Cost-Effective Pavement Preservation Solutions for the Real World

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16. Abstract (Limit: 250 words)

This report presents a summary of pavement preservation activities and recommended uses, expected longevity, and expected pavement life extension. It also includes some basic information intended to be used by those less familiar with pavement preservation, pavement management, life cycle cost analysis, cost estimating, contracting methods and others to help inform and educate in this important aspect of pavement engineering. Tools and techniques are presented to assist local agency engineers in evaluating costs, benefits, timing, longevity, and the decision-making process for developing an effective pavement preservation program on an individual pavement segment or over an entire network. The report includes examples using real pavement engineering data from several cities and counties in Minnesota to demonstrate topics such as activity timing and the benefits of a preventive maintenance plan rather than a reactive one. A set of guidelines was developed as part of the associated project intended to serve as reference material and as a training program.

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Cost-Effective Pavement Preservation
Solutions for the Real World

Final Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This study was initiated to investigate the types and methods of selecting pavement preservation techniques that are ongoing in Minnesota and to provide guidance and insight for local agency engineers and maintenance supervisors in the development of pavement preservation programs within their agencies. In recent years, the concept of perpetual pavement preservation systems and their cost effectiveness have become more prevalent. As part of this study, tools and techniques are presented to assist local agencies to evaluate the costs, benefits, timing, longevity and decision-making process in order to determine an effective pavement preservation program. This research involves a broad literature study of existing methods of preservation techniques and systems being used as well as case studies of actual pavement preservation performance. A survey was sent to Minnesota counties and cities in an effort to collect existing data on preservation systems and methods from various Pavement Management Systems (PMS). Once the data was collected and reviewed, the project team selected pavement sections from various agencies to investigate further with the local engineers and maintenance supervisors. The team interviewed selected agencies regarding their experiences with pavement preservation and pavement management. The most common preservation techniques include routine maintenance and minor rehabilitation that are non-structural. Treatments such as crack sealing, seal coats, thin overlays, micro surfacing are all examples of common preservation techniques used by local agencies. Real world data was used to help close the gap between the expected design life of a treatment to the actual performance life of the applied treatment. This report provides guidance and shows the local engineer or maintenance supervisor the tools and methods needed to select reliable preservation techniques by utilizing data collected in their own county or city. The report also discusses the life-cycle cost analysis techniques used to make solid economic decisions regarding the type and timing of the treatment. There is and will be a continuing need for more agencies to develop and maintain a PMS that will enable the end user to determine the right treatment on the right road at the right time.

Chapter 1. INTRODUCTION

This report describes the development of guidelines and an educational document for developing effective pavement preservation strategies. The intended audience includes engineers and others working for local highway agencies (counties, cities, and other municipalities) who have responsibility over pavement networks and systems, as well as the long-term preservation and cost effectiveness of those systems while maintaining adequate levels of service.

Project Objectives

The primary objective of this project the development of a set of guidelines, or best-practices, and a source of information for further study in the topics of pavement preservation, pavement management, construction, and other areas. The main deliverable of the project is an interactive document intended to serve as a reference manual for those with responsibilities in this area. Thus, the document is made up of sections or modules, which can be accessed individually or read sequentially throughout the document.

The interactive document produced as a result of this project is not intended to provide specific answers or strategies for highway and street agencies when developing plans for pavement preservation. It does, however provide the user with the appropriate background and sources of information with which to develop a pavement preservation program with associated activities, timing, and prioritization.

Content of the Report

This report describes the activities of the research team over the duration of the project, the development of the interactive document, its external review, and the training program for its dissemination and intended use. Chapter 2 describes an extensive literature review on the major components of the project and the topics included in the interactive document. Chapter 3 discusses the data collection and analysis that was conducted by the research team to evaluate the expectations and actual implementation of pavement preservation and other activities by a sampling of highway and street agencies in Minnesota. Chapter 4 describes the development of the interactive guidelines document and adds more information that was not included in the previous chapter. Chapter 5 presents conclusions and recommended ways of using the document and accessing the information it contains.

Chapter 2.   LITERATURE REVIEW

This chapter includes the review of literature and other tools and guidelines that were used in the development of the information described in this report. The chapter is divided into specific pavement preservation sub-categories, including:

- Definitions,
- Preservation activity selection,
- Pavement management systems,
- Cost effectiveness evaluation,
- Timing and prioritization of activities, and
- General pavement preservation program guidelines.

The sources included in this literature review, together with those included in the references section, comprised the basis for the initial development of the interactive guidelines.

Definitions

Geiger, D.R., *Pavement Preservation Definitions*, FHWA Memorandum dated 12 September 2005.
The U.S. Department of Transportation and the Federal Highway Administration (FHWA) released a memo to ensure consistency and clarification in the use of specific terms relating to pavement preservation.

A proactive approach to pavement preservation enables State transportation agencies (STAs) cost effective and time efficient methods of rehabilitating and reconstructing with minimal traffic disruptions. Providing the public with improved safety, reduced congestion, and smoother, longer lasting pavements is the goal of the FHWA and is the result of true pavement preservation. The purposes of pavement preservation are to "reduce aging" and "restore serviceability," not to "increase capacity" or to "increase strength."

A Pavement Preservation program consists primarily of three components:
1. Minor rehabilitation (non-structural)
2. Preventive maintenance
3. Routine maintenance

There are different types of pavement preservation and not all are effective for the desired outcome. It is important to consider the intended purpose of the treatment before it is applied to the pavement. Table 1 shows the characteristics of certain pavement preservation activities and what they are able to provide as well as not provide. For example, preventive maintenance should be able to restore the function of the existing pavement and extend its service life, but not increase its structural capacity or strength.

Table 1. Pavement Preservation Guidelines (1).

Pavement Preservation Guidelines					
	Type of Activity	Increase Capacity	Increase Strength	Reduce Aging	Restore Serviceability
	New Construction	X	X	X	X
	Reconstruction	X	X	X	X
	Major (Heavy) Rehabilitation		X	X	X
	Structural Overlay		X	X	X
Pavement Preservation	Minor (Light) Rehabilitation			X	X
	Preventive Maintenance			X	X
	Routine Maintenance				X
	Corrective (Reactive) Maintenance				X
	Catastrophic Maintenance				X

Pavement Preservation is "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."

An effective preservation programs addresses pavements while they are still in good condition. A cost-effective treatment in a timely manner will restore the pavement almost to its original condition. By doing so, the cumulative costs of such treatment are substantially less then reconstruction or major rehabilitation over the life of the pavement. In addition the disruption of traffic is less for more frequent and minimal treatments in comparison to larger construction treatments.

Preventive Maintenance is "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)."

Preventive maintenance should be applied to pavements in good condition having significant remaining service life (RSL). It applies cost-effective treatments to the surface or near-surface of structurally sound pavements. Examples include the following:

- Asphalt crack sealing
- Chip sealing
- Slurry or micro surfacing
- Thin and ultra-thin hot-mix asphalt (HMA) overlay
- Concrete joint sealing
- Diamond grinding
- Dowel-bar retrofit
- Isolated, partial and/or full-depth concrete repairs to restore functionality of the slab

Pavement Rehabilitation consists of "structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays."

It is important to note that rehabilitation can be divided into two categories – minor rehabilitation and major rehabilitation. Minor rehabilitation provides non-structural enhancements to the existing pavement and would be placed in the category of pavement preservation. Major rehabilitation provides structural enhancements that increase the life of the pavement or improve the load carrying capacity.

Routine Maintenance "consists of 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 is day-to-day activities that are scheduled by maintenance personnel to maintain and preserve the pavement at a satisfactory level.

Examples of routine maintenance procedures include:
- Cleaning of roadside ditches and structures
- Maintenance of pavement markings and crack filling
- Pavement patching
- Isolated overlays

Other activities such as corrective and catastrophic maintenance and reconstruction are important, but outside of the realm of pavement preservation.

Preservation Activity Selection

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements***, Foundation for Pavement Preservation, Washington DC, 2000.**
The Foundation of Pavement Preservation (FPP) funded a study to provide information on the various types of pavement preservation treatments.

This report specifically addresses flexible pavement preventive maintenance including types of pavements that are candidates for preventive maintenance, the available treatments, where and when they should be used, their cost effectiveness, the factors to be considered in selecting the appropriate treatment strategy, and a methodology to determine the most effective treatment for a particular pavement.

The objectives of the study were to:
1. Review existing practices related to selecting appropriate preventive maintenance strategies.
2. Develop a framework for the selection of the most appropriate preventive maintenance treatments.
3. Prepare a summary report which documents the findings.

Establishing a Pavement Preservation Program
A successful and efficient pavement preservation program will have the support and cooperation of upper management as well as a comprehensive education effort aimed at the customer.

The following elements should be considered when developing a pavement preservation program:
1. Establish program guidelines
2. Determine maintenance needs
3. Provide framework for treatment selection
4. Develop analysis procedures to determine the most effective treatment
5. Include a feedback mechanism to determine program effectiveness

Preventive Maintenance Treatments
There are a number of preventive maintenance treatments for flexible pavements. The timing of the various treatments are applied determines whether they are preventive or corrective treatments. Common distress types in flexible pavements include:
- Rutting
- Cracking
- Bleeding
- Roughness
- Weathering
- Raveling

The following table matches possible maintenance treatments to associated distress types. However, if the identified stresses are related to a structural deficiency, the pavement would most likely not be a candidate for preventive maintenance. In such a situation either rehabilitation or reconstruction should be considered.

Table 2. Possible Preventive Maintenance Treatments for Various Distress Types (2).

Pavement Distress	Crack Sealing	Fog Seal	Microsurfacing	Slurry Seal	Cape Seal	Chip Seal	Thin HMA Overlay	Mill or Grind[a]
Roughness								
Nonstability Related			X		X		X	X
Stability Related							X	
Rutting			X				X	X
Fatigue Cracking[b]		X	X	X	X	X	X	
Longitudinal and Transverse Cracking	X		X	X	X	X	X	
Bleeding			X			X		X
Raveling		X	X	X	X	X		

Key: X = appropriate strategy
[a]This is a corrective maintenance technique
[b]For low severity only; preventive maintenance is not applicable for medium to high severity fatigue cracking

The report defines the various treatments as follows:

1. Crack Sealing – treatment used to prevent water and debris from entering cracks in the pavement. It may require routing to clean the crack and create a reservoir to hold the sealant
2. Fog Seal – an application of diluted emulsion (normally 1 to 1) to enrich the pavement surface and hinder raveling and oxidation. This is considered a temporary application.
3. Chip Seal – treatment used to waterproof the surface, seal small cracks, and improve friction. Typically it is used on low-volume roads. However, it can also be used on high volume highways and expressways.
4. Thin Cold Mix Seals – treatments include slurry seals, cape seals, and micro surfacing which are used on all types of facilities to fill cracks, improve friction, and improve ride quality.
5. Thin Overlays – includes dense-, open-, and gap-graded mixes (as well as surface recycling) that are used to improve ride quality, provide surface drainage and friction, and correct surface irregularities. They are generally 1.5 inches (37 mm) in thickness.

The costs and expected lives of the various treatments are summarized in Table 3 of the report. These values can vary depending on the project and its specifications and environmental surroundings.

Table 3. Typical Unit Costs and Expected Life of Pavement Maintenance Treatments (2).

Treatment	Cost/m^2	Cost/yd^2	Expected Life of Treatment		
			Min.	Average	Max.
Crack Treatment[a]	0.60	$0.50	2	3	5
Fog Seals[b]	0.54	$0.45	2	3	4
Slurry Seals[c]	1.08	$0.90	3	5	7
Microsurfacing[d]	1.50	$1.25	3	7	9
Chip Seals[e]	1.02	$0.85	3	5	7
Thin Hot-Mix Overlay[f]	2.09	$1.75	2	7	12
Thin Cold-Mix Overlay[f]	1.50	$1.25	2	5	10

Notes:

[a] Assumes typical crack density of 0.25 yd/yd^2

[b] 0.2 l/m^2 (0.05 g/yd^2) of a 1:1 dilution of CSS emulsion and water

[c] 7 kg/m^2 of ISSA Type II slurry

[d] 14 kg/m^2 of ISSA Type II microsurfacing

[e] 15 kg/m^2

[f] 30 to 44 mm/m^2

Framework for Treatment Selection and Timing
Pavement treatments applied after the initial construction either preserve the life of the pavement or extend it (rehabilitation). Figure 3.1 in the report provides a classification of the variety of the different treatment types used by highway agencies.

Chapter 3 of the report presents the use of decision trees and matrices as well as an approach to the optimal timing of implementing the specific treatment. An emphasis on the preventive treatments is shown in response to a more common approach to rehabilitation.

Highway agencies commonly use decision trees and decision matrices as tools when selecting a pavement treatment. Both depend on rules and criteria set forth by the agency, which are generally based on past experiences. The types of data considered in the development of these tools include:

- Pavement surface type and/or construction history
- An indication of the functional classification and/or traffic level
- At least one type of condition index, including distress and/or roughness
- More specific information about the type of deterioration present, either in terms of an amount of load-related deterioration or the presence of a particular distress type.
- Geometrics, in order to indicate whether pavement widening or shoulder repair should also be required
- Environmental conditions in which the treatment is to be used

There are both advantages and disadvantages of these tools. Advantages include:
1. The reflection of the decision process normally used by the agency
2. The flexibility to modify both the decision criteria and the associated treatments
3. The capability to generate consistent recommendations
4. The relative ease with which the selection process can be explained and programmed

Disadvantages include:
1. The focus of only one or two treatments that have worked well in the past
2. Improved or newer techniques that may be more effective are often overlooked or not considered
3. The use of decision trees and matrices, by themselves, does not ensure the selection of the most cost-effective treatment

Decision Trees

Figure 3.2 of the report provides an example of a maintenance and rehabilitation decision tree using five criteria as the basis for treatment selection. The decision tree used was for demonstrational purposes. However, it represents a simplified tool that does not take into consideration certain environmental conditions and traffic levels, which may have an important impact on both the cause of the distress as well as the treatment. More complicated decision trees are included in the reports Appendix B of the report.

The five criteria used are as follows:
1. Structural deterioration
2. Environmental cracking
3. Surface wear
4. Fatigue cracking
5. Rutting

In Figure 3.3 the report gives a series of decision trees based on specific distresses. Each tree then considers other external influences such as traffic, existing pavement conditions and environmental surroundings.

Asphalt Recycling and Reclaiming Association, U.S. Department of Transportation, and the Federal Highway Administration. Basic Asphalt Recycling Manual (BARM), 2001.
The Asphalt Recycling and Reclaiming Association (ARRA) has worked together with the U.S. Department of Transportation and the Federal Highway Administration to develop the Basic Asphalt Recycling Manual (BARM). Published in 2001 the BARM is an overall comprehensive look at different types of pavement rehabilitation and some of the advantages and disadvantage. It explains different uses and gives general specifications for many recycling techniques as well as the importance of regular pavement maintenance requirements. There are five broad categories that have been defined by ARRA to describe the various asphalt recycling methods.
1. Cold Planing (CP)
2. Hot Recycling
3. Hot In-Place Recycling (HIR)
4. Cold Recycling (CR) – including cold in-place recycling (CIR)
5. Full Depth Reclamation (FDR)

Where the BARM is written to help aid in deciding which rehabilitation procedure could help improve the performance of a road, it is important to note that it is not written in such detail so that one could use it to completely evaluate, design, specify, and/or construct an asphalt recycling project. It does however, provide information on:
- Various asphalt recycling methods
- Benefits and performance of asphalt recycling
- Procedures for evaluation of potential projects
- Current mix design philosophies
- Construction equipment requirements and methods
- Quality Control/Quality Assurance, inspection and acceptance techniques
- Specific requirements
- Definitions and terminology

Benefits of asphalt recycling are included in the BARM and include the following:
- Reuse and conservation of non-renewable natural resources
- Preservation of the environment and reduction in land filling
- Energy conservation
- Reduction in user delays during construction
- Shorter construction periods
- Increased level of traffic safety within construction work zones
- Preservation of existing roadway geometry and clearances
- Corrections to pavement profile and cross-slope
- No disturbance of the subgrade soils unless specifically planned such as for FDR
- Improved pavement smoothness
- Improved pavement physical properties by modification of existing aggregate gradation, and asphalt binder properties
- Mitigation or elimination of reflective cracking with some methods
- Improved roadway performance
- Cost savings over traditional rehabilitation methods

Chapter 2 gives an overview of some rehabilitation strategies, in particular, pavement maintenance, pavement rehabilitation and pavement reconstruction.

Time and/or traffic along with the pavement quality dictates when certain procedures must be done in order to maintain an appropriate and safe level of performance. Starting with regular routine maintenance to complete reconstruction, Figure 1 below, (Figure 2-1 in the BARM manual) shows the general behavior of a typical pavement section.
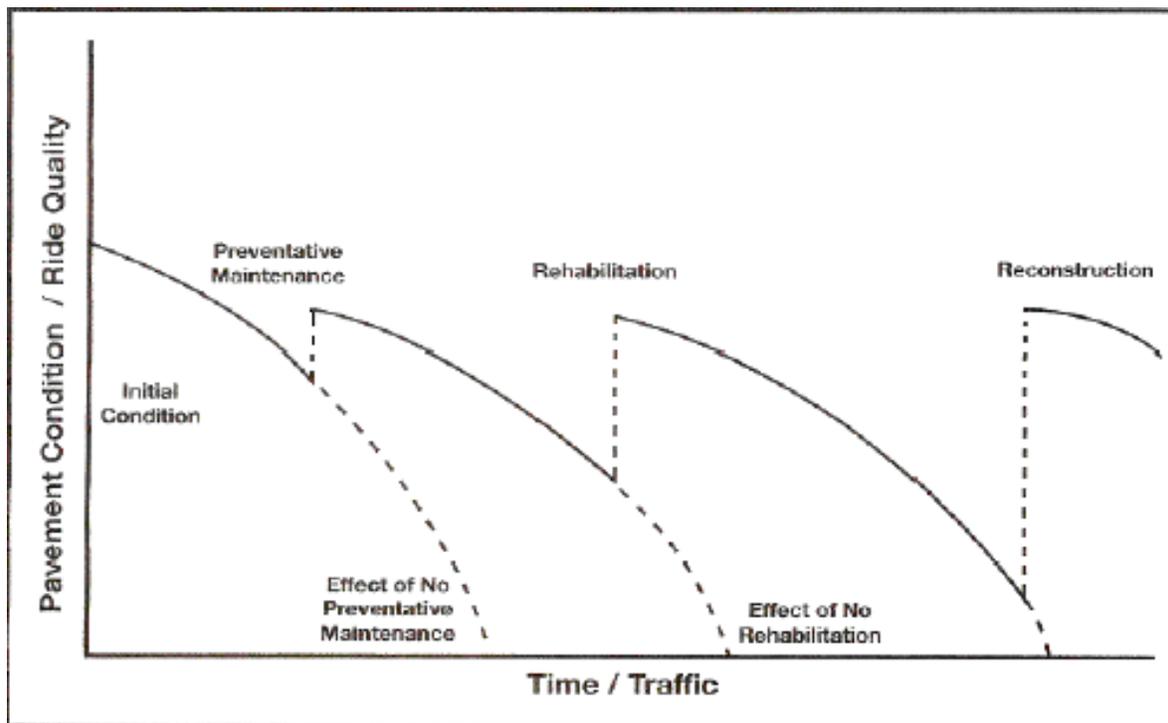
Figure 1. Pavement Deterioration vs. Time (3).

