are O.K. for all treatments described above
1. See Distress Manual, pg. 28

Chip Seal Surface Treatments

(Mn/DOT Special Provision 2356, pg. 28)

Preventive Maintenance Benefits

Modern Minnesota chip seals can be defined as a polymer modified asphalt emulsion layer, covered by a layer of aggregate cover that is one stone (or chip) thick, then covered again with a fog seal of a hard based, slow setting asphalt emulsion (Css-1h) to lock in the aggregate particles and blacken the surface [8]. Chip seals must be properly designed to account for the condition of the existing roadway, traffic, and aggregates, the Minnesota Seal Coat Handbook is the recommended design reference. Chip seal surface treatments are used primarily to seal an existing asphalt surface against water, solar radiation and wind which can oxidize the asphalt binder causing it to age and become brittle leaving it more susceptible to cracking. Chip seal treatments have the added benefit of increasing surface friction, retarding surface raveling, and sealing very small cracks, all of which could extend the service life of the pavement [8].

Pavement Selection and Timing

Typically Mn/DOT applies a chip seal to pavement sections that are between four to seven years old, have no load related distresses, or structural issues, and have had crack treatments installed at least one year prior. A chip seal is normally placed on low to medium volume roads with AADT less than 10,000 if traffic levels are greater than this a micro surface treatment can be used [10]. Mn/DOT preventive maintenance staff expect modern Minnesota chip seals to last approximately 10 years; however it must be stated that the expected service of the chip seal is not the same as the expected improvement in the overall service life of the pavement. Note that chip seals should be re-applied on a regular cycle in coordination with other treatments in order to obtain the maximum preservation benefits.

Table 2. Application of Chip Seal Surface Treatments

Chip Seal Surface Treatment (CRS-2p emulsion covered by Mn/DOT FA-2,3, swept and fog sealed with Css-1h(d)	
Pavement Age	Generally 4 to 7 years, some agencies apply the year of construction, or the year after
Pavement Surface Condition	Any condition ranging from black and flushed to varying degrees of oxidation and porosity. Small cracks O.K.
Pavement Distress (See Distress Manual pg. 28)	No load related distresses. Low to moderate raveling, low to moderate block cracking, low to moderate low severity transverse and longitudinal cracks are O.K.
Functional Application Cycle	Chip Seals constructed with polymer modified asphalt binder and designed properly can be expected to last 7 to 10 years
Visual Application Cycle	The 'new hot mix' appearance diminishes with the fog seal after 2 to 3 years
Allowable Traffic (ADT)	Low and Medium (<10,000), Use caution on higher volume roadways
Shoulders	Recommended, but fog seal may be more cost effective
Recreational Trails	Recommended, but use FA-1 Gradation
Rumble Strips	Not Recommended

Micro-surface Treatments

(See Mn/DOT Special Provisions 2356, page 28)

Preventive Maintenance Benefits

Micro-surface treatments can be defined as a mixture of fine aggregate, asphalt emulsion and mineral filler such as Portland cement; this treatment uses a chemically controlled curing process which typically allows traffic to use the roadway within one hour, as opposed to slurry seals which use a thermally controlled curing process [7]. Furthermore the additional mix stability, resulting from the latexes, makes this treatment ideal for higher volume roads, where a chip seal would be impractical. This treatment is applied as in slurry form and placed by a slurry box that uses a screed to control the surface elevation. A micro-surface can be applied in relatively thick layers, which makes it ideal for filling in ruts, and correcting other deformations. The main disadvantage of this treatment when compared to a chip seal or other surface treatments is its relatively high unit cost. Micro-surfacing also can be used to restore friction to an otherwise sound pavement surface.

Pavement Selection and Timing

Typically when a micro-surface treatment is applied to asphalt pavement sections in preventive maintenance mode the sections might exhibit moderate to severe oxidation and/or low friction, are between four to ten years old, should have no load related distresses, structural issues, and have had crack treatments installed at least one year prior. This treatment can also be applied as a corrective measure to restore the transverse cross section profile to fill in ruts and other deformations. Micro-surface treatments can be expected to last at least seven years when placed on medium to high volume roads, and much longer if placed on low volume roads; however the service life is dependant upon the condition of the roadway and therefore, the micro-surfacing life is expected to be less with decreasing surface condition, especially with the presence of heavy cracks. Note that this treatment, as is the case with chip seals, should be re-applied on a regular cycle in coordination with other treatments in order to obtain the maximum preservation benefits.

