PREVENTIVE MAINTENANCE TREATMENTS OF FLEXIBLE PAVEMENTS: *A SYNTHESIS OF HIGHWAY PRACTICE*

FHWA/MT-06-009/8117-26

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

October 2006

prepared by

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PREVENTIVE MAINTENANCE TREATMENTS OF FLEXIBLE PAVEMENTS: A SYNTHESIS OF HIGHWAY PRACTICE

Final Project Report

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State of Montana
Department of Transportation
Research Programs

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U.S. Department of Transportation
Federal Highway Administration

October 2006

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Access No.	3. Recipient's Catalog No.
FHWA/MT-06-009/8117-26		

4. Title and Subtitle Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice	5. Report Date October 2006 6. Performing Organization Code
7. Author(s) Eli Cuelho, Robert Mokwa and Michelle Akin	8. Performing Organization Report Code
9. Performing Organization Name and Address Western Transportation Institute PO Box 174250 Montana State University – Bozeman Bozeman, Montana 59717-4250	10. Work Unit No. (TRAIS) 11. Contract or Grant No. MSU G&C #426380 MDT Project #8117-26
12. Sponsoring Agency Name and Address Research Programs Montana Department of Transportation 2701 Prospect Avenue Helena, Montana 59620-1001	13. Type of Report and Period Covered Final Report May 2005 – August 2006 14. Sponsoring Agency Code 5401

15. Supplementary Notes

Research performed in cooperation with the Montana Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. This report can be found at http://www.mdt.mt.gov/research/docs/research_proj/prevent_maint/final_report.pdf.

16. Abstract

An extensive literature review was conducted to synthesize past and ongoing research related to highway pavement maintenance and preservation techniques. The literature review was augmented with a web-based email survey that was distributed to all 50 U.S. states, Washington D.C. and 11 Canadian provinces, for a total of 62 recipients. The literature review and survey results provide interesting qualitative overviews of the state-of-the-practice of preventative maintenance treatments, and how these treatments are instigated, managed, and accessed by transportation department personnel throughout North America. This report focuses on studies that quantified the performance of various preventive maintenance treatments, including the effect these treatments have on pavement performance. The study indicates that ranges of reported life expectancies for treatment systems vary widely, as does reported unit costs. The lack of conclusive quantitative data is attributed to variations in the many aspects of treatment systems. Additional research is needed to quantify and enhance our understanding of the short and long-term effects that treatment systems have on highway pavement surfaces. State- or region-specific research is critically important to ensure that funds are wisely used for extending the life of a pavement section or for repairing ailing pavement surfaces.

17. Key Words	18. Distribution Statement
Pavements, preventative maintenance, asphalt surface treatments, survey, synthesis	No restrictions. This document is available to the public through NTIS, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the valuable contributions and input provided by Research Programs of the Montana Department of Transportation. A global thanks is extended to all of the anonymous respondents of the email survey. Their time invested to complete and submit the survey is greatly appreciated.

Acknowledgement of financial support and matching dollars for this research is extended to the Montana Department of Transportation, the Western Transportation Institute, and the Montana State University Civil Engineering Department.

EXECUTIVE SUMMARY

An extensive literature review was conducted to synthesize past and ongoing research related to highway pavement maintenance and preservation techniques. The literature review was augmented with a web-based email survey that was distributed to all 50 U.S. states, Washington D.C. and 11 Canadian provinces, for a total of 62 recipients. The literature review and survey results provide interesting qualitative overviews of the state-of-the-practice of preventative maintenance treatments, and how these treatments are instigated, managed, and accessed by transportation department personnel throughout North America.

This report focuses on studies that quantified the performance of various preventive maintenance treatments, including the effect these treatments have on pavement performance. Preventive measures examined in this study included: crack sealing, thin overlays, chip sealing, microsurfacing, cold in-place recycling, ultrathin friction courses, fog seals, slurry seals, cape seals, and scrub seals. To the extent possible, the synthesis identified the adequacy of existing data and methodologies in terms of: 1) establishing appropriate preventive maintenance treatments, 2) evaluating the effectiveness of these treatments, and 3) examining the reported life-cycle cost of various alternatives.

The survey was successful in obtaining a significant percentage of respondents; in all, there were 47 individual responses to the survey from 34 U.S. states and 5 Canadian provinces. From a programmatic viewpoint, over 90% of North American states/provinces have a preventative maintenance program for pavements. Over half of these programs (~67%) are funded through a dedicated budget item, which reportedly varies over a large range from $2 million to $150 million. The average annual budget for preventative maintenance was about $40 million. About 70% of the jurisdictions have a written manual or decision tree that provides guidelines for preventative maintenance activities. However, there is no standardized ‘one size fits all’ approach for selecting an appropriate preventative maintenance measure for a given roadway. Once the decision is made to implement a treatment, it appears that most respondents base their selection of a particular system on their previous experience. Information from the literature review supports the survey results, in that there are few, if any, well-documented and reliable quantitative approaches for selecting the optimum treatment system and for determining when the optimum time occurs for implementing a system. Consequently, this lack of quantifiable metric necessitates a heavy reliance on the experience of personnel and rules of thumb.

The ranges of reported life expectancies for treatment systems vary widely, as does reported unit costs. This lack of conclusive data is attributed to variations in the many aspects of treatment systems, including: construction practices; emulsion types and concentrations; mix designs; climatic conditions; traffic volumes; aggregate type, texture and gradation; and the condition of the receptor pavement. There is clearly a need for additional research to quantify and enhance our understanding of the short and long-term effects that treatment systems have on highway pavement surfaces. State- or region-specific research is critically important to ensure that funds are wisely used for extending the life of a pavement section or for repairing ailing pavement surfaces. An applied research program is recommended that includes the use of full scale highway test sections. It is suggested the research program be structured to address the most critical aspects of treatment applications, with a specific focus on Montana's rural, northern, and mountainous conditions.

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1 INTRODUCTION

1.1 Background

Preserving and maintaining Montana's transportation infrastructure is a necessary, but expensive endeavor. Millions of dollars are spent each year to maintain nearly 24,000 lane-miles of pavement throughout the state of Montana. Not only does this represent a significant percentage of the transportation department's budget, but the performance of pavement maintenance and preservation measures are readily observed and evaluated by the driving public. Consequently, knowledge of the effectiveness of current maintenance techniques is of critical interest to engineers and managers of Montana's highways.