A timely and routinely executed pavement maintenance schedule will extend the life of the pavement. However, a Pavement Management System (PMS) that is designed and implemented to track and record relevant pavement information is beneficial in maintaining such a schedule.

Pavement maintenance can be labeled as "preventive" or "corrective". Preventing moisture to infiltrate the pavement and correct or prevent deterioration due to environmental effects are generally the two main objectives.

Some of the many ways this can be accomplished include:
- crack sealing
- pothole repairs
- shallow patching to repair locally distressed areas or to rectify surface irregularities such as bumps and dips
- rut filling
- drainage improvements including cleaning culverts and drains, cleaning and/or re-grading existing ditches, etc.

Skok, G., Labuz, J., Westover, T., Dai, S., Lukanen, E., *Pavement Rehabilitation Selection,* **Local Road Research Board, INV-808, 2008.**

The objective of the project was to outline best practices for the selection of asphalt pavement recycling techniques. The report examines cold in-place recycling, full depth reclamation, and mill & overly (M&O). The objective was divided into five tasks:

1. Gather information/evaluate current reclaimed roads
2. Define decision process parameters
3. Develop decision tree (checklist)/process
4. Implement trial checklist
5. Develop best practices

The report begins with a literature review including definition of terms and procedures, case studies of particular rehabilitation techniques and approaches, ranging from Ontario, Canada to Nevada and Pennsylvania. Ramsey County contributed information on their experience with pavement rehabilitation and its effectiveness was shown through their pavement management system.

Actual performance information was collected through site visits to various cities, counties, and Minnesota Department of Transportation (MnDOT) district engineers. This information was organized in a database to be used with a PMS.

Condition survey results were summarized using MnDOT's system of the Pavement Quality Index (PQI).

Equation 1 and Table 4 (Table 1.1 in the Skok et al. report) briefly explain the PQI.

$$PQI = \sqrt{SR * PSR} \qquad (1)$$

Table 4. Pavement Rating Scale According to MnDOT Procedures (4).

Index Name	Pavement Attribute Measured by Index	Rating Scale
Ride Quality Index (RQI)	Pavement Roughness	0.0 – 5.0
Surface Rating (SR)	Pavement Distress	0.0 – 4.0
Pavement Quality Index	Overall Pavement Quality	0.0 – 4.5

Index Name	Pavement Attribute Measured by Index	Rating Scale
Ride Quality Index	Pavement Roughness	0.0 – 5.0
Surface Rating	Pavement Distress	0.0 – 4.0
Pavement Quality Index	Overall Pavement Quality	0.0 – 4.5

Analysis of CIR projects and relating falling weight deflectometer (FWD) results with MnDOT's rating system showed increased strengths and pavement condition post rehabilitation. Figures 2

and 3 (Figures 1.5 and 1.8 from the report) show some of the improvements from CIR in MnDOT District 1.
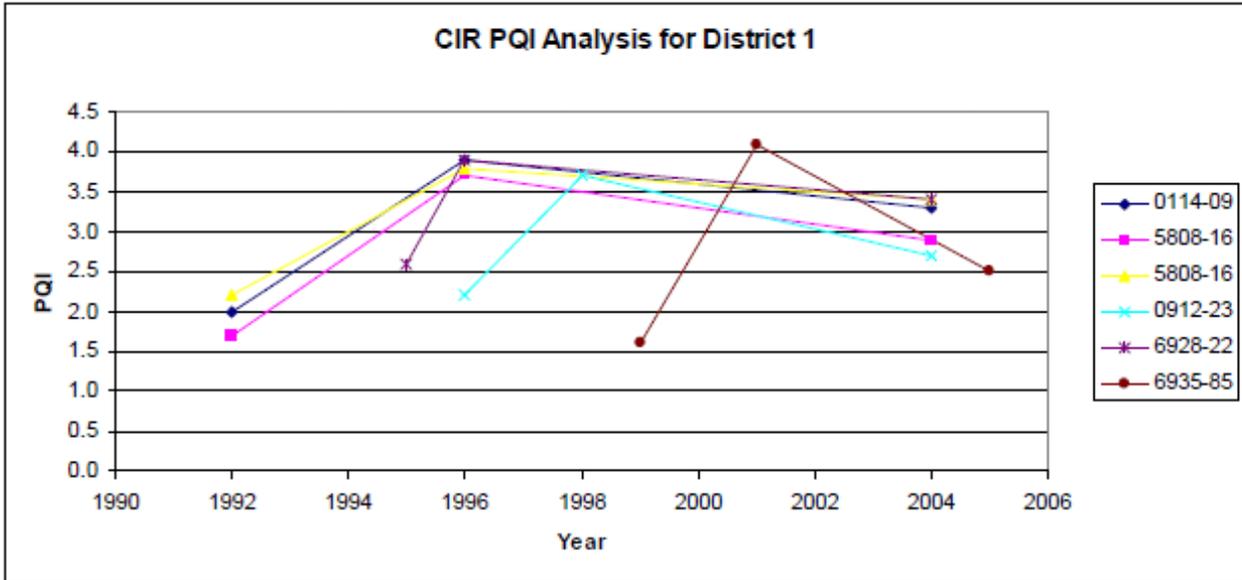
Figure 2. PQI Analysis for MnDOT CIR Projects in District 1, (4).
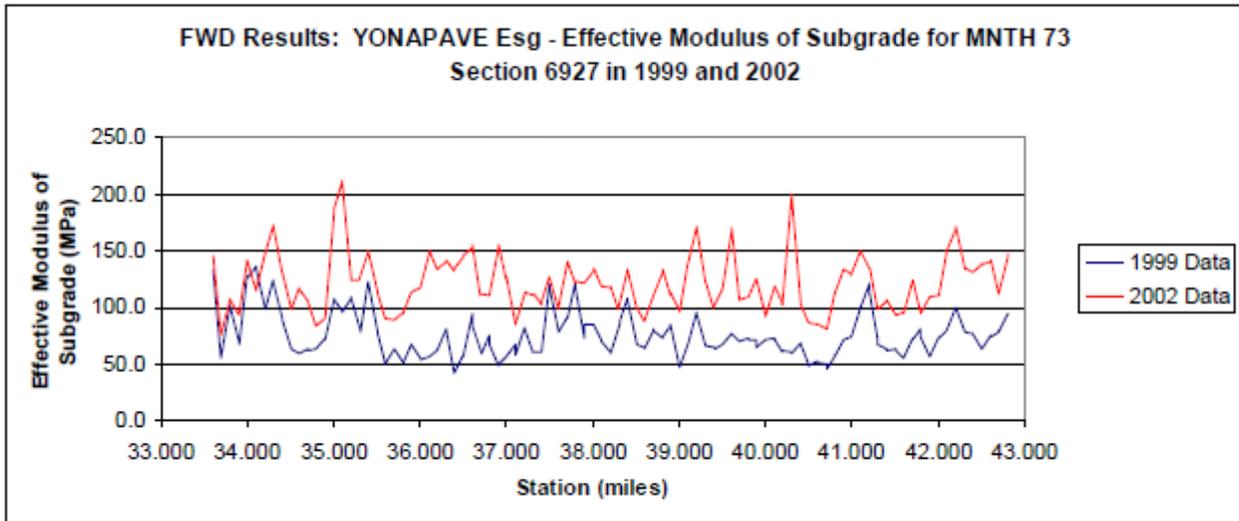
Figure 3. The Effective Subgrade Modulus Determined by YONAPAVE, (4).

Decision process parameters were developed to conduct a system analysis to relate pavements in a system in general, and a consistent way to determine which pavements need rehabilitation.

Specific projects were selected to be part of a pavement improvement program. Determining the cause of the distress for a given section of pavement was important in the design of a specific cross-section of pavement and to select the most suitable type of rehabilitation. Project parameters for analysis were:

- Rut depth
- Transverse crack severity
- Longitudinal crack severity
- Multiple cracking
- Alligator cracking
- Raveling and weathering
- Patching

The processes included Individual Weighted Distresses (IWD) and Total Weighted Distresses (TWD). IWD and TWD were correlated using distress type, severity, weighting factor, percent distress. The TWD was then converted to a surface rating. Table 5 (Table 3.3 of the report) shows examples of relationships between degradation and the type of rehabilitation in regards to SR.

Table 5. Degradation Rate for Various Rehabilitation Techniques, (4).

Rehabilitation Type	SR Degradation Rate, Decrease in SR per year
Cold-in-Place	0.040
Full-Depth	0.021
Thin Mill and Overlay	0.040
Medium Mill and Overlay	0.065
Thick Mill and Overlay	0.021

The report explains each rehabilitation type and why and when it used. Combining this information and the structural adequacy, tonnage, and pavement thickness design, as well as recommended checklists, best practices were developed with the use of a good PMS to help make an economical decision on which rehabilitation process to use for specific roadways.

Pavement Management Systems

Zimmerman, K.A., and D.G. Peshkin, *Integrating Preventive Maintenance and Pavement Management Practices***, Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, Iowa State University, 2003**

> "the use of pavement management tools to support preventive maintenance programs is impacted by the degree to which preventive maintenance treatments are integrated into a pavement management system."

The Preventive Maintenance Concept
FHWA's definition of preventive maintenance: "pavement preservation involves a systematic approach to preserving the investment in existing roadways by improving pavement performance and extending pavement life in a cost-effective manner."

Benefits of preventive maintenance include:
- Higher customer satisfaction with the road network,
- The ability to make better, more informed decisions on an objective basis,

- The more appropriate use of maintenance techniques,
- Improved pavement conditions over time,
- Increased safety, and
- Reduced overall costs for maintaining the road network.

Three Approaches to Integration
1. Recommendations for preventive maintenance candidate sections as a default to the analysis of pavement rehabilitation and reconstruction needs.
2. Incorporate a single treatment into the PMS decision tools that represents many types of treatments. This requires less effort to establish, but more effort to implement on a case by case basis, as shown in Figure 4 (Figure 2 in the report) where preventive maintenance is selected to preserve pavements already in good condition.
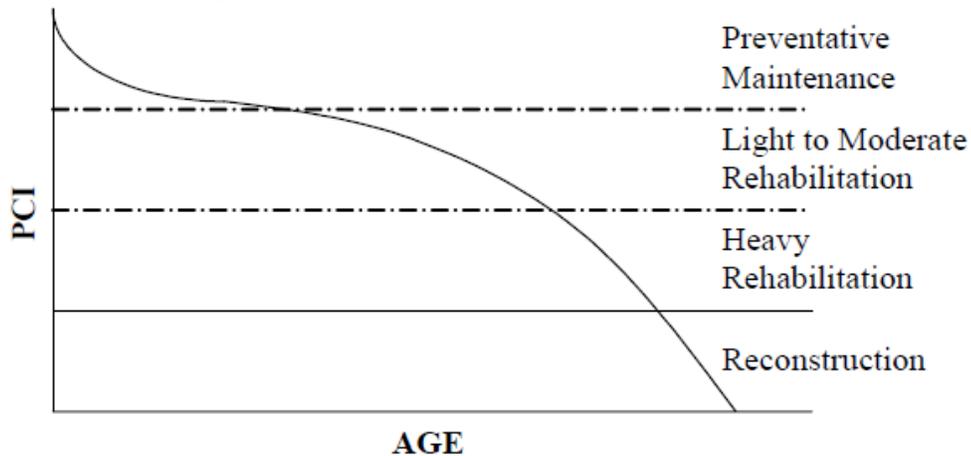
Figure 4. PCI Deterioration Curve and Default MTC Treatment Levels (5).

3. Define specific treatments, and incorporate them into the decision analysis. Requires more effort to establish, but less effort to implement.

Steps and Components in Integrating
- Pavement Condition Assessment and Condition Indexes
- Pavement Performance Models
- Pavement Treatment Rules
- Treatment Impact Rules

Figure 5 (Figure 4 in the report) shows another example of using pavement preservation to extend pavement life.

Average Pavement Condition over Time
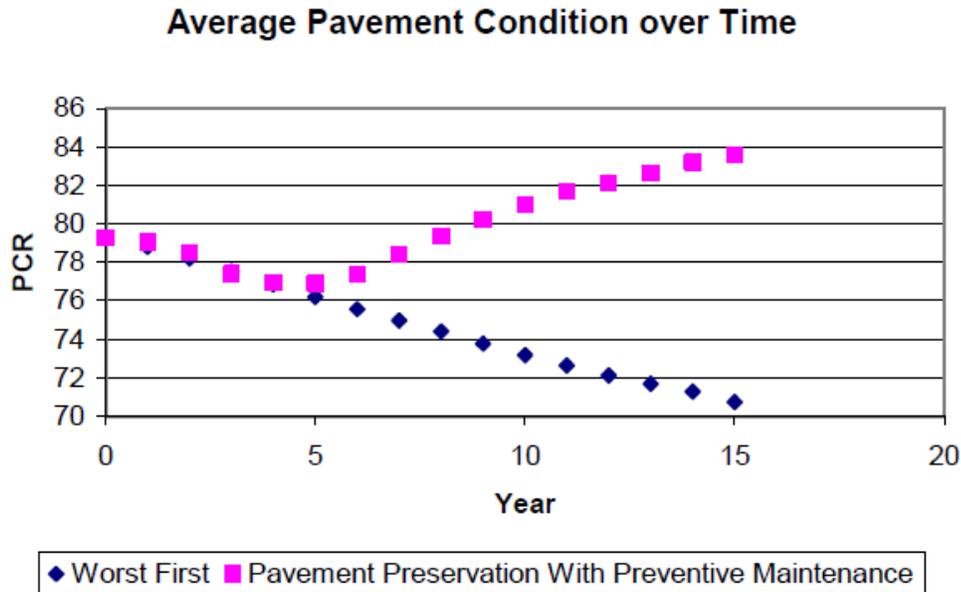
Figure 5. Benefits Associated with the Use of Preventive Maintenance Treatments (5).

**Kathy Jaschke, *Ramsey County Public Works Pavement Management Report*,
Published by Ramsey County, MN, February, 1999.**
The 1999 Ramsey County, Minnesota, Pavement Management Report presents a summary of the pavement conditions in 1999 compared to 1984 when the pavement management system was started. The report states that:

- There has been a dramatic rise in the overall pavement condition rating from 68.5 to 91.6. The increase is attributed to an aggressive recycling, overlay, and reconstruction programmed to the turn back program which improved and turned back many of the poorer condition roads, i.e. roads that were turned back to the county from MnDOT.
- 88% of the roads have an excellent, good or fair quality (smoothness).
- The estimated investment of the road system is $677 million.
- The average age of County roads has decreased from 39 years in 1987 to 12 years in 1998. Age is defined as the time since last construction or rehabilitation.
- 17.3 km of roadway remain subject to spring load restrictions, down from 55.4 km in 1984. The goal is to have no roads subject to load restrictions.
- $19.8 million per year is needed to maintain the County road system.
- Total mileage of unimproved and gravel shoulders has decreased from 173.8 km in 1987 to 29 km in 1998.

The stiffness of roadway pavements determines the vehicle axle loadings that can be carried over a long period of time without damage. Spring load restrictions were imposed on 151.1 km in 1987, 69.8 km in 1993 and 17.3 km in 1998.

One important way to compare maintenance treatments is to compare the number of transverse cracks developed from 1986 through 1997. The increase in cracks is plotted on a chart in the reference. Table 6 presents this data.

Table 6. Average Cracking, Ramsey County, Minnesota, 1999 (6).

Maintenance Procedure	Length, Miles	Number of Transverse Cracks per 1000 feet after 12 years
New Pavement	52	19
Cold in-place Recycling	57	48
Mill and Overlay	59	82

The Ramsey County 1999 Pavement Management Report shows how consistent pavement data can be used to establish the most appropriate construction, rehabilitation and a maintenance program. Over a period of time actual performance results can be observed and used.

Cost Effectiveness Evaluation

Labi, S. and K.C. Sinha, *Life-Cycle Evaluation of Flexible Pavement Preventive Maintenance*, **Journal of Transportation Engineering, Vol. 131 No. 10, October 2005.**
Balance between sustained performance and increased maintenance costs.

"if preventive maintenance is applied too infrequently, user costs and reactive maintenance costs increase and overall life-cycle costs can be very high. On the other hand, if preventive maintenance is applied too frequently, it is uneconomical because the excessive expenditure outweighs the additional benefits of extended pavement life and increased average pavement condition."

Questions Asked
1. On what basis can agencies determine that their current levels of pavement management expenditure are too high, too low, or just right?
2. Is it always cost-effective to keep increasing PM expenditure?
3. How do the above trends vary by pavement functional class?
4. Does the inclusion of user cost influence the nature of relationship between PM and its cost effectiveness?

Evaluated 14 maintenance strategies and provides age at first application and intervals thereafter for the following activities.
- Thin (HMA) overlay
- Micro surfacing
- Chip seal
- Crack seal

In addition, specific default actions are specified as corrective maintenance elements, which are conducted typically at a 3-year interval, but also as needed. These include:
- Shallow patching
- Deep patching
- Leveling
- Bump grinding

Since this is a life cycle cost analysis (LCCA) method, each strategy was evaluated for total life cycle cost as well as annualized life cycle cost. Pavements were divided into "pavement families" as follows.

- Family I: Interstate, Asphalt
- Family II: National Highway System (NHS), Non-Interstate, Asphalt
- Family III: Non-NHS, Asphalt

This paper was basically a method for determining life cycle cost of a strategy, and comparing the cost to a "do-nothing" strategy. Effectiveness was calculated as the increase in remaining service life relative to the "do-nothing" strategy.

Labi, S. and K.C. Sinha, *Measures of Short-Term Effectiveness of Highway Pavement Maintenance***, Journal of Transportation Engineering, Vol. 129 No. 6, November 2003.**
This paper focuses on the short-term effectiveness of maintenance activities. The paper assumes that "there is a performance jump after a specific maintenance treatment and considers that the rate of deterioration after treatment is not necessarily reduced, but could be the same, decreased, or even increased. This is a more flexible assumption that is more consistent with reality."

The paper discusses three measures of deterioration reduction for pavements. These include *deterioration reduction level* (DRL), *performance jump* (PJ), and *deterioration rate reduction* (DRR).

Timing and Prioritization of Activities

Humphries, J.A., and E. Ma, *Optimization of Pavement Preservation Activities***, Annual Conference of the Transportation Association of Canada, Quebec City, 2004.**
Defines four levels of activities included in Alberta's new (as of 2002) pavement preservation program:
1. **Normal maintenance** – routine activities that occur on a regular basis such as crack filling and pothole repair.
2. **Reactive maintenance** – activities which are done in response to events beyond the control of the department.
3. **Preventive maintenance** – application of cost-effective treatments to preserve, retard future deterioration, and maintain or improve the functional condition of the highway surface.
4. **Rehabilitation** – activities that restore the original pavement serviceability.

Recommends the use of life-cycle cost analysis and decision support software systems, such as the Highway Cost Model developed by MIT, Highway Design and Maintenance Standards Model (HDM-4) developed by the World Bank and others, or Highway Economic Requirements System (HERS) developed by FHWA.