Table 3. Application of Micro-surface Surface Treatments

Pavement Age	Generally 4 to 10 years
Pavement Surface Condition	Any condition ranging from black and flushed to varying degrees of oxidation and porosity including moderate to severe oxidation.
Pavement Distress (See Distress Manual pg. 28)	Low to moderate raveling O.K. Can be used to fill ruts and other depressions, as well as correct transverse cross-section profile and restore surface friction.
Functional Application Cycle	At least 7 years on higher volume roadways, significantly longer on lower volume, and/or less distressed pavements [10]
Visual Application Cycle	The 'new hot mix' appearance diminishes as the treatment oxidizes in 3 to 5 years
Traffic (ADT)	Can be placed at all traffic levels, including high (>10,000)
Shoulders	Recommended, but fog seal may be more cost effective
Recreational Trails	Recommended, but use Type 1 Gradation
Rumble Strips	Not Recommended

Thin Overlay Treatments

(Mn/DOT Special Provision 2360/2350, page 28)

Preventive Maintenance Benefits

Thin overlays (including thin mill and overlays) are hot mix asphalt overlays that are less than two inches thick. They can be used as preventive maintenance treatments and to improve the functional characteristics of the pavement, but this treatment generally does not add significant structural capacity. There are three different types of mixes that are used: dense graded, open graded friction courses, and gap graded but the most common by far is the dense graded mix.

Pavement Selection and Timing

Thin overlay treatments may be placed when the surface exhibits moderate to extreme raveling, low and perhaps some medium severity longitudinal and transverse cracking with some secondary cracking. Patches that are in good condition should not prohibit the placement of an overlay. Milling is advisable when there are severe surface distresses present, to correct the profile, or whenever there are curbs present [10] but if severe surface distresses are present, an in depth engineering analysis is required to see if a thin overlay (or thin mill and overlay) would still be an appropriate treatment.

Mn/DOT typically applies this treatment to pavement sections that do not have too much load related distress, no fatigue cracking, and no more than three previous overlays. The pavement usually has a poor ride, or some rutting. If the pavement has rutting, it should have had rut filling performed some time in the past before receiving a thin overlay. A thin overlay, or a thin mill and overlay can correct pavements with poor ride, but deteriorated cracks and localized failures will reflect through the new surface. Milling is typically performed if the pavement has curbs, otherwise it is omitted.

Table 4. Application of Thin Overlay, or Thin Mill and Overlay Surface Treatments

Pavement Age	Greater than 7 years
Pavement Surface Condition	Varying degrees of oxidation and porosity including moderate to severe oxidation and moderate to severe raveling.
Pavement Distress (See Distress Manual pg. 28)	No load related distresses such as fatigue cracking. Moderate block cracking, moderate to severe raveling, low to moderate transverse and longitudinal cracking are O.K. Can be used to fill ruts and other depressions, as well as correct transverse cross-section profile. More distressed pavement sections should be milled prior to receiving overlay.
Functional Application Cycle	Average of 12 to 16 years, but highly dependant on condition of existing pavement
Visual Application Cycle	The 'new hot mix' appearance diminishes as the treatment oxidizes in 3 to 5 years
Traffic (ADT)	Can be placed at all traffic levels, including high volume (>10,000) roads
Shoulders	Recommended to overlay in conjunction with mainline
Recreational Trails	Recommended
Rumble Strips	Not Recommended, but can be used to fill in rumble strips if desired

Crack Treatments

(Mn/DOT Special Provision 2331, Mn/DOT Specs. 3719, 3723, 3725)

Preventive Maintenance Benefits

There are three main types of crack treatments that are currently used in Minnesota. Crack sealing is used for active cracks and crack filling is for cracks that show little or no movement. All treatments are designed to prevent moisture infiltration into the base and sub grade which can weaken the pavement's subsurface structural layer, a contributor to pavement deterioration [13]. A recent Mn/ROAD study showed that 85 percent of the water entering edge drains was entering through the crack at the interface of the PCC mainline pavement and bituminous shoulder, therefore it is recommended to seal these joints, as well as any curb and gutter joints.

Clean and Seal: Cracks are prepared by blowing out debris with compressed air and heating the crack face with a hot air lance before filling with sealant [13]. This technique is used on all types of pavement systems in Minnesota and typically uses Mn/DOT Specified 3723 Sealant, or 3719 in the case of more severe longitudinal cracks with the Engineer's permission. This procedure is most cost effective when applied to narrow width cracks.

Crack Filling: Differs from crack sealing mainly in the preparation given to the crack prior to treatment, the type of material used and the type of crack treated. When compared to the clean and seal method, crack filling usually involves much less crack preparation, uses either crumb rubber, or asphalt emulsion, and is usually reserved for more worn pavements with wider more random cracks and also for pavements whose cracks show little movement. Various fillers may not exhibit the same type of adhesive or elastic properties that is expected of the sealant.