To ensure that preventive maintenance and rehabilitation of flexible pavements is cost effective, periodic evaluations of various preservation treatments are necessary. Previous work has been performed to establish the life-cycle cost of specific preventive maintenance treatments on flexible pavements. However, much of this work does not directly apply to Montana's climate, soil types, traffic levels, or construction and design techniques. Therefore, research specifically oriented to the peculiarities of the Montana highway system may be necessary to better quantify maintenance preservation benefits in terms of increased pavement life, serviceability, and reduced overall costs. This report represents the first step in the research process in which available information related to the performance of specific preventive maintenance techniques has been studied and categorized. A concise informative synopsis of the current state-of-the-practice is presented in this report based on a detailed review of published technical literature and a web-based email survey of applicable transportation department personnel throughout the United States and Canada.

1.2 Objectives and Scope

The primary objectives of this study were to identify and report on existing and emerging treatment systems and technologies that could be used to enhance or even replace current approaches used by the Montana Department of Transportation. This report focuses on studies that quantified the performance of various preventive maintenance treatments, including the effect these treatments have on pavement performance. Preventive measures examined in this study include: crack sealing, thin overlays, chip sealing, microsurfacing, cold in-place recycling, ultrathin friction courses, fog seals, slurry seals, cape seals, and scrub seals. To the extent possible, this synthesis identifies the adequacy of existing data and methodologies in terms of: 1) establishing appropriate preventive maintenance treatments, 2) evaluating the effectiveness of these treatments, and 3) examining the reported life-cycle cost of various alternatives.

The review conducted as part of this study consisted of two parts: 1) a detailed literature review and 2) a web-based email survey of applicable transportation department personnel throughout the United States and Canada. The literature review involved an extensive review and synthesis of past and ongoing research and published data related to highway pavement maintenance and preservation techniques. A survey of applicable personnel from U. S. and Canadian transportation departments was conducted to gather additional data to supplement the literature review. The web-based survey was distributed using an email listserv maintained by the AASHTO RAC (the American Association of State Highway and Transportation Officials Research Advisory Committee).

The primary objectives of the survey were to solicit information from U. S. states and Canadian provinces to determine: 1) the types of pavement preventive maintenance systems they currently use, 2) their use of materials and techniques, and 3) how preventive maintenance systems are evaluated in their respective programs. The survey was categorized to obtain information from the following three areas:

- details about the respondents' job as it relates to preventive maintenance of pavements,
- information related to the preventive maintenance program within the respondents' state/province, and
- information related to specific preventive maintenance treatments or techniques.

In general, results from specific questions in the survey were qualitative and provided information that was useful for making general conclusions regarding preventive maintenance practices within individual states and provinces.

The survey was designed to target individuals within state or provincial departments of transportation that had intimate knowledge about preventive maintenance practices and procedures within their state. The listserv maintained by AASHTO RAC was well suited in this regard. Managers of research programs within each state were asked to forward the survey to areas within their agency involved with preventive maintenance/pavement preservation. Altogether there were 47 individual responses to the survey from 34 states and 5 provinces. This translated into a response rate of 62.9 percent by state/province.

2 LITERATURE REVIEW

2.1 Introduction

The following preventive maintenance techniques are presented in this section, based on the results of the literature review: crack seals, thin overlays, chip seals, microsurfacing, cold in-place recycling, ultrathin friction course, fog seals, slurry seals, cape seals, and scrub seals. A description of each treatment is provided, including its advantages and disadvantages. Approximate unit cost estimates for the treatments are provided based on published studies conducted for a variety of states in the U. S. The year for which the dollar value is based is also shown to account for the time value of money. The performance of the treatment is also described, both in tables listing treatment life estimates and in results of studies applying the treatment.

Evaluating the longevity or performance of a treatment depends on the parameters used to measure effectiveness. There are several performance measures available for pavement preservation techniques. Consequently, any conclusions about a particular treatment's performance depend on the methods of measuring and evaluating potential or actual failure modes such as rutting, cracking, or some other distress. The most common performance measure reported in the literature is the life of the treatment, although this information is limited since the performance of a particular treatment may not be a good indicator of how the overall pavement system is performing. It is postulated that the most important and useful metric for planning and for pavement management systems is the extension of pavement life provided by the treatment. This measure is useful because it not only takes into account the treatment life but it also inherently includes the effects of the pavement condition prior to applying the treatment.

2.1.1 Crack Sealing

2.1.1.1 Description

Crack sealing is a widely used and relatively low-cost preventive maintenance treatment. Generally, crack sealing is performed to keep water from penetrating into the pavement structure and compromising the base layers of the pavement. Proper placement is important to ensure that the sealant maintains its integrity as long as possible. Several materials and techniques are available to do this work. According to Ohio DOT (2001), crack sealing, in contrast to most other preventive maintenance techniques, should be performed in cooler weather when crack widths have expanded. Some advantages and disadvantages of crack sealing are summarized in Table 1.

Table 1: Advantages and Disadvantages of Crack Sealing

Advantages	Disadvantages
• Relatively low cost when compared to other preventive maintenance treatments	• Relatively short life span
• Effective means to prevent water infiltration into the pavement structure	• May cause bleeding through overlay
• Technology is well understood and widely used	• Cost-effectiveness not well established

2.1.1.2 Performance

Clear, quantitative assessments of whether crack sealing indeed slows the deterioration of the pavement structure are rare and limited. In a literature review conducted by Hand et al. (2000), 100 potential references regarding crack sealing were collected and reviewed. Only 18 of these references were found to specifically address cost-effectiveness of joint and/or crack sealing relative to pavement performance, and only four of the 18 contained valuable quantitative data. Furthermore, many of these studies, similar to this one, have focused on the performance of material/technique combinations rather than cost-effectiveness. In addition to the literature review, Hand and his colleagues interviewed recognized experts in this area to investigate the quality and usefulness of current research. Overall, from their interviews and literature review they concluded that "all of these efforts revealed little quantitative evidence to prove the cost-effectiveness of joint/crack sealing" (Hand et al., 2000).