"Pilot Study" Objectives:
1. Identify the categories and types of data required for an economic analysis decision support system.

2. Gain an understanding of the models used by an economic analysis decision support system.
3. Explore the linkages required between an asset management system and an economic analysis decision support system.
4. Verify the program level results produced by an economic analysis decision support system for Alberta provincial highway projects.

The pilot study examined 57 rehabilitation projects and 520 preservation projects.

Findings
The study only evaluated the HDM-4 software. They found that it requires a vast amount of data about each project to develop a recommended solution (about the highway network, vehicle fleet, traffic flow and climatic conditions, and highway construction activities (rates, unit costs, effectiveness). The HDM-4 model is effective, however, in developing preservation strategies.

Peshkin, D.G., T.E. Hoerner, and K.A. Zimmerman, *Optimal Timing of Pavement Preventive Maintenance Treatment Measures*, NCHRP Report 523, Transportation Research Board, 2004.
This is one of the more comprehensive reports reviewed on the subject. Part of this research included the development of an analysis tool to compute optimal timing of preventive maintenance treatments (OPTime).

Factors that should be considered, or presented in a set of recommendations for pavement preservation include the following.

- Pavement deterioration
- Treatment timing
- Treatments attributes
    o Purpose of the treatment
    o Applicability (traffic, environment, pavement condition)
    o Contraindications
    o Construction considerations
    o Expected performance and cost
    o Customer satisfaction
- Evaluation factors
    o Climate
    o Traffic
    o Conditions addressed
    o Contraindications

The report describes a method of weighting factors for treatments, pavement conditions, costs, and expected benefits. From this weighting process, with some of the weighting factors assigned subjectively, an optimal timing can be determined for a particular combination. Figure 6 below diagrams the relative benefits in terms of pavement performance due to an activity conducted at a certain point in the life span of a pavement. Notice that while the life of the pavement is

extended only a few years, the area marked "Benefit Area" is a larger part of the overall performance.
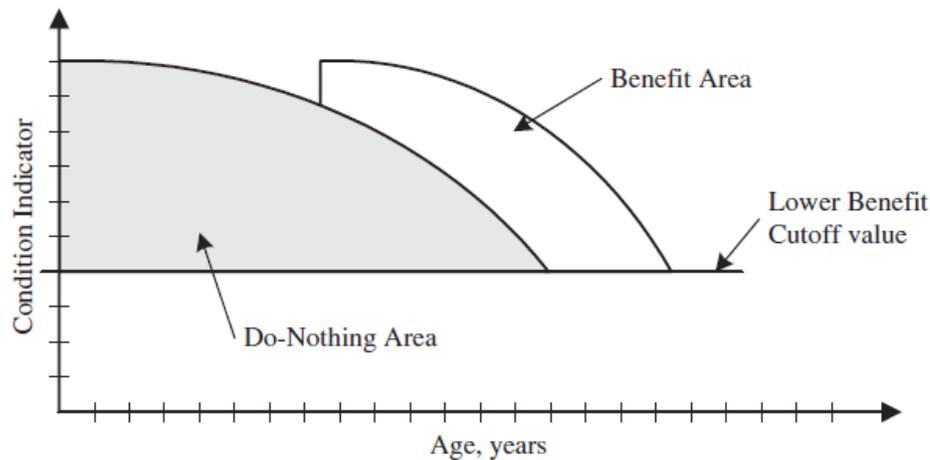
Figure 6. Conceptual Illustration of the Do-nothing and Benefit Areas (7).

The methodology described in this report can be applied to individual projects or combined to represent network level analysis.

The steps described in the report for establishing optimal timing include the following.

1. Analysis session setup - select particular treatment and specific application ages to be used in the analysis.
2. Selection of benefit cutoff values. This represents that concept that treatments may be applied *too soon* or *too late* to provide much benefit.
3. Compute performance areas associated with the "do-nothing" case
4. Compute overall expected service life of the "do-nothing" case
5. Compute expected service life of the "post-treatment" case
6. Compute performance areas associated with the "post-treatment" case
7. Compute benefit associated with each individual condition indicator
8. Compute overall benefit
9. Compute costs
10. Determine most cost-effective timing scenario

Hall, K.T., et al., ***Rehabilitation Strategies for Highway Pavements***, **NCHRP Web Document 35 (Project C1-38), Transportation Research Board, Washington, DC, May 2001.**
This report focuses on rehabilitation strategies, rather than preservation strategies. Many of the steps involved in the analysis methods presented and the conclusions are applicable to preservation activities.

According to the Summary of Findings, the project reported in this document was "conducted to develop a process for selection of appropriate rehabilitation strategies for the ranges of pavement types and conditions found in the United States."

The report lists six methods common to strategy selection, including:

1. Data collection,
2. Pavement evaluation,
3. Selection of rehabilitation techniques,
4. Formation of rehabilitation strategies,
5. Life-cycle cost analysis, and
6. Selection of one pavement rehabilitation strategy from among the alternatives considered.

The six steps and their associated sub-steps are illustrated in Figure 7.

The report provides suggested "trigger values" for key condition levels at which a pavement is generally considered to need a structural improvement. It also provides guidance in conducting traffic analyses, condition surveys, destructive and non-destructive testing, and others.

Step 1. Data Collection

| Roadway Section Definition | Pavement Section Inventory | Traffic Analysis | Distress Survey | Nondestructive Deflection Testing |
| Materials Sampling and Testing | Profile and Roughness Measurement | Friction Measurement | Drainage Inspection | Other Nondestructive Testing |

Step 2. Pavement Evaluation

| Distress Evaluation | Structural Evaluation | Functional Evaluation | Drainage Evaluation |

Identification of Uniform Sections

Step 3. Selection of Rehabilitation Techniques

| Techniques Indicated by Structural Evaluation | Techniques Indicated by Functional Evaluation | Techniques Indicated by Distress Evaluation | Techniques Indicated by Drainage Evaluation |

Step 4. Formation of Rehabilitation Strategies

Combine Rehabilitation Techniques Into Strategies

Rehabilitation Design   Materials Selection

Rehabilitation Performance Prediction

Compare Predicted Performance with Performance Standards

Construction and Traffic Control Plan

Step 5. Life-Cycle Cost Analysis

| Select Analysis Period | Select Discount Rate | Determine Agency | Determine User Costs | Determine Other Costs | Determine Residual |

Compare Strategies by Common Economic Measure

Weigh Agency Costs versus User Costs

Assess Sensitivity of Results to Key Parameters

Step 6. Selection of Rehabilitation Strategy

Weigh Monetary versus Nonmonetary Factors

Select Rehabilitation Strategy

Figure 7. Pavement Rehabilitation Process (8).

Pavement Preservation Program Guidelines

Wood, T., R. Olson, et al., *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements***, MnDOT Report MN/RC 2009-18, Minnesota Department of Transportation, St. Paul, MN, May 2009.**
This report includes good information on the types of performance data that should be collected, as well as the types of degradation and distress mechanisms in flexible pavements, as they are used by MnDOT.

The report also provides information, with associated data, to indicate the effect of pavement preservation activities on pavement performance, as shown in Figure 8 (Figure 1 in the report).
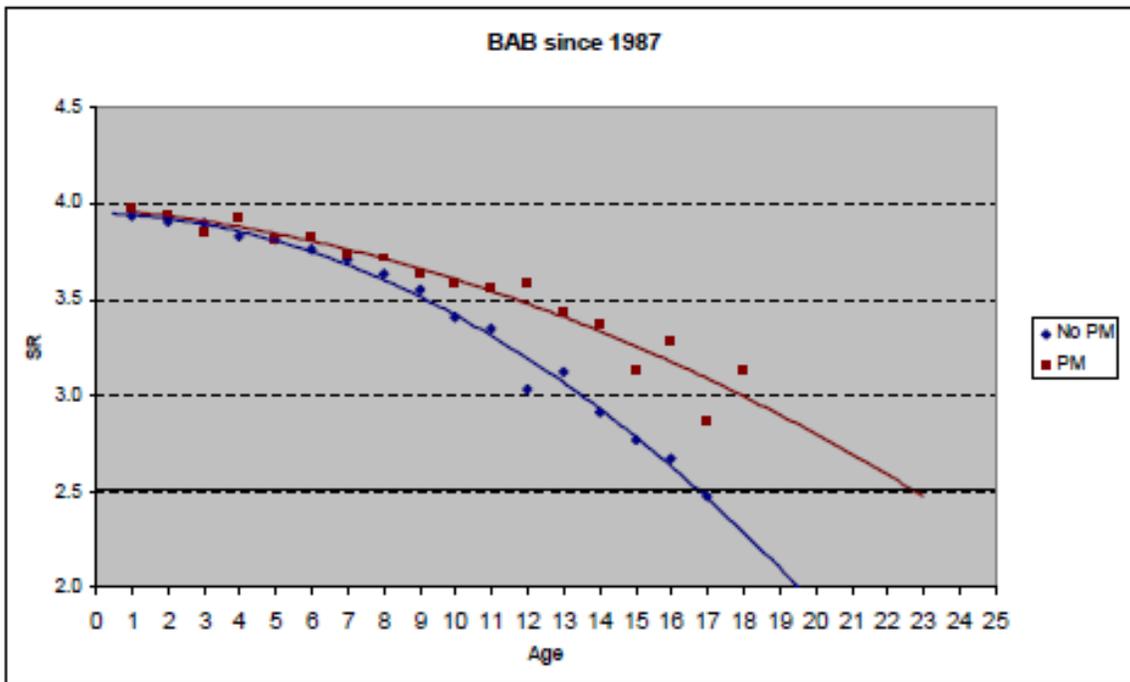
Figure 8. Bituminous Aggregate Base Pavements with and without PM (9).

The report also included a sample of maintenance strategies selection from the City of Eagan. Figure 9 (Figure 3 in the report) shows the difference in expected pavement performance with simple routine maintenance only (in red) and a program of chip sealing every six or seven years and overlay every 20 years (in blue).
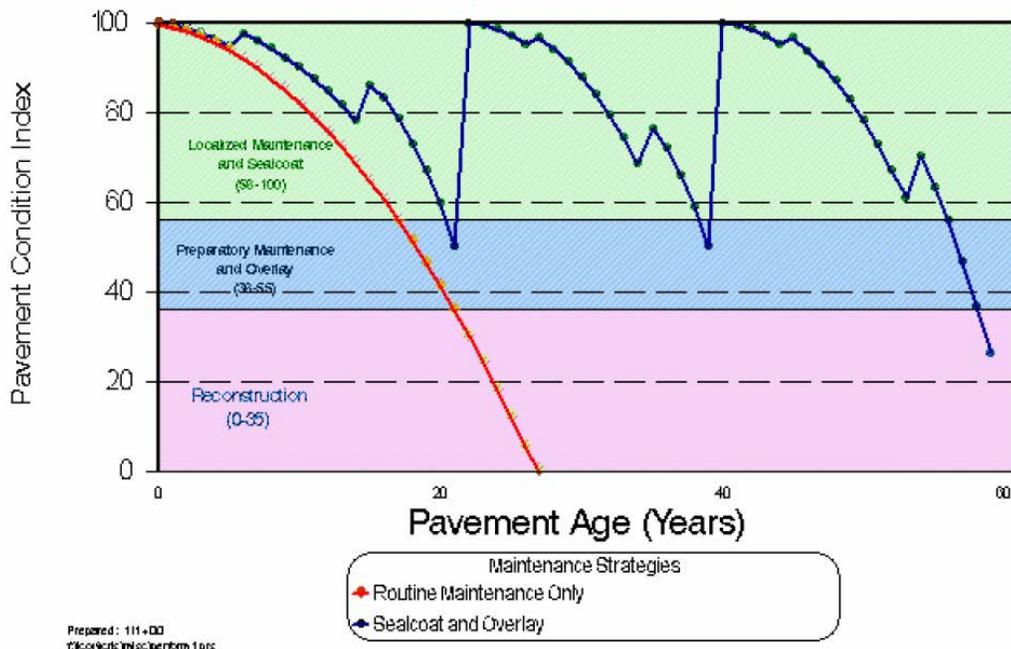
Figure 9. Pavement Deterioration for the City of Eagan (9).

The report also includes a section on timing of preventive maintenance activities, with discussions regarding both network and project level analyses. It also gives fairly detailed information about various types of treatments, including:

- Spray-applied fog seal and rejuvenator
- Chip seal treatments
- Micro surface treatments
- Thin overlays
- Crack treatments

The discussion of each treatment listed above is augmented with additional information regarding application rates, application cycles (timing), favorable conditions, limits on average daily traffic (ADT) and other information pertinent to the individual applications.

Minnesota Department of Transportation, *Pavement Preventive Maintenance Program Guidelines,* **January, 2001.**
A pavement preventive maintenance program accomplishes three things:

1. Protect the pavement structure
2. Slow the rate of pavement deterioration
3. Correct pavement surface deficiencies

22

Proper maintenance activities should be considered until repair costs exceed the benefits from the selected treatment or until the distress is structural rather than functional. It is recommended that each agency should develop a unique pavement preventive maintenance action plan.

A maintenance program should include surface treatments caused by environmental and pavement material deficiencies. Other treatments include limited shoulder and drainage work.

Pavement preventive maintenance is defined by the American Association of State Highway and Transportation Officials (AASHTO) and FHWA as:

"planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserve the system, retards future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity).

Project Selection
The Minnesota Department of Transportation program uses decision trees within their Pavement Management System and pavement condition surveys to help select specific projects. Michigan currently has had a working pavement preventive maintenance program for a number of years and it used as a guide in formulating MnDOT's program. Appendix B of the report describes some of Michigan's information from their program.

Treatment types
The report describes treatment types on hot mix asphalt pavements, portland cement concrete (PCC) pavements and shoulders.

Hot Mix Asphalt Pavements Treatments
- Crack treatment – rout and seal
- Crack treatment – clean and seal
- Chip seal or Seal coat
- Micro surfacing
- Ultra-thin overlay
- Thin hot mix asphalt overlay
- Surface milling with thin hot mix asphalt overlay
- Edge drain outlet cleaning and repair

PCC Pavement Treatments
- Concrete joint resealing
- Concrete crack sealing
- Concrete spall repair
- Edge drain outlet cleaning and repair
- Concrete pavement restoration
- Full concrete pavement panel replacement
- Dowel bar retrofit
- Diamond grinding

Shoulder Treatments
- Fog seal
- Seal coat
- Longitudinal pavement/shoulder joint

Frequency
At the time of this report, Michigan and Georgia were two states with an established preventive maintenance program with substantial results showing high benefit to cost (B/C) ratios. As a guide, it is suggested to attempt to cover 10% of the system per year with a pavement preservation treatment.

Johnson, Ann, *Best Practices Handbook on Asphalt Pavement Maintenance*, Minnesota Technology Center, Minnesota Department of Transportation, February, 2000.
This handbook focuses on pavement preservation and preventive maintenance, with the emphasis on preventive maintenance. Preventive maintenance is performed while the pavement is still in good condition with minimal distresses.

Common flexible pavement stresses are:
- Cracking
- Roughness
- Weathering
- Raveling
- Rutting
- Bleeding

Maintenance treatments covered in this handbook include:
- Crack repair w/sealing
- Crack filling
- Full depth crack repair
- Fog seal
- Seal coat
- Double chip seal
- Slurry seal
- Micro surfacing
- Thin hot mix overlays
- Pot holes and pavement patching

The handbook is in two parts. Part I provides background information about asphalt maintenance and preservation. Part II presents maintenance techniques for a variety of distresses and conditions.

Maintenance is defined in three ways:

"Preventive Maintenance: Performed to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities."

"Corrective Maintenance: Performed after a deficiency occurs in the pavement, such as a loss of friction, moderate to severe rutting, or extensive cracking. May also be referred to as "reactive" maintenance."

"Emergency Maintenance: Performed during an emergency situation, such as a blowout or server pothole that needs repair immediately. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be performed."

The manual emphasizes the importance of pavement preservation and management system. Having both will allow its user to more accurately identify and assess the condition and the most economical treatment.

Critical elements of a successful pavement preservation program are:
1. Selecting the roadway
2. Determining the cause of the problem
3. Identifying and applying the correct treatment(s)
4. Determining the correct time to do the needed work
5. Observing performance

Condition surveys and non-destructive testing can be used to help choose the correct time to apply a selected treatment. Using the output of the condition survey, threshold limits can be developed to define when a treatment type should be implemented. Figure 10 (Figure 1-2 in the report) shows the increased pavement condition over time and traffic with properly implemented maintenance versus a continual decline over the same given time.
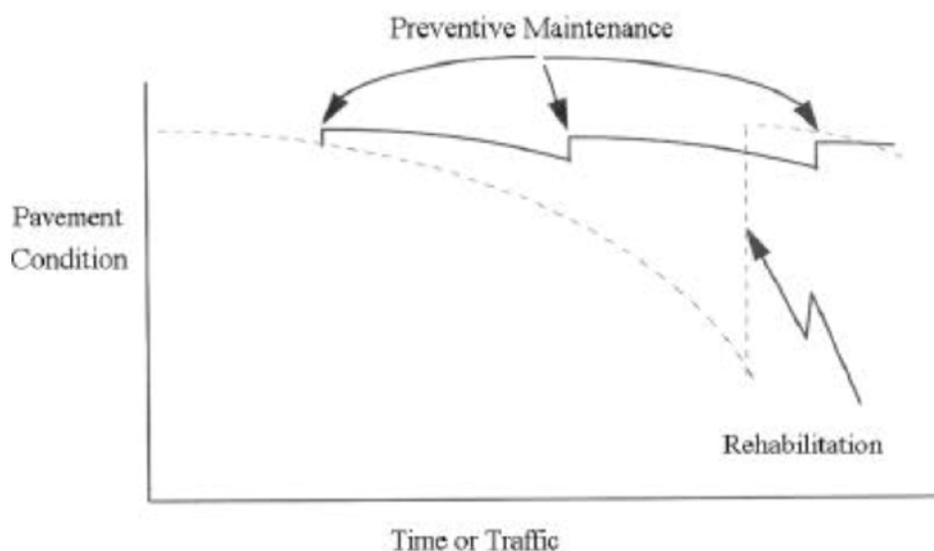
Figure 10. Performance of Preventive Maintenance Treatments (10).

Table 7 (Table 3-1 in the report) show the most common flexible pavement distresses, along with their corresponding best practices for rehabilitation. Recommended applications are given for crack sealers and fillers, surface treatments, and pothole patching. The table lists each type of maintenance technique along with reasons for using each one. Treatment life and costs are summarized. The values will vary depending on the project location and its environmental condition. It is recommended that each agency prepare a similar table using expertise within their area. Other tables in that report show further breakdowns of recommended treatments for cracks and surface defects.

Part II of the manual explains actual treatment practices. Tables 4-1 through 6-1 show recommended applications for crack sealant and fillers, surface treatments, and patching. Each treatment type is explained giving methods, suggested traffic control, limitations, and estimated costs. The appendices describe each distress type and how the severity of each is rated.

Table 7. Asphalt Maintenance Techniques (10).