Rout and Seal: Pavement is prepared by using a saw or router to create a reservoir centered over an existing ***transverse*** crack. The routed crack is then filled with the recommended 3725 sealant [13]. This is used on transverse cracks on all pavement types in Minnesota. Rout and seal is recommended only for transverse cracks because generally longitudinal cracks do not open and close to the extent that the additional width resulting from routing is needed to allow the sealant material to stretch and not break the bond with the pavement.

Pavement Selection and Timing

Mn/DOT generally identifies a pavement as a candidate for crack treatment as one that doesn't have too much load related distress, poor ride, nor too much rutting, and the most recent activity being either new construction or a new overlay. This initial crack sealing usually occurs within the first 2 to 5 years after construction when all the cracks are low severity, but Mn/DOT also does some crack filling when pavements are much older [10].

Crack sealing or filling may be the best option when the crack density is moderate and crack edges have some or little deterioration; crack treatments are not recommended for a pavement in an advanced state of decay, or one scheduled for reconstruction within a few years. A pavement should not be chosen as a crack sealing candidate based solely on the level of block cracking, however light block cracking can be treated together with the primary crack type being treated. It is recommend that crack treatments occur during the spring or autumn time frame and in dry conditions. In addition to using the appropriate sealant for the crack type, it is important to follow manufacturer recommendations with regard to sealant heating and placement temperatures, and to avoid mixing different manufacturer's brands or different types of sealants.

Figure 6: Excessive Crack Sealing

Table 5. Application of Crack Treatment and Material by Crack Type and Severity

	Treatment Method & Material		
Type of Crack or Distress[1]	**Clean & Seal (Material)**	**Rout & Seal (Material)**	**Crack Filling (Material)**
Transverse			
Low Severity	3723	3725	Not Recommended
Medium Severity	3723	3725 for spacing >250 ft	3723 for spacing > 20 ft
High Severity	3719 (w/ engineer approval)	Not Recommended	3719 (w/ engineer approval)
Longitudinal			
Low Severity	3723	3723	Not Recommended
Medium Severity	3719 (w/ engineer approval)	3723	3723
High Severity	3719 (w/ engineer approval)	3723	3719 (w/ engineer approval)
Block			
Low Severity	3723	3723	Not Recommended
Medium Severity	Not Recommended	Not Recommended	Not Recommended
High Severity	Not Recommended	Not Recommended	Not Recommended

1. See Distress Manual pg. 28

Table 6a. Summary of Treatments

	Treatment Method & Material						
Type & Severity of Crack or Distress	**Clean & Seal**	**Rout & Seal**	**Crack Filling**	**Fog Sealing**	**Chip Seal**	**Micro-surface**	**Thin OL, Thin M&OL**
Transverse Cracking							
Low Severity	Use 3723	Use 3725	Not Recommended	O.K.	O.K.	O.K.	Not Recom mended
Med. Severity	Use 3723	Use 3725	Use 3723	Not Recommended	O.K.	O.K.	OL
High Severity	Use 3719 (w/ approval)	Not Recommended	Use 3723	Not Recommended	Not Recommended	O.K., Life may be reduced	M&OL
Longitudinal Cracking							
Low Severity	Use 3723	Use 3723	Not Recommended	O.K.	O.K	O.K.	Not Recom-mended
Med. Severity	Use 3719 (w/ approval)	Use 3723	Use 3723	Not Recommended	O.K	O.K.	OL
High Severity	Use 3719 (w/ approval)	Use 3723	Use 3719 (w/ approval)	Not Recommended	Not Recommended	O.K., Life may be reduced	M&OL
Block Cracking							
Low Severity	Use 3723	Use 3723	Not Recommended	O.K.	O.K.	O.K.	$
Med. Severity	Not Recommended	Not Recommended	Not Recommended	Not Recommended	O.K.	O.K.	OL
High Severity	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended	OL

Table 6b. Summary of Treatments

	Treatment Method & Material						
Type & Severity of Crack or Distress	**Clean & Seal**	**Rout & Seal**	**Crack Filling**	**Fog Sealing**	**Chip Seal**	**Micro-surface**	**Thin OL, Thin M&OL**
Raveling							
Low Severity	Crack Treatments will not Correct Raveling Distress			Use Css-1h	O.K.	O.K.	Not Recommended
Med. Severity				Use Css-1h, or CRS-2pd, or Rejuvenator	O.K.	O.K.	OL
High Severity				Use CRS-2pd, or Rejuvenator	O.K.	O.K.	OL
Pavement Type or Traffic Level							
Traffic Level (ADT)	Can be placed at all traffic levels, including high volume (>10,000) roads			Low (<1,000) Use Caution	Medium (<10,000) Use Caution	Can be placed at all traffic levels, including high volume (>10,000) roads	
Shoulders	O.K. to Place on Shoulders			O.K	O.K.	Not Recommended	O.K. In Conjunction with Mainline
Rumble Strips	O.K.	Use Caution	O.K.	O.K.	Not Recommended	Not Recommended	Not Recommended
Recreational Trails	O.K., Consider Trail Users in Material Selection			O.K.	O.K., Use FA-2	O.K., Use Type 1	O.K.