The extension of pavement life provided by crack filling and sealing is less documented. A paper survey by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies to determine, among other things, the average life extension provided by crack treatment. The respondents reported a minimum increase in pavement life of less than 2 years, a maximum increase of 9 to 10 years, and the most repeated selection by the 45 respondents was 2 to 4 years, for crack filling on flexible pavements. Note, however, that all of these reported ranges for the extension in pavement life appear to be based on perception instead of well-designed, quantitative experimental analyses. Average treatment life as reported by various sources is summarized in Table 2, the average of which is approximately 4 years. A review of treatments under Michigan's preventive maintenance program determined the extension in pavement life of their crack sealing procedure varied from 0 to 4 years. The analysis of treatments was based on the state's distress index (B.T. Bellner & Associates, 2001). Colorado also expects the upper limit of pavement life extension to be 4 years. However, this is limited to low truck traffic of 400 trucks per year; the life extension is significantly reduced to 2 years for truck traffic in excess of 6,000 trucks per year.

Table 2: Crack Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Geoffroy, 1996	2.2	Crack seal in Indiana
Geoffroy, 1996	2 to 5	Route and seal in Ontario
Geoffroy, 1996	2	Crack fill in New York
Geoffroy, 1996	2 to 5	Route and seal in New York
Johnson, 2000	7 to 10	Average reported value in Minnesota, performed on new pavement

Cost of crack sealing is relatively low when compared to other preventive maintenance techniques. The average cost per lane mile is approximately $5,300. This figure obviously depends upon the density of cracks on a particular roadway, as well as local contracting and construction costs, and materials and techniques used. Published costs for crack sealing are summarized in Table 3.

Table 3: Crack Seal Costs per Lane Mile

Cost per lane mile, (12-ft width), $	Location	Year Data Taken	Reference
1,000 – 4,000	None specified	1999	Ohio DOT, 2001
2,900 – 11,750	MI	1998	B.T. Bellner & Associates, 2001
6,900 (typical)	MI	1998	B.T. Bellner & Associates, 2001

2.2.1.4 Individual Research Studies

Chong & Phang, 1987

The Ontario Ministry of Transportation (MTO) conducted several crack sealing experiments to determine the most cost-effective method of managing cracks in flexible pavements. The original practice consisted of spraying asphalt emulsion and scattering aggregate on cracks. Then the ¾ in by ¾ in route and seal method was employed in the 1970s, but the technique and materials were developed for concrete pavements. Experiments in the 1980s led to the recommendation of a 1.5 in by 0.4 in route design with the sealant material slightly overfilled to compensate for contraction that takes place while cooling (Chong & Phang, 1987).

Joseph, 1992

While the experiments in the 1980s resulted in MTO endorsement of various materials and route configuration, they also considered whether crack sealing was more cost-effective than not treating cracks (Joseph, 1992). In 1992, 31 test sites constructed in 1986 were evaluated based on roughness, pavement condition index, and distress manifestation index. The crack sealing was performed on pavements of varying ages: less than 3 years, 4 to 6 years, and 7 to 9 years (Joseph, 1992). The evaluation of performance curves led to the conclusion that crack sealing extended pavement life by 2 to 5 years. Furthermore, the data indicated that increased costs were associated with not sealing cracks.

Cuelho & Freeman, 2004

Cuelho and Freeman (2004) conducted a thorough study of crack sealing methods and materials to determine the most cost-effective means of sealing cracks on Montana highways. The test sites included various combinations of eleven sealant materials and six sealing techniques. Monitoring of the test sites included visual inspections, nondestructive structural readings (using the Falling Weight Deflectometer – FWD) and roughness. An estimate of the useful life of various combinations was determined. Results showed that the shallow and flush method of sealing cracks was most effective when used with sufficiently elastic materials. FWD and roughness testing did not show differences between sealed sections and a control section. Life expectancies ranged between 6 months, for the worst performing material/technique combinations, to an estimated 175 months for the best, although an estimated life greater than seven to ten years is unlikely.

2.1.2 Thin HMA Overlay

2.1.2.1 Description

The application of hot-mix asphalt (HMA) as an overlay to an existing pavement is often considered a preventive maintenance treatment when the overlay is between 0.75 to 1.50 inches thick (Peshkin et al., 2004). The HMA typically consists of plant-mix asphalt cement and aggregate. The three general categories of thin overlay mixes, distinguishable by their aggregate gradations, are dense-graded, open-graded and gap-graded aggregate mixes. In a dense-graded aggregate, the gradation uniformly represents the full range of sieve sizes. In an open-graded mixture, the gradation mostly consists of particles of one size, is generally porous to water which can reduce hydroplaning, but can be slicker during freezing wet weather, thus requiring more deicing chemicals (Jahren et al., 2003a). In a gap-graded aggregate, the gradation contains coarse and fine particles, but lacks medium-sized particles. Gap-graded aggregate is used in stone matrix (or mastic) asphalt (SMA) mixes along with a stabilizer. SMA was developed in Germany to resist wear by studded tires and is generally considered more durable than the others mixes (Gatchalian et al., 2006).

A thin overlay can be placed with or without milling the existing pavement. It is recommended to mill the surface when segregation, raveling, or block cracking are present (Hein & Croteau, 2004). Milling also provides additional asphalt for recycling operations (more asphalt is recycled in the United States than any other material (Smith, 2003)), maintains clearance near overhead structures, and provides high skid resistance for traffic before the overlay placement. If rutting is evident, the pavement can also receive a leveling course instead of milling. The advantages and disadvantages of thin HMA overlays are summarized in Table 4.

Table 4: Advantages and Disadvantages of Thin HMA Overlays

Advantages	Disadvantages
• Works well in all climate conditions (Johnson, 2000)	• Subject to delamination, reflective cracking, and maintenance problems (Johnson, 2000)
• Provides minor amount of structural enhancement (Ohio DOT, 2001)	• Curb and bridge clearance may be an issue without milling (Johnson, 2000)
• At least marginally effective for almost all pavement conditions (Hicks et al., 2000)	

2.1.2.2 Performance

The treatment life of a thin HMA overlay is relatively long in many cases (Table 5). The average of the service life values in Table 5 is over eight years. These life estimates are probably more accurate than estimates for other treatments since thin overlays have been widely used. Pavement life extension, however, has been studied less; yet some estimates are available. A survey by Labi & Sinha (2003) sent to highway agency districts and sub-districts in Indiana returned very high estimates of pavement life extension. The Vincennes District in Indiana perceives an extension of pavement life of 10 to 15 years and the Petersburg Sub-District perceives 10 years, based on a frequency of application approximately every 10 years. A paper survey by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies. The reported minimum increase in pavement life was approximately 2 years, the maximum increase at 9 to 10 years, and the most repeated selection by the 29 respondents was 7 to 8 years. Note, however, that all of the reported ranges for the extension in pavement life appear to be based on qualitative perceptions rather than well-designed, quantitative experimental analyses.