Technique	Reasons for use							Average Treatment Life (years)	Average Unit Cost	Reference Page
	Friction	Raveling	Rutting	Potholes	Cracking					
					Low	Med	High			
Crack Treatments										
Crack repair with sealing										
Clean and seal					X	X		3	$0.20/lf	26
Saw and seal								7-10	$1.70/lf	28
Rout and seal					X	X		3	$0.70/lf	30
Crack filling						X	X	2-3	$0.25/lf	32
Full-depth crack repair							X	5	$5.00/lf	34
Surface treatments										
Fog seal		X						1-2	$0.15/sy	38
Seal coat	X	X						3-6	$0.55/sy	40
Double chip seal	X	X						7-10	$1.50/sy	43
Slurry seal	X	X						3-5	$1.50/sy	45
Microsurfacing	X	X	X					5-8	$1.75/sy	47
Thin hot-mix overlay		X	X					5-8	$25/ton	49
Pothole and Patching Repair										
Cold-mix asphalt				X				1	$55/ton[a]	54
Spray injection patching				X				1-3	Not Available[b]	55
Hot-mix asphat				X			X	3-6	$25/ton	57
Patching w/slurry or microsurfacing material				X			X	1-3	$0.85/sy[a]	58

[a]Cost for materials only.
[b]Price varies with conditions.
lf=lineal foot
sy=square yard

Chapter 3. LOCAL AGENCY EXPERIENCE

This chapter describes the data collection efforts for this project and the subsequent analysis using some of the data collected. The information needed for this component of the project was comprised of several types, and was obtained from various cities and counties within Minnesota. An initial request was made for cities and counties to participate in this project by providing data from their pavement management systems. Several agencies responded and provided permission for their pavement management consultants to release the requested data. Thus, basic inventory information, historical condition data, and historical construction activities (initial construction, maintenance, preventive activities, and rehabilitation activities) were obtained by the research project team. After receiving this specific data from the various agencies, the project team followed up with detailed interviews of those responsible for pavement management and preservation.

The remainder of this chapter presents the data collected, in summary form, and the specific analyses conducted from which case studies were developed as well as overall trends in terms of actual vs. expected timing of pavement construction activities.

Data Collection

This part of the project consisted of several meetings to determine the appropriate data to request from pavement management systems maintained by the county and city agencies. As part of this effort, the project team contacted GoodPointe Technology for assistance in identifying clients and data that may be available. Below is a list of basic information deeded necessary for the analysis to be successful.

1. Basic inventory information
   a) Segment location (county, roadway designation, termini or stations)
   b) Segment length and width

2. Construction information
   a) Date of last reconstruction
   b) Dates and types of maintenance and rehabilitation activities
   c) Quantities of maintenance and rehabilitation materials (overlay thickness, seal coat quantities, etc.)
   d) Unit (or total) cost of construction, maintenance and rehabilitation activities

3. Condition and traffic information
   a) Periodic surface rating index values (SR, PQI, etc.)
   b) Estimated traffic (ADT, vehicle classification, etc.)

Identification of Data Sources

The project team contacted GoodPointe Technology to request pavement management data for several of its clients who had provided permission for the release of the data, to identify roadways that may be candidates for further analysis. Another objective of this request was to identify cities and counties that have been collecting pavement management data for long

periods of time, and to identify individuals with whom the project team could conduct in-depth interviews regarding their objectives, processes, and experiences with pavement management.

The initial request for permission for GoodPointe to release data was sent through the Minnesota city and county engineers associations. A number of cities and counties responded and provided permission for GoodPointe to release limited information, as described in a letter sent to each city and county engineer.

After receiving large amounts of data for each agency, the project team searched the records and identified approximately 200 roadway segments for which adequate data existed in terms of quantity, history, and variety of pavement preservation activities. A summary of this information is provided later in this chapter. From the list of potential roadways, the project team identified a smaller group of agencies with whom to conduct in-depth interviews.

The following is a list of agencies identified for interviews and additional data collection. Up to 25 and as few as 4 roadways were selected from each agency. A list of all roadways selected as candidates for further analysis is provided at the end of this chapter.

Cities	**Counties**
Bloomington	Dodge
Cottage Grove	Hennepin
Eden Prairie	McLeod
Edina	Scott
Hutchinson	
New Hope	
Rochester	
Roseville	
Shoreview	

In-Depth Interviews

The project team met with representatives from the agencies participating in the study to gain more insight into their expectations, desires, and actual experiences with pavement preservation. This section provides a list of the general questions asked and other topics discussed of the agencies visited. It also provides a summary of the responses to these questions and topics that were received from the agencies.

General Questions and Topics

1. What treatments do you regularly use for pavement preservation and for maintenance?
2. How long to you expect the treatment to last?
3. How long does the treatment actually last, in general?
4. How do you determine which roadways receive treatments?
   a. Are they regularly scheduled?
   b. Base of review?
   c. Preventive or Reactive?
5. What types of training does your agency need?

6. Are your pavement maintenance and preservation projects constructed by contractors or in house forces?
7. Do you use MnDOT special provision for your pavement maintenance and preservation projects?
8. What is the overall life cycle of your roadways?

Other topics were discussed as they were initiated by the agencies.

Interview Summaries
This section provides a basic summary of the individual interviews and the information assembled based on the discussion and the responses to the questions.

1. *What treatments do you regularly use for pavement preservation and for maintenance?*
   In general, most agencies do not conduct specific pavement preservation activities as much as they do pavement maintenance and rehabilitation. The maintenance and rehabilitation activities conducted by the agencies include the following.

   - Crack sealing
   - Patching
   - Chip seal
   - Overlay
   - Mill and Overlay
   - Full-depth Recycling

   As expected, each agency has its own preferences, likes and dislikes.

2. *How long to you expect the treatment to last?*
   The primary activities for which the agencies have longevity expectations are chip seals, overlays, and full-depth reclamation. The general consensus is that chip seals should last about 7 years, and up to 9 years. Overlays are expected to extend the life of the pavement for about 8-10 years, and FDR should be a more permanent solution, lasting 20-25 years.

3. *How long does the treatment actually last, in general?*
   When asked about the actual number of years that the various activities last, more activities were mentioned (primarily more differentiation in the overlay category). The following list describes various activities and general amount of time each treatment performs.

   - Chip seal: as little as 5 years, as long as 10 years, and average 7 years.
   - Overlays
     o 1.5" blade level bituminous overlay: 7 years
     o 1.5" bituminous overlay: 7 yrs
     o 5" concrete overlay: 20+ yrs
   - FDR: 15 years, but as much as 20-25 years (limited responses)

4. *How do you determine which roadways receive treatments?*
    The primary responses to this question related to the frequency with which agencies conduct condition surveys, and how they interpret the data. Some agencies conduct condition surveys every year, capturing 1/3 of the roadways each year. One agency conducts a condition survey once every 3 years, but collects data on all of the roadways during that year.

    Regarding the data reduction and decisions on which roadway receives which treatment, the prevalent response is that the "worst condition, with the most traffic" receives attention. In addition, some agencies mentioned a long-range plan where future needs are anticipated and budgets are estimated. Through these processes the agencies attempt to maintain their goals for system wide pavement condition index (PCI) values, with the constraints of budget, time, and traffic.

    One benefit to using a pavement management system is that over time, most systems will begin to use the actual condition survey data entered by the agency in the analysis. For an agency's specific roadways, the system will develop customized deterioration curves based on that data, rather than the default curves supplied by the software. Thus, a more relevant analysis can be conducted that will more closely optimize the use of pavement preservation, maintenance, and rehabilitation funding for an agency.

    Specific "triggers" have been developed by some of the agencies to identify when pavement sections are in need of some type of maintenance or rehabilitation. Two examples of these are given below.

    Example #1
    55-100   Chip seal
    40-70   Overlay
    25-40   Localized subgrade corrections and reconstruction
    0-25   Total reconstruction

    Example #2
    66-100   Chip seal
    36-65   Overlay
    0-35   Reconstruction

    Other agencies use the PCI as a classification system for their pavement network, as follows.

    86-100   Excellent
    71-85   Good
    51-70   Adequate
    36-50   Marginal
    0-35   Poor

Agencies attempt to keep the average roadway PCI value to a certain level, as an indicator of the overall quality of their roadway network. One agency reported a desire to maintain this average PCI above 80, while another attempts to maintain an average "in the upper 70s". Overall, most reported a slight decline in average PCI over the past decade.

5. *What types of training does your agency need?*
   The agencies discussed areas within pavement preservation, maintenance, and rehabilitation where they feel the need for additional training. Many of the responses related to specific training on the ICON or other pavement management software. Those specific needs are not listed here, since that training can be obtained from the software vendor. The other training needs described by the agencies interviewed are listed below.
   - More training using pavement management system
   - How to use PMS data to make better decisions
   - What pavement design and maintenance tools are available and how to use them.
   - How to address pavement preservation and maintenance at the political level (how to present pavement preservation and maintenance decisions and recommendations to appointed and elected officials).
   - Additional information on the MnDOT method of condition surveys – how to conduct them and interpret the data.

6. *Are your pavement maintenance and preservation projects constructed by contractors or in house forces?*
   For the most part, the agencies contract the major work, but conduct patching and some seal coating by in-house personnel.

7. *Do you use MnDOT special provision for your pavement maintenance and preservation projects?*
   Most of the agencies use a modified form of the MnDOT construction specifications for their pavement maintenance activities. Special provisions modifying those specifications include changes for local conditions such as soil types and available materials. Some agencies use their own specifications as primary documents, and reference MnDOT specifications as needed for standardized items.

8. *What is the overall life cycle of roadways in your jurisdiction?*
   One agency stated that its standard pavement life cycle for county roads and county state aid highways is a 60-year life expectancy, 1½-inch overlays constructed at 20 and 40 years after initial construction, and two chip seals during each 20-year interval. Another agency indicated a similar program, with the following schedule of activities over a life span of 50 to 60 years.
   - Initial construction
   - Final lift at 1 year
   - Chip seal and overlay cycle every 15-20 years
     - Chip seal at 2-3 years
     - Chip seal at 10-12 years
     - Overlay at 15-20 years

Other agencies indicated expected life spans of 20-25 years (for full-depth reclamation) and 30-40 years for standard bituminous pavement. These expected life spans obviously depend on the soil types and the levels of traffic experienced by the roadway, but the pavement designs attempt to take these conditions into consideration to provide the desired design life.

9. *Other topics?*
   Other topics discussed by the agencies interviewed for this project include the following.
   - Long-term planning is necessary to avoid (or to anticipate) large "bubbles" of repairs.
   - MnPAVE designs too thin

Budgets for pavement preservation, maintenance, and rehabilitation are difficult to quantify and compare. Below are several examples of maintenance and rehabilitation (including reconstruction) budgets and the associated number of centerline miles for which the agency is responsible.

Table 8. Examples of Budgeted Funds per Mile for Maintenance and Rehabilitation.

Annual Budget	Total Miles	Budgeted $/mile
$2,000,000	225	$8,889
$785,000	350	$2,243
$250,000	76	$3,289

Pavement Management Data

As mentioned previously, the pavement management data that was collected assisted in identifying the appropriate agencies for further investigation, which led to the in-depth interviews discussed above. This section describes the pavement management data collected from the participating agencies, which includes the basic geometry, ADT, current condition, and the various types of maintenance and preventive activities conducted by the agencies.

Summary of Data

Pavement data collected from the different cities and counties consisted of the following:
- Street/Roadway Identification
- Termini
- Length
- Width
- ADT Date
- ADT
- Current Condition Index
- Project Dates
- Project Types
- Layer Types
- Material Types
- Layer Thickness

This produced a large amount of data, even for the few agencies for which PMS data was provided. A summary of each agency's data is given below. The information in Table 9 provides the range of ADT, current Condition Index, and segment geometry, as well as the common maintenance and preservation activities conducted by the agency on the road segments included in the study. This table does not necessarily include all of the activities that each agency utilizes in their pavement management program. A list of all the activities conducted by the agencies surveyed for this project is given below.

Table 9. Summary of PMS Data Provided by Various Agencies.

Agency	ADT Range	Condition Index	Preservation Activities	Other Activities
Bloomington	230 to 14,000	6 to 97	Crack Seal Seal Coat	Overlay
Cottage Grove		28 to 99	Crack Seal Seal Coat	Mill & Overlay
Eden Prairie	250 to 10,000	70 to 100	Seal Coat Overlay	Overlay
Edina		61	Crack Fill Seal Coat	Mill & Overlay
Hennepin	3,899 to 14,900	39 to 100	Crack Seal Seal Coat	Mill & Overlay Overlay
Hutchison		32 to 100	Crack Seal	Mill & Overlay Overlay
McLeod County	85 to 7,800	4 to 98	Crack Seal Seal Coat	Mill & Overlay Overlay
New Hope		37 to 100	Crack Seal Seal Coat	Mill & Overlay Overlay
Rochester		10 to 100	Seal Coat	Edge Mill & Overlay Overlay
Roseville		49 to 100	Seal Coat	Mill & Overlay Overlay
Scott County	1,650 to 17,000	69 to 73	Seal Coat	Mill & Overlay Overlay
Shoreview		23 to 95	Crack Fill Seal Coat	Mill & Overlay

As mentioned, the list of activities above is not comprehensive. The activities listed below are a complete list from all road segments and all activities by the agencies included in this study, recorded in pavement management databases.
- Crack Seal
- Crack Fill
- Saw and Seal
- Slurry Seal
- Chip Seal
- Chip Seal
- Full-depth Patch
- Spot Overlay
- Thin Overlay (1" or less)
- Mill and Overlay
- Overlay

Using the information provided by the agencies, it is possible to develop distribution graphs such as the pavement condition index distribution in Figure 11. In this figure, PCI values of 0 and 100 represent about 2 and 5 percent of the segments, respectively. The validity of the entries, especially the "0" entries, is questionable since these are more likely to be a default value for any segment without data.
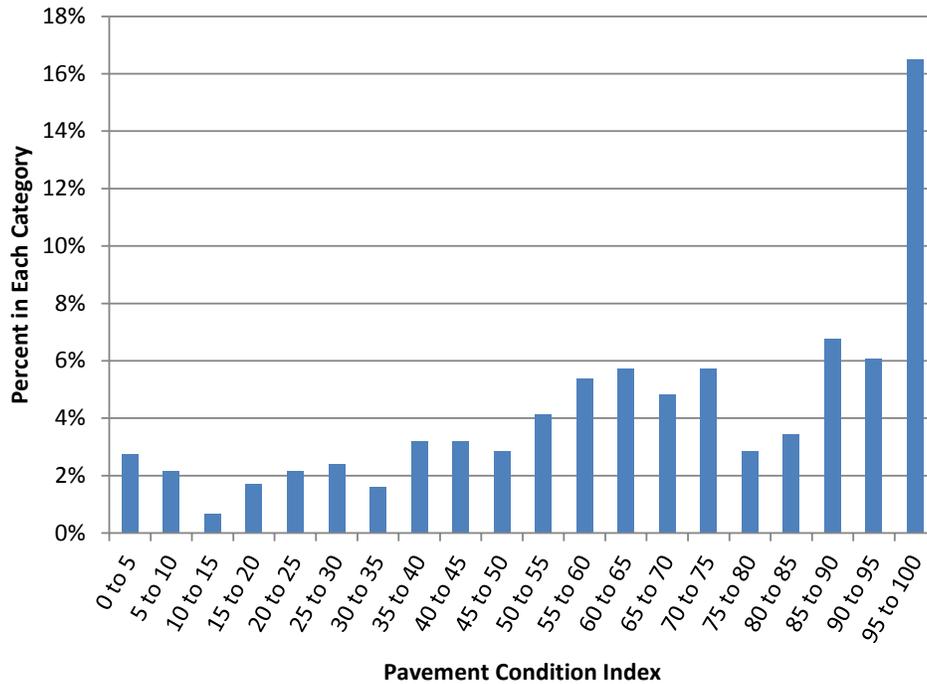

Figure 11. Sample Pavement Condition Index Distribution.

Much of the data collected from these agencies were used in the analysis and guidelines development in the next chapter. Several of the case studies and examples use data obtained from these agencies.

Chapter 4. GUIDELINE DEVELOPMENT

This section describes the guidelines development conducted by the project team. The data were analyzed to evaluate the historical pavement rehabilitation, maintenance, and preservation activities that these agencies conducted in the previous decade. Some agencies were able to supply data reaching back 12 years, while others only had two to three years of data. Some agencies provided some very basic information dating as far back as 20-30 years. As previously mentioned, the data provided by these agencies were used in the analysis and guidelines development in this chapter.

Definitions

As described in the literature review, the Federal Highway Administration defines Pavement Preservation as:

> "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations" *(1).*

Further, the FHWA states that a Pavement Preservation program consists of three components: Preventive Maintenance, Minor Rehabilitation (non-structural) and some Routine Maintenance. These components are expected to accomplish one or both objectives of reducing aging and restoring serviceability. Essentially, these activities extend the life of pavement by protecting the structure and maintaining smoothness.

The National Center for Pavement Preservation defines pavement preservation as "a cost-effective set of practices that extend pavement life and improve safety and motorist satisfaction while saving public tax dollars." *(11)*

The US Congress defined *Pavement Preservation Programs and Activities* as "programs and activities 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 road user expectations". *(12)*

The FHWA defines the three components of pavement preservation as follows. *(1)*

> **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).

> **Pavement Rehabilitation** Structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays. "Minor Rehabilitation" consists of "non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develops in flexible pavements due to environmental exposure." *(13).*

Routine Maintenance Consists of 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.

Other activities that are often necessary but are not considered part of a pavement preservation program include corrective maintenance, catastrophic maintenance, and pavement reconstruction.

The AASHTO Highway Subcommittee on Maintenance defined Routine Maintenance as consisting of

"non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develops in flexible pavements due to environmental exposure. Because of the non-structural nature of minor rehabilitation techniques, these types of rehabilitation techniques are placed in the category of pavement preservation." *(14)*

The Minnesota Department of Transportation borrows from the FHWA Pavement Preservation Expert Task Group in defining pavement preservation as

"a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations without increasing structure or capacity."

MnDOT further defines Preventive Maintenance as efforts "to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities" *(10)*

MnDOT includes the following in the realm of pavement preservation activities.

- Flexible Pavements
  - Chip Seal
  - Crack Sealing
  - Fog Seal
  - Micro surfacing
  - Thin Overlays and Ultra-thin Bonded Wearing Course (Paver placed surface seal, or NovaChip)

- Rigid Pavements
  - Diamond Grinding
  - Joint Sealing / Joint Repair

As will be discussed in the following section, only a few of the activities listed above have been utilized by the cities and counties participating in this project. The activities employed most

often include chip seal and crack seal. Other agencies and groups include additional activities as part of pavement preservation for flexible pavements, including:

- Flexible Pavements
    - Rejuvenation
    - Sandwich Seal
    - Slurry Seal
    - Cape Seal

- Rigid Pavements
    - Patching (including full-depth patching)
    - Load transfer retrofit
    - Whitetopping

With these definitions, it is important to understand what pavement surfaces are good candidates for preventive maintenance activities, and pavement preservation programs in general. The following figures show examples of flexible pavement surfaces. Figure 12 is of a newly-constructed flexible pavement, and a similar-looking pavement surface shown in Figure 13 is a good candidate for pavement preservation treatments. As mentioned before, once the pavement surface shows evidence of distresses, as in Figure 14, it is likely past the time when preservation treatments are expected to be beneficial.