Note: Thin OL, Thin M&OL and Micro-surface treatments can be used to correct rutting and transverse cross-section of roadway
All Surface Treatments except for fog sealing improve surface friction

Chapter 3: Conclusions and Recommendations

Since the introduction of superpave in the late 1990's, it has become the standard in Minnesota for state, city and counties. Mn/DOT is eliminating the 2350 specification for the 2009 construction year. Superpave implemented new binder tests and specifications to more accurately and fully characterize asphalt binders. These tests and specifications are specifically designed to address HMA pavement performance parameters such as rutting, fatigue cracking and thermal cracking. During this same period, changes in the overall bituminous mix specifications have also improved. These include aggregate selection, mix design and quality control/quality assurance. Superpave and other specification improvements have substantially eliminated rutting and delayed cracking. Reflective cracking still occurs in overlays. Thermal cracking, the most prevalent type of cracking seen in Minnesota, still occurs but at a lesser rate. The petroleum based asphalts used in pavements still oxidize and harden with time, eventually causing the pavement to become brittle and potentially crack and deteriorate. Superpave specifications don't adequately address long-term age-hardening caused by oxidation or increased moisture sensitivity with aging. Preventive maintenance is still needed to protect the investment made in good pavements. Based upon the analysis of Mn/DOT pavement management data, preventive maintenance did extend the life of the bituminous on aggregate base and to a lesser extent, the bituminous over bituminous pavements. Unfortunately, the amount of scatter in the data made it impossible to perform a life cycle analysis.

There is no 'one size fits all' approach to timing and selecting the preventive maintenance treatments for asphalt pavements. However extensive engineering experience, along with pavement management data, has shown that appropriately applying high quality preventive maintenance products to asphalt pavements can help to prolong the service life of the pavement.

In general the best time for preventive maintenance is any time before the condition of the pavement deteriorates to a state that it must be rehabilitated, or reconstructed. Preventive maintenance on pavements that are too far gone is ineffective, wastes resources and contributes to negative perceptions of preventive maintenance. Sealing cracks, joints and surfaces as early as possible to prevent water infiltration, and limit the pavement's exposure to ultraviolet radiation and oxygen is recommended. Crack sealing should be done as soon as transverse cracks have had a chance to form. Surface treatments are less costly to place when the surface is in better condition. Thin overlays and thin mill and overlays can be placed on pavements in poorer condition, and with higher traffic volumes than other surface treatments; however they last longer and perform better when placed earlier in the pavement's life when it is not severely distressed.

Applying preventive maintenance early in a pavement's life when the pavement is in good condition may be difficult for an engineer to justify to the public, or politicians, when there are pavements in poor condition that need attention. This is made worse because pavement preservation benefits are not as easily quantifiable as they are for pavement rehabilitation or reconstruction. Thus a pavement preservation strategy needs a champion, public and political understanding, secure funding, and a long term agency commitment in order to succeed. It is also recommended that a short section of a preventive maintenance project be skipped for long term side by side monitoring of the effects of the treatment. Side by side observation of performance of these skipped sections is the only way that pavement engineers will eventually be able to quantify the benefits of the various preventive maintenance treatments.

Additional steps recommended to address the questions of cost effectiveness of preventive maintenance and promote the use of preventive maintenance are the following:

- Determine how surface texture changes over time and how those changes relate to aging
- Determine the causes of non-load related cracking.
- Measure the effects of de-icing chemicals on HMA.
- Evaluate the safety enhancements that surface treatments may provide
- Evaluate the effects that PM treatments have on noise
- Develop training for all of the possible users of PM.

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Additional Resources

1. Mn/DOT Specs and Standards:
   http://www.dot.state.mn.us/tecsup/spec/index.html

2. Mn/DOT Special Provisions – See Boiler Plate SP 2005 Book (Dual Units):
   http://www.dot.state.mn.us/pre-letting/prov/index.html

3. Mn/DOT Approved Products List:
   http://www.dot.state.mn.us/products/index.html

4. Mn/DOT Distress Manual:
   http://www.dot.state.mn.us/materials/manuals/pvmtmgmt/distressmanual.pdf

5. Mn/DOT Seal Coat Handbook – Revised 2006:
   http://www.lrrb.org/pdf/200634.pdf

6. Best Practices Handbook on Asphalt Pavement Maintenance:
   http://www.lrrb.org/PDF/200004.pdf

7. The National Center for Pavement Preservation:
   http://www.pavementpreservation.org/

8. Spray Applied Polymer Surface Seals Study:
   http://www.pavementpreservation.org/fogseals/Docs/Final_Report.pdf