Table 5: Thin HMA Overlay Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Geoffroy, 1996	> 6	according to NCHRP
Geoffroy, 1996	8	according to New York State DOT
Geoffroy, 1996	8 to 11	according to FHWA
Hicks et al., 2000	7 to 10	average life in Ohio
Hicks et al., 2000	2, 7, 12	min, average, max (respectively)
Johnson, 2000	5 to 8	average reported value in Minnesota
Ohio DOT, 2001	8 to 12	expected life in Ohio
Peshkin et al., 2004	7 to 10	when placed for preventive maintenance
Wade et al., 2001	10 to 12	interstates with OGFC in Florida

2.1.2.3 Cost

Costs for thin HMA overlays often depend on thickness, aggregate properties and whether the surface was milled. Cost estimates are available, (Table 6) and the average cost of treatment is about $14,600 per lane mile, based on the value of the US dollar at least six years ago.

Table 6: Thin HMA Overlay Costs per Lane Mile

Cost per Lane Mile 12-ft width, ($)	Location	Year Data Taken	Reference
12,300	None specified	2000	Hicks et al., 2000
15,000 – 17,000	OH (1 to 1.5 in. thick)	1997	Hicks et al., 2000
17,600 – 25,000	OH	1999	Ohio DOT, 2001
12,300 – 14,100	None specified (dense-graded)	2001	Peshkin et al., 2004
11,900	None specified (dense-graded, 1 in. thick)	2000	Wade et al., 2001
8,800 – 10,000	None specified (open-graded, 1 in. thick)	2000	Wade et al., 2001
14,200 – 16,600	None specified (speculated for SMA, 1 in. thick)	2000	Wade et al., 2001

2.1.2.4 Individual Research Studies

Jahren et al., 2003a

Jahren et al. (2003a) of Iowa State University conducted a study on thin maintenance surfaces for the Iowa Department of Transportation. Field test sections were constructed for the study to examine thin overlays, single and double chip seals, fog seals, cape seals, slurry seals, microsurfacing, and untreated sections. Results from each of the test sections were difficult to compare since they were constructed at different times, at different locations and on different highways. Consequently, the performance of each test section was described separately and only limited comparisons were made.

In September and October of 1997, two 1500-ft test sections on US 151 and US 30 were constructed to examine, among other things, thin overlays. The thin overlays were 1.5 inches thick and used ½-inch aggregate. Since these test sections were constructed late in the season, many of the treatments did not receive adequate curing. Other problems occurred with the test sections as a result of an inexperienced construction crew.

Another set of test sections was constructed in August of 1998 on US 69 applying the lessons learned from the previous year. Improved construction quality and curing conditions resulted in more favorable results. The two thin overlays constructed in 1998 were new to Iowa; one used a hot sand mix in the northbound lane and the other using NovaChip™ in the southbound lane. The sand mix consisted of 80% quartzite manufactured sand and 20% local mason sand. A polymer-modified binder that reportedly provided good performance in both high and low temperatures was also used. The NovaChip™ consisted of a gap-graded local limestone aggregate with a maximum size of ½ inch applied on a heavy emulsion tack coat.

Data for surface condition index, skid resistance, and roughness index were measured before and after construction. The surface condition index (SCI) ranges from 100 to 0, where 100 represents an excellent pavement condition and 0 represents complete pavement failure. The procedure used to measure SCI was reportedly consistent with the US Army Corps of Engineers PAVER System. The skid resistance (SR) measurements were performed according to ASTM standards E501 and E524 to determine the friction number. The roughness index (RI) measurements in this study followed ASTM standards E950 and E1170. The data collected roughness with wavelengths up to 300 feet, while the International Roughness Index (IRI) is sensitive to wavelengths between 4.2 and 75 feet. Thus the RI information presented is not directly comparable to the IRI, but was used to make relative comparisons between test sections.

The authors concluded that considering all the treatments they tested on the various highways, the thin overlay was the top performer with respect to SCI and RI values. While the SR values did improve with the thin overlay, some of the other treatments realized even greater improvements. The authors also determined that rutting, raveling, and longitudinal and transverse cracking distresses were improved three years after the thin overlay treatments. A cost analysis was not performed as part of this research.

2.1.3 Chip Sealing

2.1.3.1 Description

A chip seal (also referred to as a seal coat) is an application of asphalt followed by a layer of aggregate (typically one stone thick), which is then rolled into the asphalt (Gransberg & James, 2005). A chip seal protects pavement from ultraviolet rays from sun and moisture infiltration. Double chip seals are also common, in which a second chip seal is placed immediately over the first. In this application, the first chip seal uses more asphalt and larger aggregate than the second overlying chip seal. A double chip seal provides a quieter and smoother riding surface and is better suited for pavements in poor condition, in which cases a single seal coat may not be appropriate (Johnson, 2000). Johnson (2000) reported that a chip seal can be applied at any time in a pavement's life. Gransberg & James (2005) noted that the ideal benefits of chip sealing are realized in the context of a preventive maintenance program in which the treatment is applied early in a pavement's life.

Chip seals can address roads showing oxidization, raveling, bleeding, minor cracking, and reduced friction, but does not address rutting (Johnson, 2000; Maher et al., 2005; Jahren et al., 2003b; and Peshkin et al., 2004). Ohio limits chip sealing to low volume roads (less than 2,500 ADT) with rutting less than ⅛ inch. As a general practice, they repair all cracks and patches to full depth within 6 months of chip sealing (Ohio DOT, 2001). However, Gransberg & James (2005) refer to a study that determined crack sealing and patching should be completed at least 6 months before chip sealing.

Variations to standard chip seals include the use of choke stones, fog seals, and slurry seals. A choke stone is smaller aggregate applied without asphalt after the primary aggregate has been spread and rolled. Ideally, the choke stone becomes locked in the voids from traffic action, preventing the larger aggregate from dislodging. A fog seal and slurry seal can also be applied to chip seals to fill in the voids and limit aggregate loss. The specific combination of a new chip seal and a slurry seal is called a cape seal and has the added benefit of reducing tire noise (Gransberg & James, 2005). The advantages and disadvantages of chip seals are summarized in Table 7, as reported from several sources.