Figure 12. Newly-paved flexible pavement.

Figure 13. Good candidate for pavement preservation activities.

Figure 14. Not a good candidate for pavement preservation activities.

Preventive vs. Reactive

Preventive treatments are most often not specified as a result of an observed distress. Rather, they are applied with the expectation of preventing future distresses from occurring. Without relying on distresses to guide pavement maintenance decisions, the pavement engineer must rely on knowledge of pavement deterioration processes, engineering judgment, time, and traffic levels to determine the timing and type of preventive treatments.

Conditions often exist that are out of the agency's control, requiring something to be done to maintain an acceptable level of performance. As distresses become manifest, the type and extent

of treatment depends on many different variables – distress types, severity level, functional classification of the road, and traffic levels, for example. Corrective or reactive treatments are applied as needed to minimize further deterioration. This could be a similar treatment as the preventive treatments, but in this case the timing can change the type of treatment.

Expected Performance

The concept of longevity of individual treatments that an agency might apply to a pavement surface is related to the idea that pavement preservation is intended to extend the life of the pavement structure by protecting (or "preserving") it from conditions that would otherwise reduce the life of the pavement. Thus in this sense of the word, "longevity" does not relate to the life of the pavement, but rather to the time and/or traffic during which the activity can be expected to provide adequate protection.

There are many sources of information regarding what level of performance can be expected, and the amount of time a specific treatment can extend the life of a pavement. This section presents information from some of these sources, with an admonition that each pavement has its own set of conditions (climate, traffic, materials, construction, etc.) and that no table of information can provide reliable predictions for every situation.

An analysis of the Long-Term Pavement Performance data provided the information in Table 10 *(15)*. This table estimates the "average median survival time" of the treatment, and the average benefit in extending the life of the pavement, and divides the impact by type of treatment and the original condition of the pavement. In each case, placing the treatment while the pavement is in *Good* condition results in a longer average median survival time.

Table 10. Average Benefit and Median Survival Time of Various Treatments (15).

Treatment	Original Condition	6-Year Failure Probability	Average Median Survival Time	Average Median Benefit Compared to No Treatment (years)[1]	Median Survival Time with No Treatment (Control Sections)[2]
Thin Overlay	Good	25	7.5	2.2	5.5
	Fair	30	7.3	4.8	1.5
	Poor	100	2.2	2.5	0
Slurry Seal	Good	48	6.5	2	5.5
	Fair	57	5	3.5	1.5
	Poor	100	2.5	2.5	0
Crack Seal	Good	50	6.5	1	5.5
	Fair	41	7.2	5.7	1.5
	Poor	100	0.75	0.75	0
Chip Seal	Good	25	N/A	N/A	5.5
	Fair	25	N/A	N/A	1.5
	Poor	32	N/A	N/A	0

1. Median survival time = Number of years until 50% of the sections to which the treatment is applied fail (i.e., 50% failure rate)
2. Median benefit compared to No Treatment = The number of years a treatment adds to the median survival time compared to no treatment

The report also noted the following, related to the data presented in this table.

- Coefficients of Variation in the data are as high as 35%.
- Performance determinations are often done by "human interpretation" which can introduce high levels of variability in estimates of extended pavement life.
- Variability in pavement structures and materials is compounded with variability in pavement maintenance construction and materials. *(15)*

Another report *(16)* provided a similar table, with the expected performance of individual treatment types, and the extension of pavement life due to the application of the treatment, shown in Table 11.

Table 11. Expected Performance of Various Preventive Maintenance Treatments (16).

		Expected Performance	
	Treatment	**Treatment Life, yrs**	**Pavement Life Extension, yrs**
Flexible Pavement	Crack Fill	2-4	–
	Crack Seal	3-8	2-5
	Slurry Seal	3-5	4-5
	Micro surfacing	3-7	3-6
	Chip Seal – Single	3-7	5-6
	Chip Seal - Double	5-10	8-10
	Ultra-thin Bonded Wearing Course, or NovaChip	7-12	–
	Thin HMA Overlay – Dense Graded	5-12	–
	Thin HMA Overlay – Open Graded	6-12	–
Rigid Pavement	Joint Resealing	2-8	5-6
	Crack Sealing	4-7	–
	Diamond Grinding	8-15	–
	Partial-depth Patching	5-15	–
	Full-Depth Patching	5-15	–

The 1994 edition of the MnDOT Geotechnical and Pavement Manual *(17)* gave estimates of Recommended Service Lives of rehabilitation treatments. While most of the activities in the tables related to rehabilitation, the thin bituminous overlay was also included, which is sometimes considered in the realm of pavement preservation. The expected service lives and range of expected values are shown in Table 12. In this table, the expected life for the associated surface condition and design Equivalent Single Axle Loads (ESALs) is shown, with an associated Range, so that a thin bituminous overlay on a pavement with good surface condition and medium expected ESALs would likely have a 9±3 year service life.
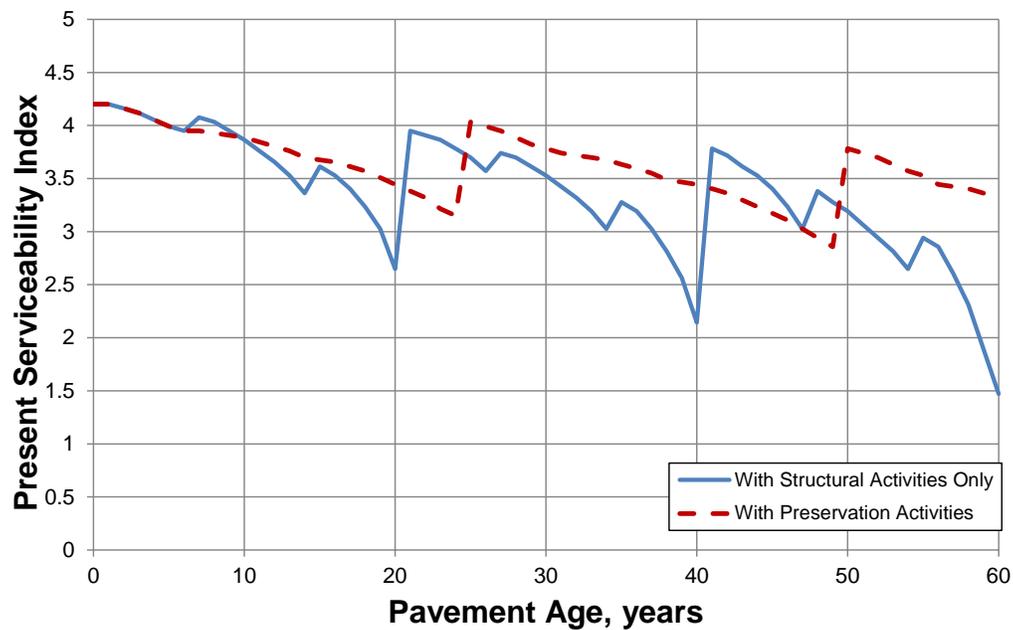
The information presented in Figure 15 is similar to that given by Peshkin, et al. *(7)* and which was presented in the literature review in Chapter 2, repeated in Figure 16, below. A similar effect is shown using real data from a research project, shown in Figure 17 *(9)* and from an actual county road in Minnesota shown in Figure 18.
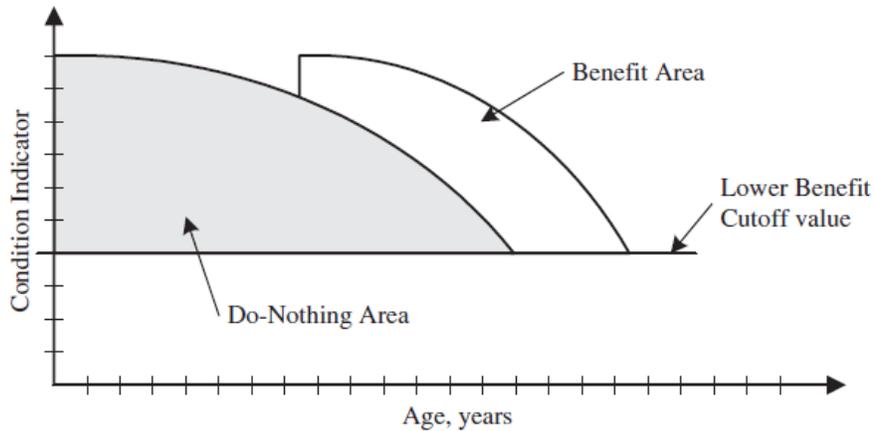
Figure 16. Conceptual illustration of the do-nothing and benefit areas (7).
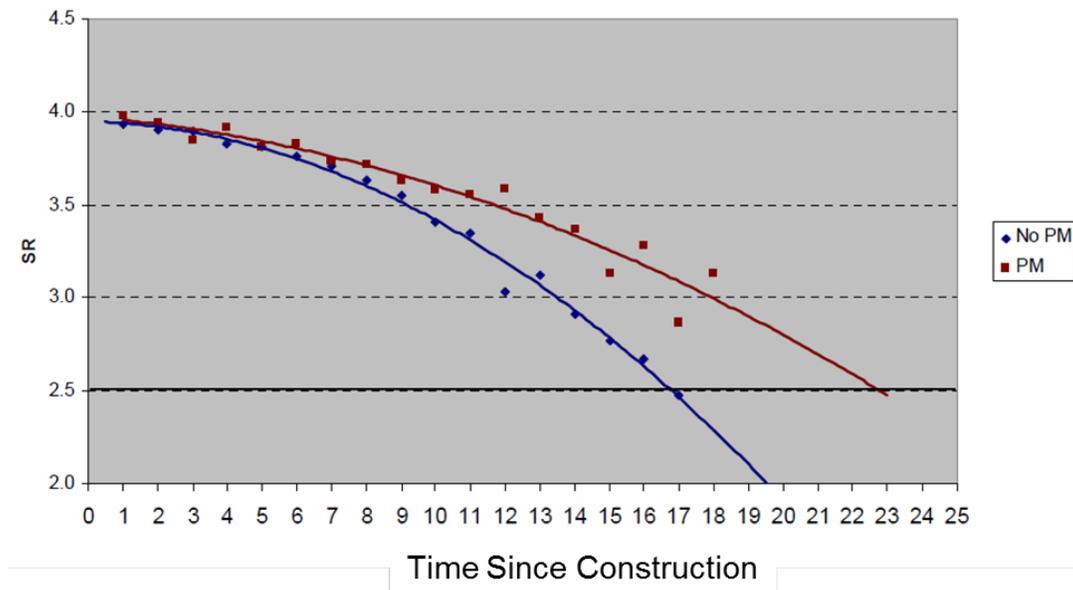

Figure 17. Surface rating over time, sample pavements in Minnesota. (9)

In order to extend the life and performance of a road, the road must have a high level of remaining structural capacity. If a road is in poor condition, preservation treatments may only improve the condition temporarily. In such cases, preservation treatments may only make the surface *look* better, but not *perform* better in terms of load-carrying capacity or extended service life.

Extending the pavement service life through a particular application requires quality materials and construction methods. A contractor may use the best materials available, but if their process and procedure is not consistent with the needs of the pavement, the results may not be what the design predicted.
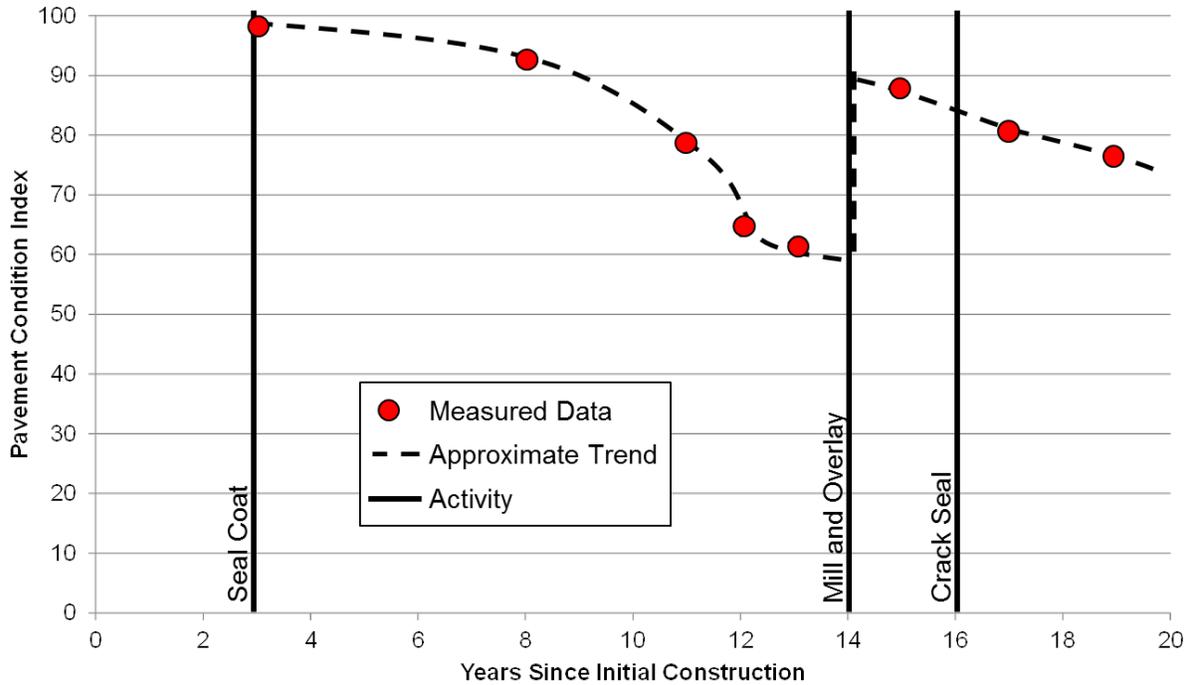
Figure 18. Actual data from a county road in Minnesota.

Pavement Management and Data Collection

In order to create and maintain an effective pavement management system, and one that will be useful in managing pavement preservation activities, several questions must be answered and topics must be understood. These include

- What data are needed?
- When and how often should the data be collected?
- Why is the data needed?
- Who should collect the data?
- How will the data be used?
- What is the difference between PSI and PCI?

Before beginning the discussion of pavement management data, it is also important to understand the advantages and disadvantages of pavement management data and the resulting analysis. This was summarized succinctly by Parkman and Bennett *(18)* in a presentation titled *The Seven Deadly Sins of Pavement Management*. They state that while much has been written about pavement management systems, "unless the entire implementation and operation is approached in a holistic manner, there is a high risk that the uptake will be limited and the system achieve only some of its potential benefits."

1. People forget the purpose of the system
2. Nobody understands how you reached your conclusions
3. Nobody understands what you are talking about
4. Too much effort for a conceptually straightforward business decision

5. Has little impact on the overall business
6. Drowning in a sea of data
7. Funding is to improve road infrastructure, not to make decisions

Pavement management systems are tools to assist in developing decisions. In general, the list above is a reminder that the systems can easily become too complex, leading to few people understanding how the system works and how it develops recommendations. Too much data can also become a problem if it means data are collected which are not then used by the system to help make decisions. Using the information in the sections below can help keep the input, output, and operation of a pavement management system simple, effective, and relevant into the future.

PSI vs. PCI

Since pavement preservation activities do not contribute to the structural capacity of the pavement, a direct effect of such activities would not be seen in a traditional Present Serviceability Index curve, but may be evidenced by a Pavement Condition Index curve. What is expected in a PSI curve when preservation activities are performed is not direct increases in PSI, but a flattening of the slope as the pavement structure declines with time and traffic. A PCI curve, conversely, might reflect the immediate visual effects of a chip seal (e.g. cracks aren't counted because they aren't seen) resulting in an increased PCI, but as cracks reflect and reappear, the PCI will gradually return to a lower value.

What to collect?

As was discussed in Chapter 3, several basic types of data are necessary in developing a pavement management system. These can be divided in to the Inventory, Construction/Materials, and Current Condition categories. The information needed in each of these categories is listed below.

1. Basic inventory
   a. Segment location (county, roadway designation, termini, milepost or other distance reference)
   b. Segment length and width
2. Construction / Materials
   a. Date of last reconstruction or major rehabilitation
   b. Reason for reconstruction or major rehabilitation (i.e.. scheduled, emergency, or other)
   c. Dates and types of maintenance and rehabilitation activities
   d. Quantities of maintenance and rehabilitation materials
   e. Unit (or total) cost of construction, maintenance and rehabilitation activities
   f. Pavement structure information – Materials, layer thicknesses, etc.
3. Condition and traffic
   a. Periodic surface rating index values (PCI, SR, PQI, etc.)
   b. Estimated traffic (ADT, HCADT, % Trucks, vehicle classification, etc.)
   c. Current condition

An important concept in conducting pavement condition surveys is that the data collected should represent what is seen, and not what is desired. It can be easy to drift into subjective data

collection when assessing the current condition of a pavement surface, even when guidelines are provided for the objective data collection.

Many references describe what is needed and how to analyze it to develop a pavement condition index. Most common include the MnDOT Pavement Distress Identification Manual *(19)* and SHRP Distress Identification Manual *(20)*.

When, and how often?

In order to manage this information for roadways, an inventory must be taken of what is considered part of the system. The agency then formulates and assigns a method of rating the roadways. Often, agencies will divide the network of roadways into sections than can be covered annually. For example, if a network is divided into thirds, all the roadways will be assessed every three years. Ultimately, an agency's budget will govern how much and how often the roadways can be evaluated. The more frequent they are rated, the better the information will be to determine what and where treatments are needed.

Why is the data needed?

One concern is that often agencies use the collected data to find the "worst condition" pavement. The temptation is to assign the highest priority to this segment, which inevitably uses the allotted funding much sooner since the required treatment for severely deteriorated pavements is often much more costly. One way of determining the best candidate for maintenance funding is the Remaining Service Life approach. This approach uses data already collected by the PMS and assigns a value to the remaining life a segment of pavement has before it needs total reconstruction. By managing the remaining life of the segments, it is possible to find a balanced approach to preserving pavements before they need more major treatments while still addressing pavements in worse conditions. It is a more "top down" approach rather than a "bottom up" approach *(21)*.

A good PMS has the capability, if enough data has been collected, to be used to develop general models of how pavements will perform and predictions of where certain roadways may require upcoming pavement preservation treatments. This takes some time to collect enough data. However, generic models can be used in cases where enough data is not available. These models can be incorporated into the selection process of which pavements receive treatments and when, until adequate specific data is collected.

Life Cycle Cost

Life-cycle cost analysis should look at the specific benefits expected from specific activities related to pavement preservation. There are many references in the literature regarding life cycle cost analysis. Several relevant references are listed in the section titled Sources of Additional Information at the end of this chapter.

As an example of three ways of considering the cost and performance over the life of a pavement, the following case is presented in different ways in Figures 19 and 20.

   A pavement section receives an overlay as a major rehabilitation project, with a cost of $250,000 per mile. The expected service life is 15 years.

At a 3% discount rate, the equivalent uniform annual cost (EUAC) for this project is $20,900 per mile per year.

If a preservation treatment is applied at year 2, which extends the life of the pavement 3 years, and costs $20,000 per mile, the new EUAC is $19,500 per mile per year.

This represents a savings of $1,400 per mile per year.
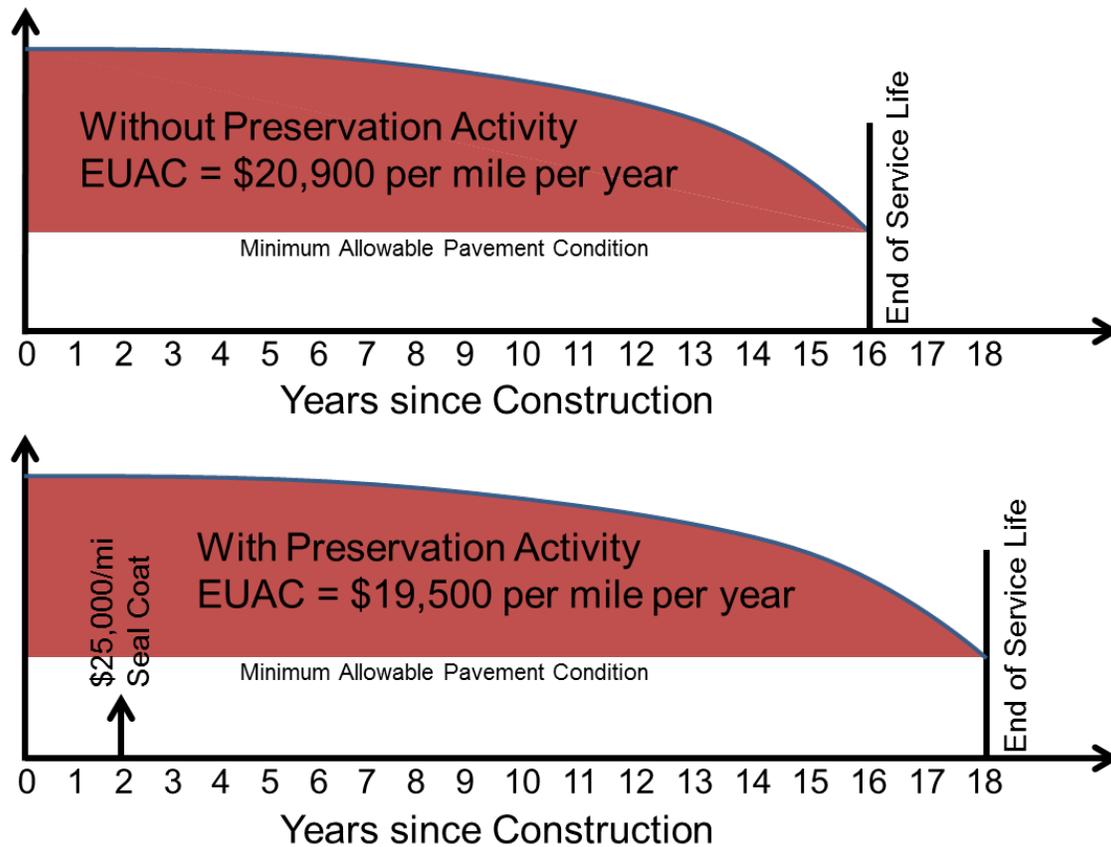
Figure 19. Example LCCA – Equivalent Uniform Annual Cost Method.

To look at this case in a different way, the extension of pavement service life might result in an increase from 863 PCI-years per mile to 946 PCI-years.

These results can be viewed in the following ways:

A 6.7% savings in terms of Equivalent Uniform Annual Cost: ($20,900 - $19,500) / $20,900

A 9.6% improvement in performance: (946 – 863) / 863

Or a 14.9% improvement in the cost of performance:
($24.22/mile/PCI-year – $20.61/mile/PCI-year) / ($24.22/mile/PCI-year)

46
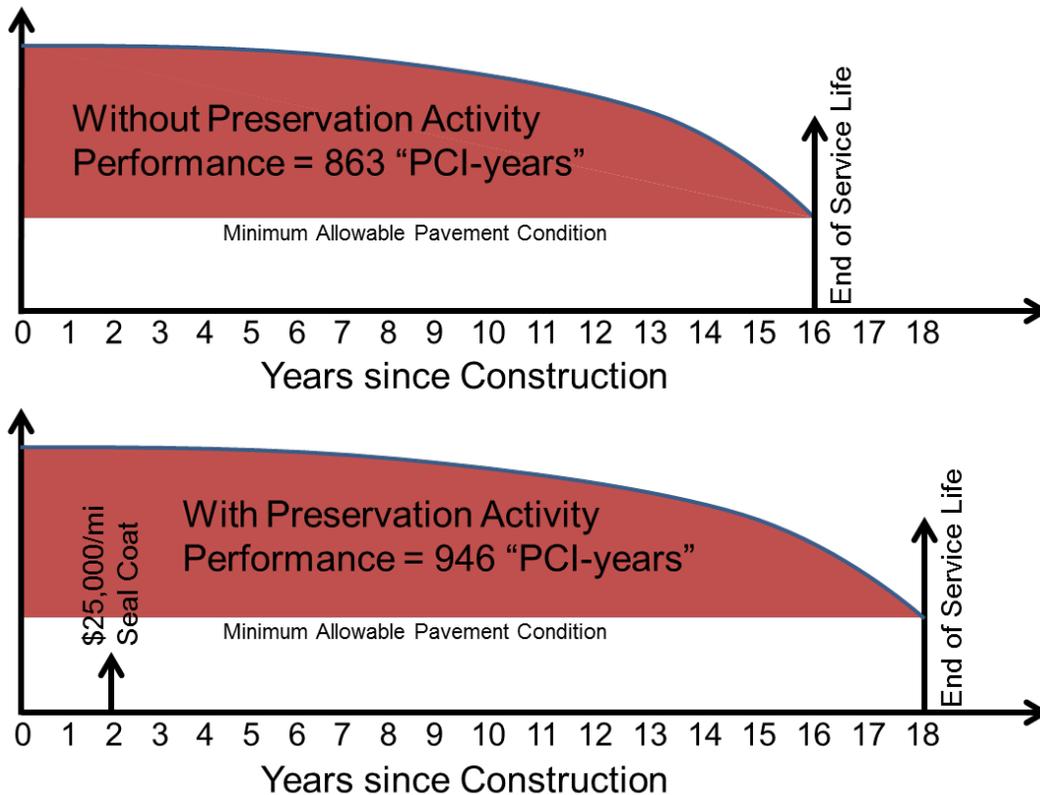
Figure 20. Example LCCA – Cost of Performance method.

Preservation Activities

As with many of the topics in this report, it cannot contain a comprehensive catalog of preservation activities and their proper use and application. This section presents many of the most common preservation treatments and some basic recommendations for their application and timing.

Crack Sealing

Crack sealing should be applied as needed whenever cracks are observed. Cracks should be sealed as soon as possible to prevent moisture from entering the pavement structure. The correct sealant type should be used for specific applications. Suggested sealant types meeting MnDOT specifications *(22)* are presented in Table 13.

Table 13. Crack Sealing Methods and Recommended Sealant Types.

Application Type	Material / MnDOT Specification
Clean & fill	3719 (crumb rubber)
Clean & fill, rout & seal	3723 (low modulus)
Rout & seal	3725 (extra low modulus)

Other recommendations for crack sealing include the following.

- Apply sealant in clean, dry cracks.
- Make a neat and clean application.
- Don't fill wet cracks
- Don't overheat the sealant material
- Don't make wide overbands

The images in Figures 21 through 24 are examples of proper crack sealing operations.

Figure 21. Crack Sealing.

Figure 22. Crack Sealing.

Figure 23. Cleaning cracks prior to sealing.

Figure 24. A clean, dry, routed crack.

Chip Seal

Chip seals are constructed by spraying one or more layers a polymer-modified asphalt emulsion binder on a roadway and embedding finely graded aggregate into it. Once the aggregate is evenly dispersed the pavement is then rolled. Chip seals are used to provide a new wearing surface on roadways that is intended to eliminate raveling, retard oxidation, reduce the intrusion of water, improve skid resistance and seal cracks. They can last on average about 7 years and are typically applied on low volume roads.

General recommendations for the design and application of chip seals are given below.
- Apply chip seal to pavements early in life. Generally within the first four years
- Only on structurally sound roadways
- Sweep as soon as possible
- Fog seal all rural chip seal
- Design the application rate for the need
  - Apply proper amount of aggregate
- Follow MnDOT's recommendation for materials and construction
  - 2356 specification *(22)*
  - MnDOT Seal Coat Handbook *(23)*

- Don't apply chip seals in September or later
- Don't leave extra rock on roadway more than one day
- Don't use a chip seal to try to hold a deteriorated pavement together

The images in Figures 25 through 28 show proper chip seal practices.

Figure 25. Chip seal emulsion application.

Figure 26. Chip seal application.

Figure 27. Chip seal application.

Figure 28. Chip seal rolling operation.

Micro Surfacing / Slurry Seal

Micro surfacing is a cold-applied paving mixture composed of polymer-modified asphalt emulsion, crushed aggregate, mineral filler, water and a hardening-controlling additive. No rolling is required and the finished surface can generally be opened to traffic soon after placement.

Like a chip seal, micro surfacing can be used as a blanket cover on pavements suffering from loss of skid resistance, oxidation, raveling and surface permeability. In addition, micro surfacing can be used to fill ruts and improve rideability by removing minor surface irregularities. This treatment can last on average 8 to 9 years. It is also suitable for all traffic levels.

General recommendations include not working too late in the fall (later than September, for example), only applying the micro surfacing slurry at a rate to produce a thickness the diameter

of one aggregate particle, and not to allow a careless application of the materials. Figure 29 provides an example of one lane of a micro surfacing application.

Figure 29. Micro surfacing.

Thin Bonded Wearing Course

A thin bonded wearing course is a combination of wearing course and a preventive maintenance treatment in one application. It is most often used on higher volume roadways. The bonding emulsion (materials and application rates) should be designed for the specific application. It is important to apply a chip seal to the HMA as soon as possible, and at the latest one season later. Figure 30 shows the application of a thin bonded wearing course.

Figure 30. Thin bonded wearing course application.

Timing of Preservation Activities

During the interviews that were conducted at each of the agencies discussed in the previous chapter, the project team asked questions regarding the expected schedule for preservation activities (and other) throughout the life of a typical pavement section. The responses were then compared to the actual timing of those activities in the past (up to 12 years). One result of this effort is the indication that many agencies conduct preservation activities and structural fixes with less frequency than they would like. This is likely related to budgetary constraints or other causes, and is not a new finding.

Case Studies

One example of a "designed" vs. "actual" set of pavement maintenance and rehabilitation strategies follows, with actual data from one of the participating agencies. In this case, the agency plans to conduct the following pavement preservation and rehabilitation activities for new pavements, according to the schedule shown in Figure 31.

Year 1:   Initial Construction
Years 2 – 21:   Chip seal every 2-3 years
Years 22 – 60:   Overlay every 8 years, with chip seals at 3 and 6 years after each overlay.

Such a plan is often not based on triggers such as condition indices, but rather on time alone. This method makes the timing easier, but also presents the possibility that some treatments will be applied earlier or later than are actually needed. Another method that can be implemented with this type of plan is to use time as a pseudo-trigger, or a time at which the roadway segment is evaluated for the need to perform the treatment or not.

Figure 31 shows this plan graphically, indicating the treatment and the year in which the activity is scheduled to take place. The overlay and two subsequent chip seal over an eight-year period is repeated until about year 60, at which time the agency intends to reconstruct the roadway.
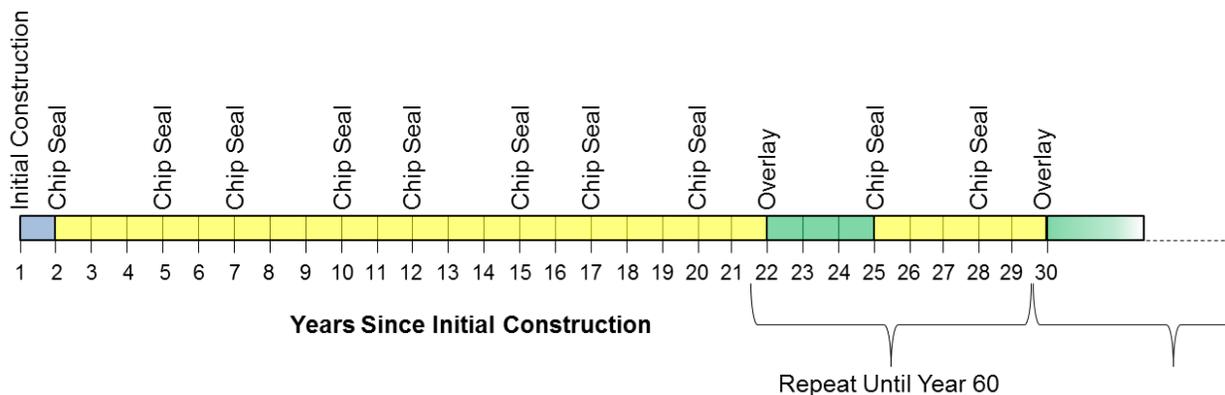
Figure 31. Sample Preservation and Rehabilitation Plan.

While the schedule shown in Figure 31 is the agency's **plan** for newly-constructed roadways, the information in Figure 32 shows a typical roadway maintained by the same agency and the activities that have actually been conducted since its construction 41 years earlier. As can be seen, chip seals have been applied less often than desired in the current plan, and an overlay was

applied many years earlier than would be expected under the plan. Since the roadway in this example was constructed many years before the current plan was developed, more frequent chip seals may be expected on newly-constructed pavements, and possibly on existing pavements such as depicted in Figure 32. One pattern that is apparent in the data in Figure 32 is that a chip seal or overlay was applied approximately every 7-10 years (8 and 9 years for the first chip seal and overlay, respectively, 7, 10, and 8 years for the next three chip seals, and 7 more years for the second overlay).
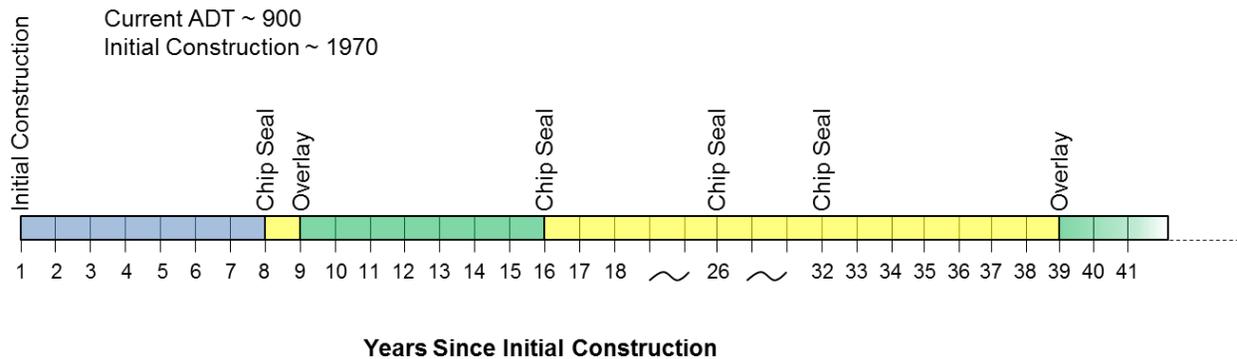

Figure 32. Actual Preservation and Rehabilitation Activities.

The timeline and plot in Figure 33 are an expansion of the years 16 through 41 in Figure 32, between the first chip seal after the first overlay, and a few years after the second overlay, with the pavement condition index values measured approximately every three years. The general decline of PCI values is evident in Figure 33, with a dramatic increase after the overlay in year 39 was applied. It appears that the chip seal, even if applied every 8-10 years, extended the life (in terms of keeping the PCI above 60) until an overlay was constructed.
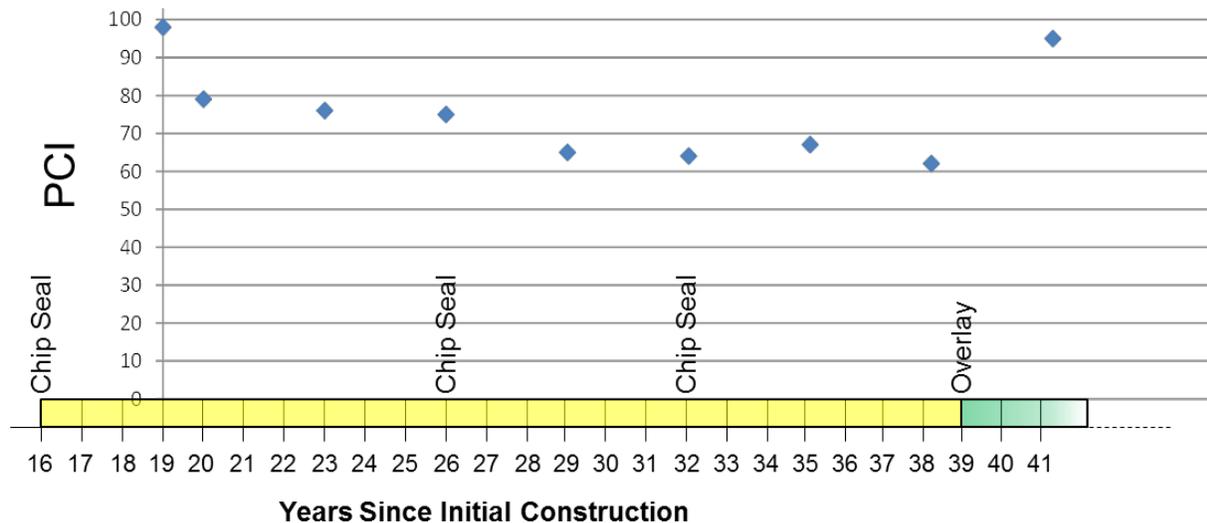

Figure 33. Actual Activities #1, with PCI Values.

Figure 34 shows similar information for a second typical roadway from the same agency. One overlay, placed at year 20 did not receive another treatment of any kind until 8 years later. The PCI of that roadway was maintained above 60 for about 6 to 9 years after the chip seal, but then

54

decreased dramatically during the three years between two PCI measurements in years 34 and 37. Unfortunately, after the significant decrease was noticed, it took five more years before an overlay was constructed.
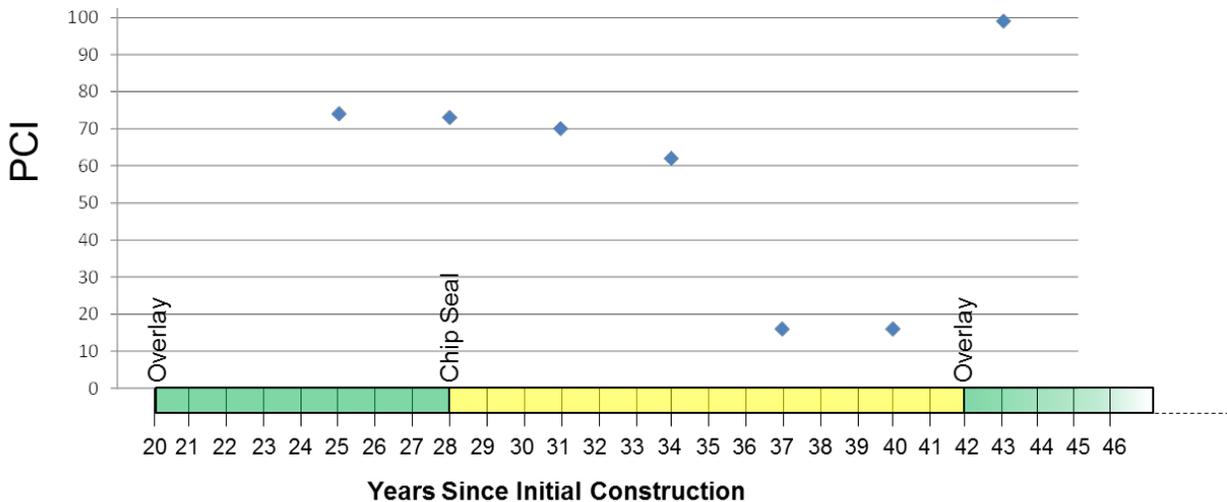

Figure 34. Actual Activities #2, with PCI Values.