Table 7: Advantages and Disadvantages of Chip Sealing

Advantages	Disadvantages
• Technology is well understood and widely used (Gransberg et al., 2005)	• Loose chips can cause damage to vehicles, especially windshields (Maher et al., 2005)
• Relatively low cost for a durable treatment (Maher et al., 2005)	• Associated with increased road noise (Gransberg & James, 2005)
• Treatment performs well in many climates (Peshkin et al., 2004)	• Cause of failure for projects not always understood (Gransberg & James, 2005)
• More effective at sealing medium-severity fatigue cracking than other treatments (Peshkin et al., 2004)	• Success requires proper application rates of binder and aggregate (Wade et al., 2001)
	• Requires reduced speeds after construction (Romero & Anderson, 2005)
	• Susceptible to snowplow damage (Jahren et al., 2003b)

2.1.3.2 Performance

Based on the literature review conducted for this study, it appears the anticipated treatment life of a chip seal can vary considerably. Based on a survey distributed by Gransberg & James (2005), it appears that the performance overseas exceeds that of the United States; however, it is not known if the data provided in the survey was qualitative or quantitative in nature. Australia and the United Kingdom reported using chip seals on about 273,000 and 213,000 lane miles, respectively – well above the 140,000 lane miles reported by the United States. The United Kingdom commonly chip seals roads that have an ADT greater than 20,000 whereas only a few states (California, Colorado, and Montana) chip seal such roads. Treatment life estimates from various references for single and double chip seal applications are provided in Table 8 and Table 9, respectively.

The study by Gransberg & James (2005) indicates that skid resistance and texture depth measurements are the primary indicators used to determine a chip seal's performance. These indicators are particularly suitable for the most common distresses affecting chip seals: bleeding and raveling. Quantitative measures of skid resistance and texture depth are commonly measured according to ASTM E274 and ASTM E965, respectively. A study by the Pennsylvania Transportation Institute determined that measuring mean texture depth by the sand patch method (ASTM E965) is the best indication of chip seal performance (Wade et al., 2001). It appears that visual distress surveys are the most common method used to measure the performance of chip seals (Gransberg & James, 2005). These periodic evaluations are typically used to decide when to apply new chip seals and not specifically to track their performance.

Gransberg & James (2005) recommend that state agencies adopt more objective, quantifiable performance measures for chip seals.

Table 8: Single Chip Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	3 to 6	for ADT 100 to 500
Bolander, 2005	4 to 12	for ADT < 100
Geoffroy, 1996	4	median life in Oregon
Geoffroy, 1996	4	average life in Indiana
Geoffroy, 1996	4 to 7	according to FHWA
Geoffroy, 1996	1 to 6	according to NCHRP
Gransberg & James, 2005	5.76	US average based on a survey
Gransberg & James, 2005	5.33	Canada average based on a survey
Gransberg & James, 2005	10	Australia average based on a survey
Gransberg & James, 2005	7	New Zealand average based on a survey
Gransberg & James, 2005	12	South Africa average based on a survey
Gransberg & James, 2005	10	United Kingdom average based on a survey
Hicks et al., 2000	3 to 5	average life in Ohio
Johnson, 2000	3 to 6	expected service life

Table 9: Double Chip Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	5 to 15	for ADT < 100
Bolander, 2005	5 to 7	for ADT 100 to 500
Hicks et al., 2000	4 to 8	average life in Ohio
Johnson, 2000	7 to 10	depending on type and amount of traffic
Maher et al., 2005	4 to 8	average life expectancy

The extension of pavement life provided by a chip seal is less documented. A paper survey by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies to determine, among other things, the average life extension provided by chip sealing. The respondents reported a minimum increase in pavement life of 2 to 4 years, a maximum increase of 7 to 8 years, and the most repeated selection by the 36 respondents was 5 to 6 years, for single chip seal applications. The maximum increase in pavement life was higher for double chip seals with 14 respondents selecting the 9 to 10 year range. Note, however, that all of the reported ranges for the extension in pavement life appear to be based on perception instead of well-designed, quantitative experimental analyses.

In a separate study, New York State Department of Transportation claims a life extension of 3 to 4 years on chip sealed sections (Labi & Sinha, 2004). Labi & Sinha (2004) report a pavement life extension of 10 to 12 years in Manitoba, due in part to the dry weather. However, the basis for these estimates was not found and may also be based on perception.

2.1.3.3 Cost

A selection of costs for chip sealing is provided in Table 10 and Table 11. Based on a circa 2000 dollar worth, single chip seals were installed for about $7,800 per lane mile and double chip seals were about $12,600 per lane mile. The tables specifically describe the year at which projects were constructed (or bid) in order to account for the time value of money.

Table 10: Single Chip Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
8,400 – 10,600	None specified	1999	Bolander, 2005
5,500 – 7,500	OH	1997	Hicks et al., 2000
3,900	None specified	1999	Johnson, 2000
5,600 – 8,800	None specified	2004	Maher et al., 2005
7,000 – 12,300	OH	1999	Ohio DOT, 2001
8,000	SD	2000	Wade et al., 2001

Table 11: Double Chip Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
13,000 – 17,600	None specified	1999	Bolander, 2005
8,500 – 12,000	OH	1997	Hicks et al., 2000
10,600	None specified	1999	Johnson, 2000
8,800 – 17,600	None specified	2004	Maher et al., 2005

2.1.3.4 Individual Research Studies

Outcalt, 2001

Three chip seal test sections were constructed in Colorado on State Highway 94 in August 1997 to evaluate the use of lightweight and standard aggregate as well as fog sealing. The applications were compared to a control section that received no treatment. All cracks within the driving and passing lanes (not in the shoulders) were sealed prior to chip sealing activities. The transverse and longitudinal cracks measured between ⅛ and ¼ inches wide; the majority of cracks being transverse. The cracks were sealed with a rubberized sealant placed 2 to 3 inches wide on the pavement surface. Lightweight chips (~60% of the standard chip weight) of expanded shale were also included in this study. The asphalt binder HFRS-2P was used on all the chip seals. Approximately one week after chip sealing, the same binder was diluted by 50% with water before applying it as a fog seal over one of the chip sealed sections.