The previous cases are only two examples of similar occurrences throughout the data acquired by the project team. These examples demonstrate the benefits of the following activities:

- Regular pavement preservation activities,
- Proper timing of rehabilitation activities,
- Regular condition surveys, and
- Development of a pavement preservation plan, and following it as closely as possible.

Minnesota Research – MN Trunk Highway 56

Some agencies have a standard policy to apply a chip seal on a new pavement the first year following construction. Crack sealing is a regular maintenance treatment, which is often followed up with a chip seal for added protection. Often agencies use their pavement management system to dictate when to apply treatments based on criteria it uses. Research has shown *(24)* that it is often better to apply the first treatment sooner rather than later. That first treatment will allow the pavement system to wear and function the way it was designed.

Interim findings from ongoing research conducted by MnDOT on Trunk Highway 56 *(24)* indicate the following benefits of chip sealing at early ages after asphalt pavement construction.

- Sealing improves resistance to aging, which is closely related to cracking
- Sealing sooner is better
  - Waiting 3 or more years after construction produced similar results in terms of fracture energy required to cause cracking
  - Sealing 1-2 years after construction showed improvement in resistance to aging in terms of cracking

55

- Fracture energy required to cause cracking is highest when chip seal is applied 2-3 years after construction, as shown in Figure 35. In this figure, higher fracture energy is better since it indicates that the asphalt concrete is more resistant to cracking. The control section did not receive a chip seal. As the figure indicates, waiting more than about two years for the first chip seal is almost equivalent to not applying a chip seal at all.
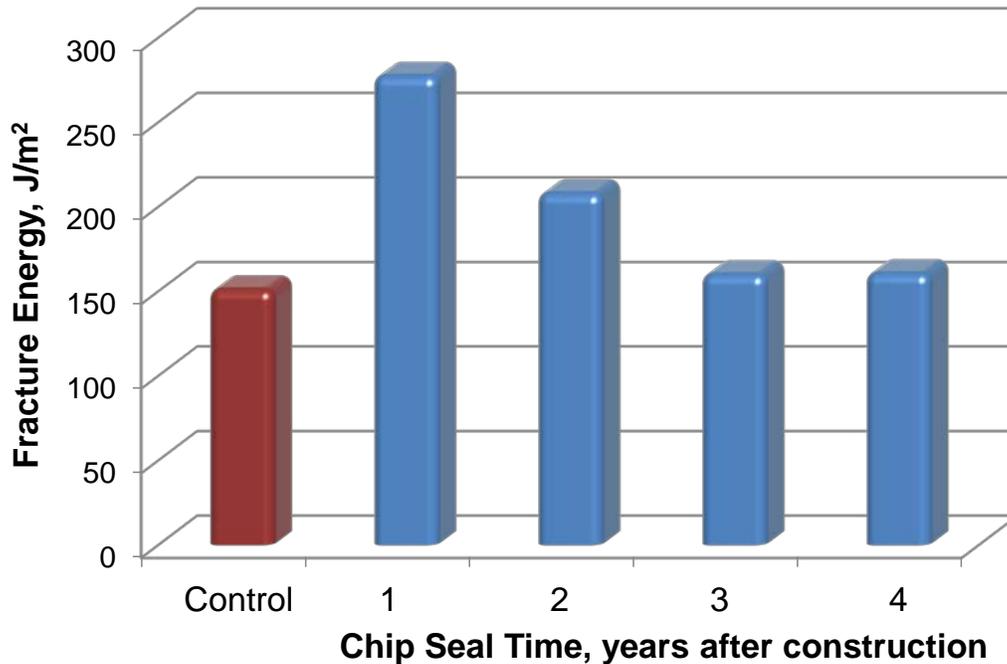
Figure 35. Fracture energy required to initiate cracks after chip seal application (24).

As a comparison among pavement preservation and rehabilitation activities, Figure 36 provides estimates of the life extension required of a treatment in order for it to be considered cost effective *(24)*. In other words, if a thin overlay or a heavy mill and overlay does not extend the life of the pavement by more than 3.0 or 2.4 years, respectively, they would not be an effective use of highway maintenance and rehabilitation funds. However, a chip seal applied within one to two years after construction "pays for itself" after only 0.4 years, indicating a much greater cost-effectiveness in terms of life extension and treatment cost.
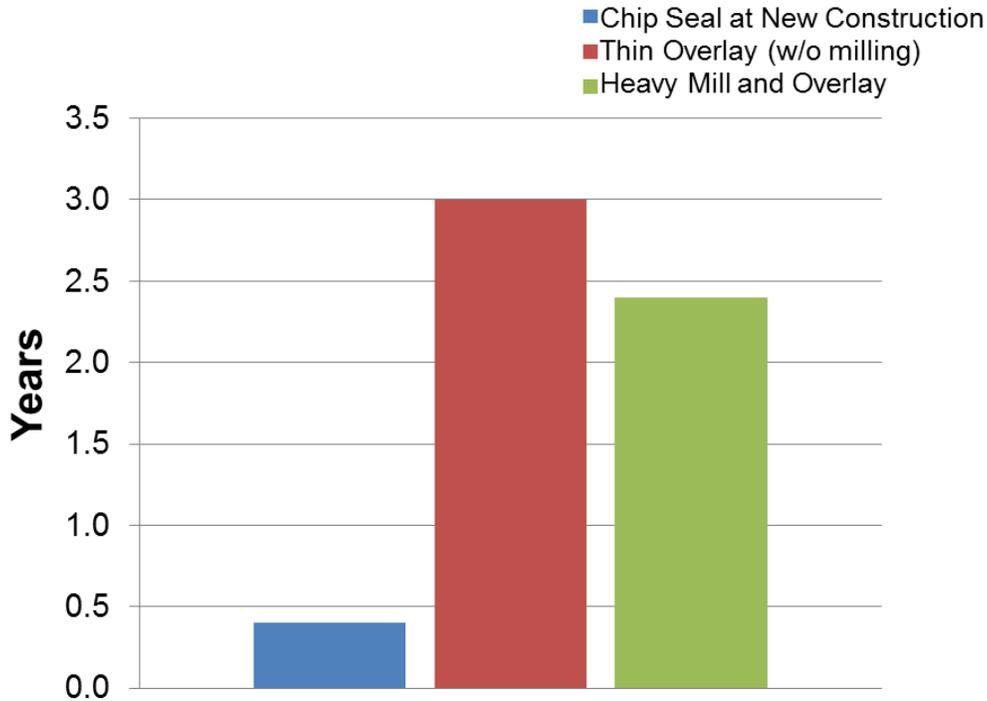
Figure 36. Estimated years of life extension for treatments to be cost-effective (24).

Prioritization at the Network Level

Prioritizing among a network of roadway segments can be challenging, and presents several unique questions:

- When is the appropriate time for a particular preservation activity?
- How long is too long to delay?
- How will I know if it is too long?
- What should I do if it has been too long?
- Will the additional costs now result in savings later?
- Which of the many roadway segments in the system deserve attention first?

From a network perspective, one of the tools used most often is the decision tree. The decision tree is intended primarily for assigning pavement maintenance or rehabilitation activities based on a common set of criteria that can be applied uniformly across the network. This is most often conducted by a computer on thousands of pavement segments within a network. The decision tree does not provide a prioritized list of roadway segments, but allows an agency to develop a program of maintenance and rehabilitation based on the collected project-level needs throughout the network. Two examples of decision trees are shown in Figures 37 and 38 – a simple type of decision tree and one that takes many more conditions into account, respectively.
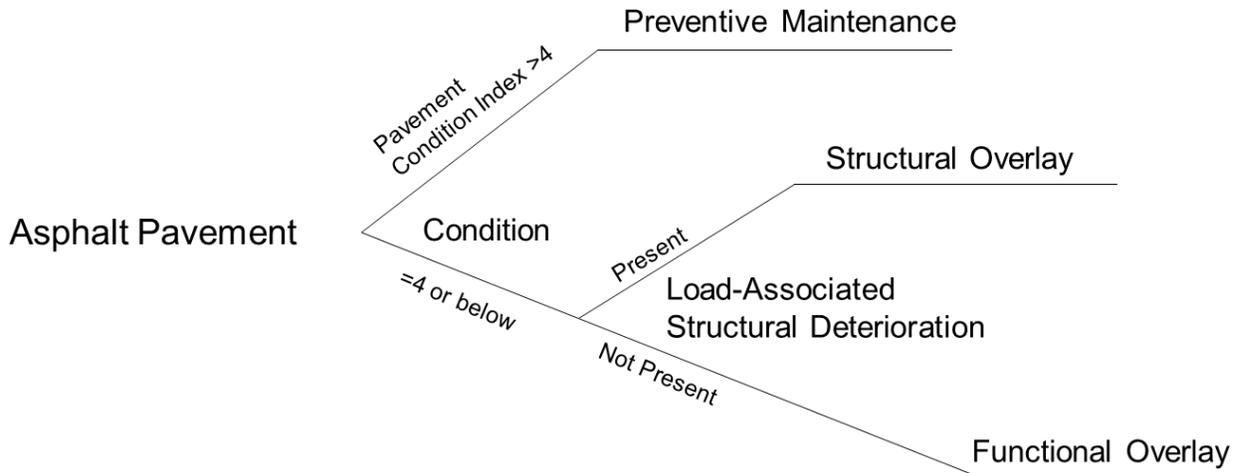
*Figure 37. Sample Decision Tree (25).*
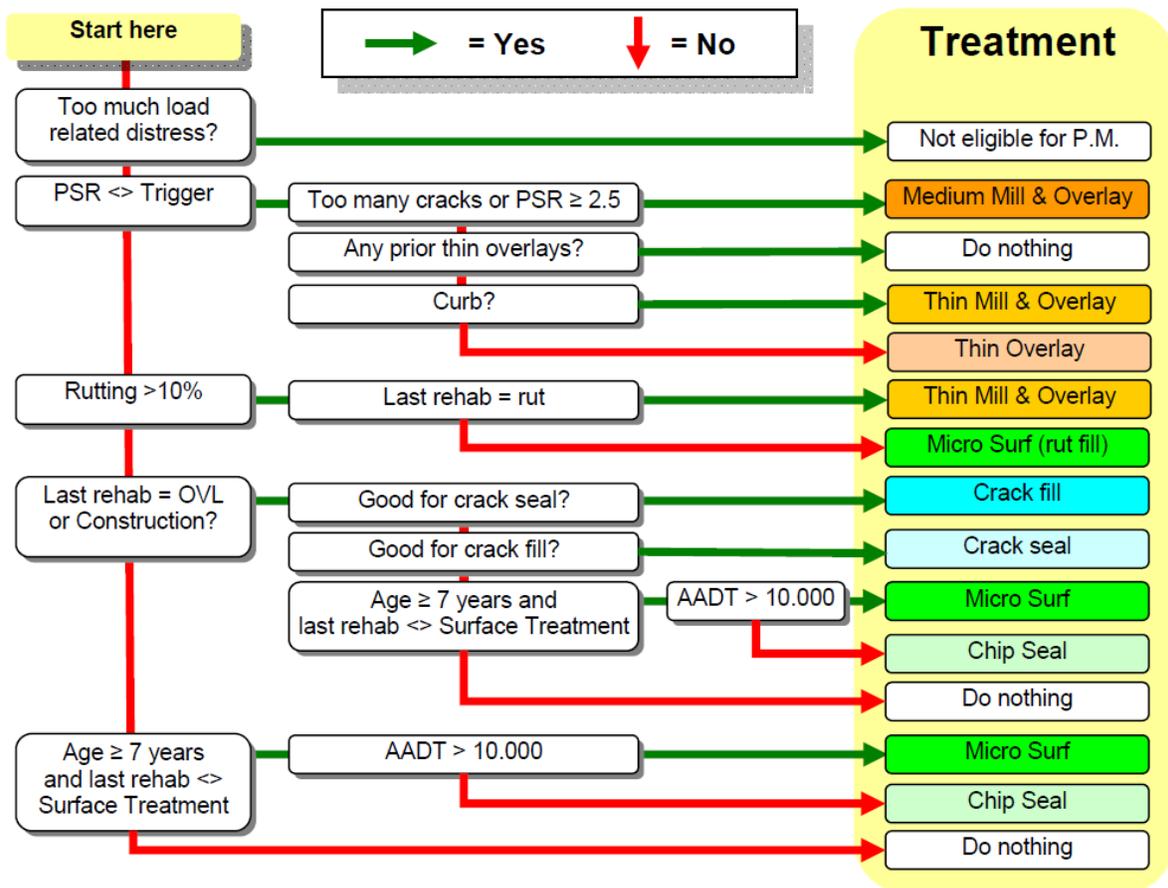
Figure 38. Condensed version of MnDOT bituminous decision tree (15).

While a decision tree can help determine the best course of action on a single roadway segment, there are several methods for taking those recommendations and developing a prioritized pavement maintenance and rehabilitation program.

- Sort by predicted $/mile/PSI-year value, as described in the next section.
- Ensure that good pavements do not fall below a threshold value where preservation activities would no longer be effective.
- Use engineering judgment to make determinations on borderline cases. Treatments used in borderline situations are more likely not to be cost-effective.
- Coordinate with other nearby roadways to gain economic benefits of larger construction projects.

Some of the above decision making can be delegated to a computerized algorithm, but final decisions and prioritizations should be done with human interaction and engineering judgment, and assisted by computerized computation. For example, a medium-sized city street network with 2,000 segments could be evaluated by algorithm and engineering judgment using the following steps.

1. Computerized decision tree to identify first set of activity assignments. These could be divided by PCI value, time since last reconstruction, time since last activity, etc.
   a) Do Nothing
   b) Preservation Activity (crack seal, minor patching, surface treatment)
   c) Rehabilitation Activity (major or minor)
   d) Reconstruction
2. For the do-nothing recommendations, check to make sure the marginal segments are truly in a condition to endure another 2-3 years without any treatment.
3. For the preservation and rehabilitation recommendations, conduct a cost analysis with predicted performance to prioritize roadway segments with the best potential to provide extended life and need less rehabilitation activity in the next 7-10 years.
4. For the reconstruction recommendations, check for segments that could wait another 2-3 years before becoming absolutely too rough or structurally deficient to continue.
5. Develop a cost analysis for the set of recommended treatments and compare to available budget.
6. If prioritized needs exceed available budget, make appropriate adjustments to the recommendations – delaying needed activity, adjusting cutoff points, and moving more segments to the "do-nothing" option for that year.

There are more sophisticated methods for optimizing and prioritizing the recommendations developed by a decision tree. These are described in *(7, 26, and others)* and often require additional pavement condition data, historical data (from which computer software develops deterioration prediction curves), and other requirements.

Peshkin et al, *(7)* introduced an Effectiveness Index to optimize the timing of specific treatments. The effectiveness index compares the benefit/cost ratio of each possible scenario with the maximum individual B/C ratio (B/C$_{max}$). In computing the B/C ratios for individual treatments, the authors utilize a method similar to that described in this report – comparing the area under performance curves for the "do-nothing" and the individual treatment predictions. Shah et al. *(26)* recommend life cycle cost analysis methods as well as parameters called "Lane-mile years" and "Highway Health Index" to help quantify the benefits of pavement preservation.

Lane Mile-Years Concept

Another method of analyzing performance and function is by using what is called, "lane mile-years". The National Center for Pavement Preservation and FHWA Office of Asset Management, published an article explaining the concept of mile-years *(21)*. They explain that it is a "top-down" approach, using historic estimates to manage entire road networks instead of breaking them up into smaller systems (i.e. projects, subdivisions, etc.)

The concept of lane mile-years assumes that every lane-mile segment of a road network is rated by the number of years remaining until the end of its life as a terminal condition. The terminal condition represents the level of minimal operating condition for that road or network. If nothing was improved during the year, the mile-years remaining will decrease by one. So for a given number of lane-miles in a road network, the mile-years of deterioration is the amount of lane-miles per year that need to be improved in order to maintain the same level of performance as the previous year.

An example is a network of 500 lane-miles. If no improvement is made in the following year the system will lose 500 lane-mile-years per year. If more than 500 lane-miles are improved in the following year the overall system will be improving. If only 500 lane-miles are improved (to increase service life by at least one year each, on average), there would be no change in the overall system.

Estimating Costs and Benefits of Preservation Activities

This section presents an analysis and summary of methods for estimating the costs and benefits of preservation activities. When considering the use of pavement preservation, the direct costs of the activities are relatively simple to estimate. The benefits of performing these activities may be less straightforward or direct, at least to determine a dollar value of those benefits.

Cost

An analysis of historical bid tabulations and/or actual contractor bids for specific projects can provide a basic understanding of the probable cost of a certain maintenance or rehabilitation activity. It is important to consider the size of the projects that are reported in the bid tabs and actual bids. Contractors incur fixed costs as well as costs that are relative to the quantities constructed. On smaller projects, the fixed costs usually amount to a larger proportion of the overall project than they do on larger projects. These costs, such as for mobilization, may be the same regardless of the project size, and thus are divided over smaller quantities, resulting in larger unit costs. Other factors to consider are the units within which the materials and construction activities are bid, layer thickness, material type, and the project location – all of which can affect the quantities and/or cost estimates.

Bid Tabulations

It is not the intent of this project to report actual costs or even bids within a certain time frame, but to provide adequate information for individual agencies to develop their own estimates for specific projects. However, as an example of a bid tabulation document, Table 14 provides a

sample of asphalt wearing course bids tabulated over a one-month time span. This type of information can be found on the MnDOT bidding and letting web site *(27)*.

Table 14. Sample of MnDOT Tabulated Bids, August 2013 (27).

Item Group	Item Number	Item Description	Units	Quantity	Dollars (000s)	Average Price	Contract Occurr.
2360	2360.501/12200	TYPE SP 9.5 WEARING COURSE MIX	TON	16,675	$852	$51.10	1
	2360.501/22200	TYPE SP 12.5 WEARING COURSE MIX	TON	166,144	$7,476	$45.00	16
	2360.501/23200	TYPE SP 12.5 WEARING COURSE MIX	TON	1,041,536	$48,785	$46.84	57
	2360.501/25500	TYPE SP 12.5 WEARING COURSE MIX	TON	248,378	$13,287	$53.50	8
	2360.503/22215	TYPE SP 12.5 WEAR CRS MIX 1.5" THICK	SY	1,853	$18	$9.75	1
	2360.503/22220	TYPE SP 12.5 WEAR CRS MIX 2.0" THICK	SY	1,853	$23	$12.50	1
	2360.503/23220	TYPE SP 12.5 WEAR CRS MIX 2.0" THICK	SY	816,277	$5,574	$6.83	3

Several items are of interest in this extracted table.