Outcalt (2001) concluded that chip seals do "extend the life of the pavement by postponing environmentally induced cracking" and that lightweight chips offer the advantages of lower transportation costs and reduced windshield damage compared to the standard chips. This study did not show any measurable benefit of a fog seal application on a newly constructed chip seal. In general, the chip seal sections were in better condition than the control section one to four years after construction.

Jahren et al., 2003a

Iowa State University conducted a study on thin maintenance surfaces for the Iowa Department of Transportation. Test sites were constructed to examine, among other things, single and double chip seals. Overall construction details for this research effort were previously described in Section 2.1.2.4 of this report. A summary of the construction of the chip seal test sections studied in this program is provided in Table 12.

Data for surface condition index, skid resistance, and roughness index were measured before and after construction. Further detail on these measurements can be found in Section 2.1.2.4 of this report. On US 30, only one of the chip seal sections performed better than the control sections, two and a half years after construction. The better performing chip seal happens to have been the only section that also received a fog seal. The chip seal and chip seal with slurry seal (i.e., a cape seal) performed worse than control section #2, and the standard chip seal scarcely outperformed control section #1. The double chip seal experienced severe bleeding within a year after construction and had to be covered with a slurry seal; thus, excluding it from the remaining analyses. The late season construction was blamed for the poor performance of many of the surface treatments on US 30. In sharp contrast, all the chip seals on US 69 performed better than the control section. The single chip seal with HFRS-2P binder was performing the best two years after construction, but there was no statistical analysis conducted to quantify the significance.

Table 12: Iowa State University Test Section Descriptions (Jahren et al., 2003a)

Test Section	Year Constructed	Highway	Aggregate Size(s)	Binder(s)	Treatments
Control 1	1997	US30	---	---	---
Control 2	1997	US30	---	---	---
Single	1997	US30	½-inch	CRS-2P	none
Single	1997	US30	½-inch	CRS	Slurry seal
Single	1997	US30	½-inch	CRS	Fog seal
Double	1997	US30	½-inch bottom, ⅜-inch top	CRS-2P	none
Control	1998	US69	---	---	---
Single	1998	US69	¼-inch	CRS-2P	none
Single	1998	US69	¼-inch	HRFS-2P	none
Double	1998	US69	½-inch bottom, ¼-inch top	HRFS-2P bottom, HRFS-2P top	none
Double	1998	US69	½-inch bottom, ¼-inch top	HRFS-2P bottom, CRS-2P top	none

The skid resistances of the chip seals on US 30 were all less than the control sections two and a half years after construction. Two years after construction on US 69, all the chip seals had higher skid resistance than the control section. The roughness of the control and chip seals was higher after construction on US 30. However, on US 69 the chip seal sections that utilized CRS-2P binder had decreased roughness after construction. Overall, chip seals performed better than the other treatments when used on pavements having greater occurrence of cracking.

Wade et al., 2001

A variety of chip seal sections using different designs and materials were constructed in South Dakota on State Route 50 specifically to investigate the performance of chip seals on high volume, high speed roads. State Route 50 is multilane with 2,125 ADT and 17% truck traffic. Chip seals and hot mix asphalt (HMA) overlays were the only surface treatments commonly applied to flexible pavements in South Dakota before 2001. This study was instigated to examine various aspects of chip sealing, including an evaluation of aggregate type and gradation used for the chips. Various alternatives were considered: quartzite chips, natural aggregate, precoated aggregate, polymer-modified emulsions, and the use of fog seals and choke stones. Altogether, 12 test sections were constructed (as detailed in Table 13); 2 of which employed South Dakota's standard design and were considered control sections. However, untreated control sections were not studied, restricting comparisons solely to the relative performance of different chip seal designs. The 12 test sections ranged from 4,000 to 6,000 feet in length.

Cracking, bleeding, raveling, rutting, and chip retention were examined along a 1000-foot portion within each test section immediately after construction and at three months.

Table 13: South Dakota Test Section Descriptions (Wade et al., 2001)

Test Section	Application	Variation	Aggregate Type
1	New Design	New aggregate gradation Polymer-Modified Emulsion	Quartzite
2	New Design	New aggregate gradation	Quartzite
3	New Design	New aggregate gradation With Fog Seal	Quartzite
4	New Design	New aggregate gradation With Choke Stone	Quartzite
5	New Design	New aggregate gradation Pre-coated Aggregate	Quartzite
6	Standard Design	None	Quartzite
7	Standard Design	None	Natural
8	New Design	New aggregate gradation	Natural
9	New Design	New aggregate gradation With Fog Seal	Natural
10	New Design	New aggregate gradation With Choke Stone	Natural
11	New Design	New aggregate gradation Precoated Aggregate	Natural
12	New Design	New aggregate gradation Polymer-Modified Emulsion	Natural

In general, the newer chip seal designs performed better than the standard chip seal historically used by South Dakota. Based on measured performance data, the authors specifically recommended widespread use of the new aggregate gradation that was evaluated in the test sections. The authors also recommended the use of polymer-modified emulsions and discouraged the use of choke stones, based on these experiments. The only recommendation regarding the use of fog seals on newly constructed chip seals was that more tests were needed before advocating statewide adoption of the practice.

2.1.3.5 Summary

Chip seals are a common pavement maintenance treatment in which asphalt emulsion and aggregate are successively applied to an existing road and rolled/compacted in place. The treatment purportedly addresses cracking, bleeding, raveling, oxidation, and reduced friction. The treatment life can be expected to last about 5 years for a single application and over 7 years for a double application. Installation costs were about $7,800 and $12,600 per lane mile (year 2000 dollars), for single and double chip seals, respectively. Standard industry literature on chip sealing promote potential advantages of using choke stones, fog seals, and slurry seals, but experimental studies present mixed results regarding any potential benefits of these variations to the standard chip seal.

2.1.4 Microsurfacing

2.1.4.1 Description

Microsurfacing is a mixture of polymer-modified asphalt emulsion, mineral aggregate, mineral filler, water, and other additives, properly proportioned, mixed, and spread on a paved surface (FPP, 2001). The dense-graded, fine aggregate in the mixture allows a thin application (as thin as ⅜ inch) that is generally not compacted (Smith & Beatty, 1999 and Labi et al., 2006). While chip seals and slurry seals have a thermal curing process, this process is chemically controlled for microsurfacing (Johnson, 2000). Microsurfacing is primarily used as a surface seal to address rutting and loss of friction; however, this treatment also limits damage from water, oxidation, and ultraviolet rays (UV). UV rays and oxidation cause weathering, raveling, and surface cracking. UV damage can propagate through a pavement surface by first damaging a thin layer at the surface, which is subsequently removed by traffic, revealing another layer susceptible to UV damage. Increased surface permeability is another side effect of UV damage in which water percolates through the surface causing additional damage and ultimately results in reduced stiffness of the pavement layers (Bolander, 2005; Smith & Beatty, 1999; and Wade et al., 2001). Development of microsurfacing is credited to the Germans in the early 1970's and has been used in the United States since the early 1980's (Kazmierowski et al., 1993). The advantages and disadvantages of microsurfacing treatments are listed in Table 14.

Table 14: Advantages and Disadvantages of Microsurfacing

Advantages	Disadvantages
• Can open road to traffic within one hour, weather permitting (ISSA, 2005)	• Requires specialty equipment (expensive) (Wade et al., 2001)
• Can be used on high and low volume traffic (Jahren et al., 2003b)	• Ingredients must be carefully selected to work together (Johnson, 2000)
• Least susceptible to snowplow damage (Jahren et al., 2003b)	• Rapid blade wear on snow plows (Jahren et al., 2003a)
• No loss of rocks (no windshield damage) (Smith & Beatty, 1999)	• Success is dependent on experienced contractor and proper mix of ingredients (Kazmierowski et al., 1993)
• Better than conventional seal coat for turning and stopping traffic action (Smith & Beatty, 1999)	• Stiff material – not effective as a crack sealer (Johnson, 2000)

Microsurfacing aggregate should be 100 percent crushed material and of high quality (e.g., granite, slag, or limestone). There are two common gradations for microsurfacing aggregate: Type II is used for general resurfacing and sealing, and Type III is used for high-volume roadway resurfacing, rut filling, and high friction results.

2.1.4.2 Performance

Estimates for the treatment life of microsurfacing vary (Table 15). While Wade et al. (2001) give a general reported life of 4 to 7 years; they provide examples of cases that vary from this typical range within their report. They describe instances of performance evaluations in which microsurfacing was used to correct rutting and loss of friction (data summarized in Table 16).

Table 15: Microsurfacing Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Geoffroy, 1996	4 to 6	according to NCHRP
Geoffroy, 1996	5 to 7	according to FHWA
Johnson, 2000	7	for high volume roads
Johnson, 2000	>7	for low volume roads
Labi et al., 2006	5	based on roughness
Labi et al., 2006	7	based on pavement condition rating
Labi et al., 2006	24	based on rutting
Peshkin et al., 2004	4 to 7	from review of literature
Smith & Beatty, 1999	7 to 10	suggested expected life
Wade et al., 2001	4 to 7	generally reported range

Table 16: Effects of Microsurfacing in Various States (Wade et al., 2001)

State	Problem	Result
Kansas	0.6 inch ruts	Ruts returned in 5 yrs
Arkansas	Rutting	Ruts returned in 4 yrs
Pennsylvania	Rutting <0.8 inch	Returned to 0.1 inches in 3 yrs
Pennsylvania	Rutting 0.8-1.0 inches	Returned 0.24-0.51 inches in 3 yrs
Pennsylvania	Rutting 0.8-1.0 inches	Returned 0.63 inches in 5 yrs
Pennsylvania	Friction	40-50 in 5½ yrs

The extension of pavement life from microsurfacing is difficult to quantify. Consequently, the literature examined herein contains limited insight regarding this information. The Vincennes district in Indiana perceives an extension of pavement life of at least 3 years, according to a survey submitted by Labi & Sinha (2003). The frequency of application was not indicated although the average pavement age was 15 years before the microsurfacing treatment was applied. The same pavement age and life extension was reported for both full-depth AC and AC-over-PCC pavements. The Michigan Department of Transportation assumes a life extension for single-course microsurfacing of 3 to 5 years and for multiple-course applications they extend their estimated life extension to 4 to 6 years (Peshkin & Hoerner 2005). No information was provided regarding the methods of analysis or the performance indicators that were used to develop these life extension estimates.

A paper survey conducted by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies. Respondents indicated that the minimum reported increase in pavement life was 2 to 4 years. The most repeated selection by the 16 respondents was 5 to 7 years and the maximum perceived increase was 7 to 8 years. Note, however, that all of the reported ranges for the extension in pavement life appear to be based on perception instead of well-designed, quantitative experimental analyses.

2.1.4.3 Cost

Costs for microsurfacing vary considerably, as shown in Table 17. Of course, costs in particular regions are a function of the availability of materials and contractors. The time value of money is important; thus, the year for which the dollar value is valid is shown. Neglecting this effect, the average costs of microsurfacing, using the data contained in Table 17, is approximately $12,600 per lane mile.

Table 17: Microsurfacing Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
6,700 – 13,100	None specified	1999	Bolander, 2005
1,000 – 1,500	AR	1995	Geoffroy, 1996
5,000 – 7,000	TN, SUT(1)	1995	Geoffroy, 1996
7,000 – 10,000	MI, MS, MO, NC, OH	1995	Geoffroy, 1996
10,000 – 15,000	ID, TX, WI, IN	1995	Geoffroy, 1996
15,000 – 25,000	KS, VA, ON(2)	1995	Geoffroy 1996
9,100	IA	1996	Jahren & Bergeson, 1999
10,400	IA	1997	Jahren & Bergeson, 1999
10,600 – 14,100	None specified	1999	Johnson, 2000
21,600	IN	1995	Labi et al., 2006
26,800	IN	2006	Labi et al., 2006
12,000 – 34,100	LA	1995-1996	Temple et al., 2002
20,600	LA (average)	1995-1996	Temple et al., 2002
8,800	None specified	2000	Wade et al., 2001
8,800 – 14,100	OH	1997	Wade et al., 2001
6,000 – 14,200	OK	1983-1991	Wade et al., 2001

Notes: (1)Salt Lake County, Utah; (2)Ontario, Canada

2.1.4.4 Individual Research Studies

Jahren et al., 2003a

Iowa State University conducted a study on thin maintenance surfaces for the Iowa Department of Transportation. In September and October of 1997, two 1500-ft test sections were constructed on US 151 and US 30. The microsurfacing aggregate was a Type III Sioux Falls quartzite. The binder was a quick setting CSS-1H Polymer Modified Binder. An additional set of test sections was constructed the following year in August of 1998 on US 69.