1. All items fall under the same Item Group (2360).
2. There are only two different primary Item Numbers in this table of seven items, but each item has a unique secondary number.
3. Three different "TYPE SP 12.5 WEARING COURSE MIX" items show different quantities and average prices. While there may be some differences in the exact material or mix design, these are essentially utilized for the same purpose.
4. The Quantity is not necessarily correlated with the Average Price. This means that quantity alone is not responsible for changes in unit prices. Of the three items mentioned above, the cheapest unit price is for an item with about 1/5 the quantity of the next lowest unit price.
5. Similar materials can be bid with different units – TON and SY. The units must be considered accordingly in such cases.

Bid Abstracts

In order to estimate a project's cost successfully, all relevant bit items must be considered. It is most often beneficial to consult bid abstracts of previously let projects. These can be found at the MnDOT web site at http://www.dot.state.mn.us/bidlet/abstract.html *(27)*. The following is a list of all items included in a typical pavement preservation project – Micro surfacing – in the summer of 2013, on a CSAH roadway in central Minnesota.

- MOBILIZATION
- REMOVALS
  - PAVEMENT MARKING REMOVAL
  - PAVEMENT MARKING REMOVAL
- BITUMINOUS MATERIALS
  - BITUMINOUS MATERIAL FOR FOG SEAL
  - BITUMINOUS MATERIAL FOR MICRO-SURFACING
  - MICRO-SURFACING SCRATCH COURSE
  - MICRO-SURFACING SURFACE COURSE
  - BITUMINOUS MATERIAL FOR TACK COAT
- TRAFFIC CONTROL
  - TRAFFIC CONTROL
  - PORTABLE CHANGEABLE MESSAGE SIGN
  - TRAFFIC CONTROL SUPERVISOR
  - WORK ZONE SPEED LIMIT
  - INTERIM PAVEMENT MARKING
  - PAVEMENT MESSAGE (LEFT ARROW) PAINT
  - PAVEMENT MESSAGE (RIGHT ARROW) PAINT
  - 24" SOLID LINE WHITE-PAINT
  - 24" STOP LINE WHITE-PAINT
  - 24" SOLID LINE YELLOW-PAINT
  - 4" SOLID LINE WHITE-EPOXY
  - 8" SOLID LINE WHITE-EPOXY
  - 4" BROKEN LINE WHITE-EPOXY
  - 4" SOLID LINE YELLOW-EPOXY
  - CROSSWALK MARKING-PAINT
  - 4" SOLID LINE WHITE-PAINT (WR)
  - 4" BROKEN LINE WHITE-PAINT (WR)
  - 4" SOLID LINE YELLOW-PAINT (WR)
  - 4" BROKEN LINE YELLOW-PAINT (WR)
  - 4" DOUBLE SOLID LINE YELLOW-PAINT (WR)

The total cost for this project (approximately 10 miles long) was estimated at about $450,000. The low bid for the project was just over $475,000. Other important information to consider on this project is its size (number of miles, square yards, linear feet, etc.), its location, the amount of other work the agency and other agencies are putting out for bid, and other parameters.

Benefits

Another way of looking at the benefits of pavement preservation activities is from a performance perspective. In the example given in Figures 39 and 40, the cumulative performance provided by a pavement structure over its life can be computed as the accumulated area under the PSI curve. The performance is indicated by the units "PSI-years." As can be seen in the figures below, the pavement which has had performance activities to extend the life of the structure has performed better over its life than a pavement where preservation activities have not augmented the life of the structure.

When combined with construction cost data, this information can be presented as $/PSI-year or, since construction costs are often considered on a per-mile basis, this could be presented as $/PSI-year per mile, or $/PSI-year/mile. As an example, a basic life-cycle cost analysis should be conducted, considering the preservation and rehabilitation activities after the initial construction (assuming that the initial construction will be the same, independent of the preservation plan). Then the total PSI-years are computed for each plan (with and without preservation activities, or when deciding on a specific activity or its timing). Finally, a comparison is made between the $/PSI-year/mile for each plan to determine its effectiveness. This example is developed more fully using sample data below.

Table 15. Sample Comparison Between Standard and Preservation Plans.

Year	Plan 1 – Overlays at 10-year Intervals		Plan 2 – Chip Seal with Overlays at 15-yr intervals	
	Activity	Cost, $/mi	Activity	Cost, $/mi
1	Initial Construction	N/A	Initial Construction	N/A
2			Chip Seal	20,000
7			Chip Seal	20,000
10	Mill & Overlay	125,000		
12			Chip Seal	20,000
15			Mill & Overlay	125,000
16			Chip Seal	20,000
20	Mill & Overlay	125,000		
21			Chip Seal	20,000
26			Chip Seal	20,000
30	Reconstruct	N/A	Reconstruct	N/A

Step 1: Conduct Life-Cycle Cost Analysis
A basic discounted analysis, using a 1% discount rate, results in the following total costs:
Plan 1 (Rehabilitation only): $215,600 / mile
Plan 2 (Preservation): $212,400 / mile

The cost of adding several chip seals and only one overlay over the life of the pavement may be similar to applying two Mill & Overlay operations over the same life span. If the preservation activities serve the purpose of extending the life of the pavement structure, such a relative comparison is reasonable.

Step 2: Determine Total Pavement Performance Value
From the condition index data in the curves shown in Figures 39 and 40, below, the overall PSI-year can be computed, by accumulating the area under the curves for the respective plans. In this case, with the terminal PSI set at 1.5, the area between the PSI curves and the terminal value is computed.
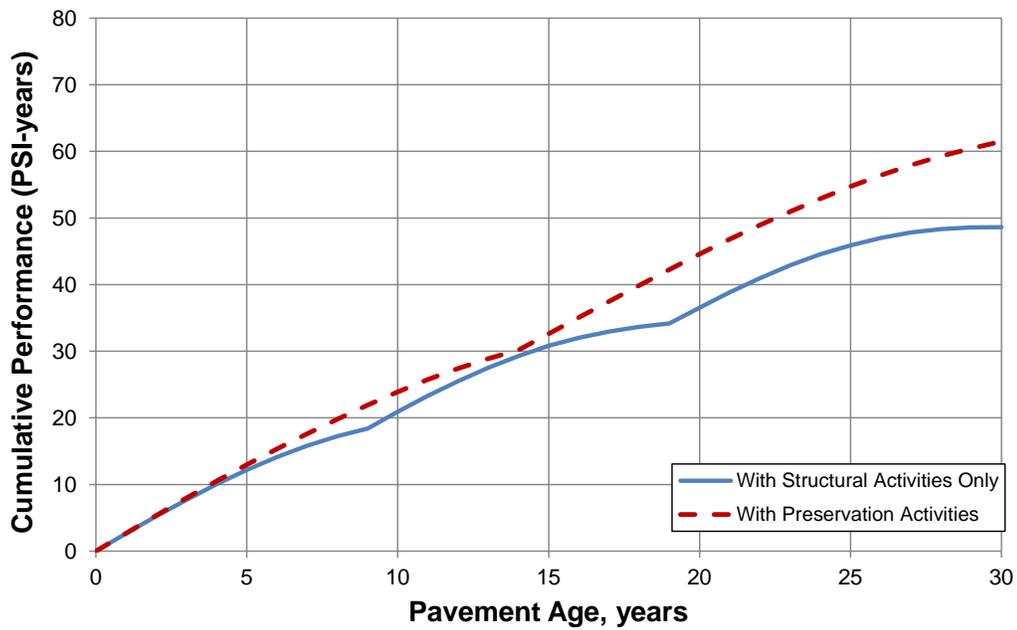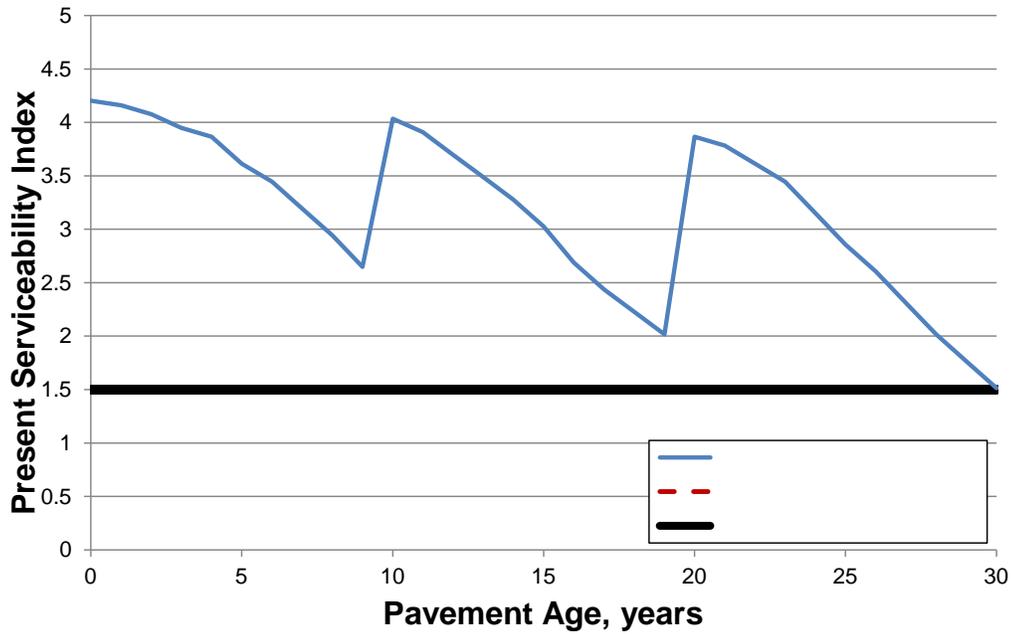
Figure 40. Example cumulative pavement performance data.

By the end of the planned life in this example, the Rehabilitation Only plan is estimated to provide a performance value of about 49 PSI-years. The Preservation plan provides about 62 PSI-years in performance. This step of the analysis can also be conducted in terms of PCI rather than AASHTO's PSI concept.

Step 3: Compute Cost per Performance Unit
    The third step is to divide the total life-cycle cost by the overall performance provided by the pavement. For the Rehabilitation Only plan, this is

$$\frac{\$215,600/mile}{49\ PSI\text{-}Years} = \$4,400\ mile/PSI\text{-}Year$$

    For the Preservation plan, the cost is:

$$\frac{\$212,400/mile}{62\ PSI\text{-}Years} = \$3,430\ mile/PSI\text{-}Year$$

Questions that cannot be answered in this report, but that must be discussed and resolved at the local agency, include the following.

- Are the additional time and expense involved in extra chip seals and other preventive activities worth the increased pavement performance?
- Are the additional user costs (disruptions to traffic, etc.) worth the increased pavement performance?
- How closely can costs and performance be estimated? How much will a change in prices affect the analysis?
- Will delaying preservation activities cause a pavement to deteriorate beyond the point where additional preservation would be useful?

Contracting Methods

This section presents some basic recommendations for ways to let pavement preservation contracts to maximize the cost-effectiveness and quality of the treatments. While there are many ways in which to specify items such as crack sealing, some methods can lead to purchasing higher quantities while filling fewer cracks (paying for crack sealing by mass or volume), and others can lead to filling more cracks but with lower quality construction (paying by the linear foot of crack length).

Bid Items
Crack Seal
- By road station
  Depends on average crack spacing, and assumes that cracks extend the full width of the pavement.

Chip Seal
- By area (square yard or square meter)
  Include aggregate and all operations except emulsion
  Eliminates overruns and encourages proper application rate to cover aggregate

Emulsion for Chip Seal
- By the gallon or by the ton
- Specify application rate

Fog Seal
- By the gallon or by the ton
- Specify application rate

Other specifications

Crack Seal
- Seal every crack
- Don't pay for overruns
- Crack sealing should be simple to inspect

Chip Seal
- Every roadway needs a different application rate.
- Require the chip seal to be designed, including application rate.

Sources of Additional Information

As has been mentioned several times in this report, it is impossible to include information and guidelines for all aspects of pavement preservation in a report of this nature. Additionally, since much work has been done by others in specific areas of pavement preservation, the project team decided to provide sources additional information for the topics discussed in this report. Some of these sources were referenced directly in this report, and others are simply good sources where an interested reader may learn more about a specific topic.

General Pavement Preservation

National Center for Pavement Preservation
www.pavementpreservation.org

What We Don't Know About Pavement Preservation
www.techtransfer.berkeley.edu/icpp/papers/22_2010.pdf

MnDOT Pavement Preservation Research
www.dot.state.mn.us/materials/pavementpreservation.html

FHWA: General Pavement Preservation Information
www.fhwa.dot.gov/pavement/pres.cfm

Preservation Approaches for High-Traffic-Volume Roadways
onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R26-RR-1.pdf

Pavement Management Systems

Implementing Pavement Management Systems
www.dot.state.il.us/blr/P052.pdf

Implementation of Pavement Management in Minnesota
www.lrrb.org/media/reports/2009RIC11.pdf

LRRB Video – Pavement Management: Better Data, Better Decisions, Better Roads at the Right Time
www.lrrb.org/media/reports/Pavement_Management.wmv

Transportation Research Board Committee on Pavement Management Systems
www.pavementmanagement.org

Pavement Management Systems Overview
www.state.nj.us/transportation/eng/pavement/pdf/PMSOverviews0709.pdf

Definition of the "Cradle-to-Grave" Pavement Management Process
www.utexas.edu/research/ctr/pdf_reports/0_4186_P1.pdf

Commercially-Available Pavement Management Systems

Dynatest
www.dynatest.com/consultancy/pavement-management-systems.aspx

NYBIT
www.nybit.com/ppmp-overview.html

StreetSaver
www.mtcpms.org/products/index.html

ICON
www.goodpointe.com/Default.aspx

PavePRO Manager
www.ims-rst.com/pavepro.shtml

VIM Road Pavement Management System
www.vim.be/projects/road-pavement-management-system

MicroPAVER
www2.apwa.net/bookstore/detail.asp?PC=SPR.PAVER

AgileAssets Pavement Analyst
www.agileassets.com/products/pavement-analyst/

Data Collection

MnDOT Distress Identification Manual
www.dot.state.mn.us/materials/manuals/pvmtmgmt/Distress_Manual.pdf

SHRP Distress Identification Manual
www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/03031.pdf

FHWA: Practical Guide for Quality Management of Pavement Condition Data Collection
www.fhwa.dot.gov/pavement/management/qm/data_qm_guide.pdf

Life-Cycle Cost

MnDOT Life Cycle Cost Analysis Method
www.dot.state.mn.us/materials/pvmtdesign/lcca.html

Life-cycle cost analysis system for pavement management at the project level
www.tandfonline.com/doi/pdf/10.1080/10298436.2011.618535

Developing a Robust Pavement Life Cycle Cost Analysis
www.cptechcenter.org/ncc/F2013Presentations/T2%20Mack%20LCCA.pdf

Evaluation of Life Cycle Cost Benefits of Some Pavement Preservation Strategies Using Caltrans PMS Data
www.techtransfer.berkeley.edu/pavementpres09downloads/harvey_thurs_prelim-lcca.pdf

Preservation Activities and Treatments

Minnesota Seal Coat Handbook 2006
www.mrr.dot.state.mn.us/research/pdf/200634.pdf

Chip Seal FAQ
www.dot.state.mn.us/materials/PDF/chip%20seal%20FAQ.docx

Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements
www.lrrb.org/media/reports/200918.pdf

Crack Sealing 101: Hot Mixed Asphalt Pavements
www.mrr.dot.state.mn.us/research/pdf/2010MRRDOC010.pdf

Recommended Practices for Crack Sealing HMA Pavement
www.mrr.dot.state.mn.us/research/pdf/2008MRRDOC021.pdf

Preventive Maintenance Fog Sealing of HMA Cul-de-Sacs
www.mrr.dot.state.mn.us/research/pdf/2008MRRDOC021.pdf

Edge-Joint Sealing as a Preventive Maintenance Practice
www.mrr.dot.state.mn.us/research/pdf/200326.pdf

Micro surfacing: NCHRP Synthesis 411
onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_411.pdf

Perpetual pavement design for flexible pavements in the US
www.tandfonline.com/doi/pdf/10.1080/10298430600619182

Review of Best Practices for the Selection of Rehab and Preventive Maintenance Projects
tti.tamu.edu/documents/0-6586-1.pdf

Timing and Prioritization

A Quick Check of Your Highway Network Health
www.fhwa.dot.gov/pavement/preservation/if07006.pdf

Reformulated Pavement Remaining Service Life Framework
www.fhwa.dot.gov/publications/research/infrastructure/pavements/13038/13038.pdf

Pavement Remaining Service Interval Implementation Guidelines
www.fhwa.dot.gov/publications/research/infrastructure/pavements/13050/13050.pdf

Pavement Rehabilitation Selection
www.lrrb.org/media/reports/200806.pdf

Repair Priorities: Transportation spending strategies to save taxpayer dollars and improve roads
www.smartgrowthamerica.org/documents/repair-priorities-2014.pdf

Optimum time for application of slurry seal to asphalt concrete pavements
paramountasphalt.com/resources/Optimum-Time-for-Application-of-Slurry-Seal.pdf

Optimization of Pavement Preservation Activities
conf.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2004/docs/s7/humphries.pdf

Optimal Timing of Pavement Preventive Maintenance Treatment Applications
onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_523.pdf

Cost Estimating and Contracting

MnDOT Average Bid Prices
www.dot.state.mn.us/bidlet/avgPrice.html

MnDOT Construction Cost Index
www.dot.state.mn.us/bidlet/costIndex.html

MnDOT Abstracts for Awarded Jobs
www.dot.state.mn.us/bidlet/abstract.html

Chapter 5. CONCLUSIONS

This project focused on the real-world application of pavement preservation techniques to extend the life of pavements and on the education of local agency engineers and maintenance supervisors regarding pavement preservation practices. There are many aspects of a pavement preservation program, each of which are often updated and modified to utilize the newest technology and best practices. The objective of this report was to develop a set of guidelines or best practices for local road authorities to inform and educate them regarding pavement preservation, pavement management, construction, and other practices. In addition to this report, there is a set of guidelines in the form of an interactive document to be used for education and future reference.

As part of the guidelines development, engineers at several local road authorities in Minnesota were interviewed with several purposes in mind:

- to collect data from which to develop case studies,
- to identify the expectations the agencies have with respect to the longevity of pavement maintenance and rehabilitation activities as well as to the life extension activities that might contribute to the pavements, and
- to gain an understanding of their use of pavement management systems.

Another part of the guidelines development was the external review conducted by the National Center for Pavement Preservation. The project team desired this review to lend credibility to the content of the guidelines.

Future work that could be done for the pavement preservation guidelines in Minnesota might include the following.

- Periodically update the information regarding available preservation activities and their associated benefits, construction recommendations, and expected longevity and pavement life extension.
- Add discussion of new preservation activities as they become more widely used.
- Augment and update the recommendations for further study in the various categories listed in the report and the interactive guidelines.
- Add case studies and other discussion regarding possible actions that could be taken by local road agencies to include newer issues and examples.

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