Data for surface condition index, skid resistance, and roughness index were measured before and after construction. Further detail on these measurements can be found in Section 2.1.2.4 of this report. On US 151, the road condition before microsurfacing was likely too low to be within the optimal period for preventive maintenance; the road probably should have qualified for some other rehabilitation instead. Two applications of microsurfacing were needed to raise the SCI to 58, more than double the control indices. In contrast, on US 30, the microsurfacing test section performed worse than the controls, which received no preventive maintenance. On the contrary, the skid resistance on US 30 was better than the control section. The US 69 microsurfacing test exhibited the best performance in which SCI and skid resistance were relatively high and the roughness was comfortably lower. The major difference reported between US 69 and the other test sections was the improved construction quality. An important factor that was not fully quantified was the road conditions prior to receiving maintenance treatments. Snowplow damage was observed on the microsurfaced section of US 69. However, the researchers attribute the majority of this problem to the use of a relatively coarse graded aggregate.

Overall, microsurfacing provided better skid resistance, but its performance is limited if significant surface cracking is present. Furthermore, high raveling of the microsurfaced roads was observed, which resulted in lower SCI values in comparison to the thin (1.5 inch hot-mix asphalt) overlay, which exhibited the best overall performance.

Labi et al., 2006

From 1994 to 2001, about 173 lane-miles received microsurfacing treatment in Indiana. Labi et al. (2006) developed a methodology to determine the long-term benefits of microsurfacing in Indiana using data collected from these treated areas. The data evaluation parameters included: pavement condition and distress, climatic conditions, and relative traffic volumes. Severe climate conditions were defined as an annual freeze index exceeding 60 degree-days. High traffic loads were defined as having an annual loading greater than 1 million ESALs (equivalent single axle loads), averaged from 1994 to 2001.

Three measures of effectiveness (MOEs) were considered: the service life, increase in average pavement condition, and the area bounded by the treatment performance curve. Three indicators for each MOE were used: pavement condition rating (PCR), rutting, and surface roughness. The matrix of MOE and indicators produced varying results. Severe climatic conditions had a larger effect than high traffic in regards to rutting of microsurfaced pavements. However, the relative effect of climate and traffic severity on treatment life based on PCR and surface roughness data was not measurable.

Kazmierowski et al., 1993

Microsurfacing test sections were constructed in August and September of 1991 to test the durability and effectiveness of the treatment in the frequent wet/freeze environmental conditions common to Ontario. Three contractors were hired to design and construct the sections on Highway 191 which has an AADT of 900 with higher traffic during the recreational summer months. Two contractors used gap-graded aggregate consisting of 100% dolomitic sandstone or quartzitic granite. The third contractor used a more open-graded mix of traprock screenings, which had the finest gradation. A quick-set cationic CSS-1H emulsion was used by all three contractors.

The highway pavement condition index (range 0 to 100) was 59 before microsurfacing. The rutting exceeded 1 inch in some sections with an average depth of 0.4 inches in May 1991 prior to surface treatment. Rutting was not much improved by April 1992 after the surface treatment. The largest decrease in average rutting occurred in the westbound lane of the third contractor's section: from 0.30 to 0.24 inches. Crack surveys conducted before and after construction showed that nearly all full-depth transverse cracks had reflected through to the surface. The secondary cracks that did not reach the bottom of the AC layer appeared as hairline cracks in the microsurfaced pavement. Changes in the roughness and skid resistance were insignificant. Information related to pavement life extension was not reported.

2.1.4.5 Summary

The advantages of microsurfacing include: less disruption to road users, wears well in stopping and turning traffic, and has limited aggregate loss. While microsurfacing works well for immediate improvements in rutting, the effects may not last long enough to warrant the potentially high cost to agencies for microsurfacing treatments. If an agency is considering adopting microsurfacing, they should be prepared to invest the time needed to develop a full mix design. Based on others' experience, agencies using this treatment should expect the microsurfaced pavement to last 4 to 7 years, and possibly extend the life of the pavement by at least 4 years.

2.1.5 Cold In-Place Recycling

2.1.5.1 Description

Cold in-place recycling (CIPR) is a method that reuses asphalt pavement in reconstruction or maintenance projects. The basic steps of CIPR involves: milling existing pavement, mixing the millings with new asphalt binder, and compacting the mixture using traditional methods. Depending on user preferences and project specifics, full or partial depth asphalt millings can be used. Full depth CIPR is often referred to as full depth reclamation (FDR). Nevada practices FDR when structural damage is suspected and limits partial depth CIPR to pavements showing only functional damage (Bemanian et al., 2006). Full depth milling may remove as much as 12 inches of pavement, while partial depth milling typically removes 2 to 4 inches of pavement (Salomon & Newcomb, 2000). Advantages and disadvantages of CIPR are listed in Table 18.

Table 18: Advantages and Disadvantages of Cold In-Place Recycling

Advantages	Disadvantages
• Addresses many different types of pavement distress (Sebaaly et al., 2004) • Good resistance to reflective cracking (Salomon & Newcomb, 2000) • Safer for the environment: conserves resources, minimal waste, minimal air pollution (Salomon & Newcomb, 2000)	• Construction dependent on temperature and moisture conditions (Sebaaly et al., 2004) • Sometimes difficult to control material and construction variations caused by changes in existing pavement properties (Salomon & Newcomb, 2000) • Long curing period required to gain strength (Sebaaly et al., 2004) • Results depend on experience of personnel (Maher et al., 2005)

In order for CIPR to be used effectively, the existing pavement must meet the following criteria: adequate structural integrity, a minimum pavement thickness, consistent roadway width, and relatively few obstructions such as manholes (Salomon & Newcomb, 2000). As with most methods, well-written specifications and a reasonable QA/QC plan are important components to a successful CIPR project.

2.1.5.2 Performance

Little information is provided in the literature regarding the life expectancy of CIPR projects, or the additional life this technique provides to a pavement. Researchers commonly note the advantage of CIPR to resisting reflective cracking. A comparison of CIPR projects and adjacent control sections in Pennsylvania showed an average of 2.2 times more cracking in the control sections than the CIPR sections during a pavement condition survey that was conducted 8 to 14 years after treatment. The control sections had received a conventional overlay treatment.

Pennsylvania began using CIPR in 1983 and has experienced many successful projects with this method. While a 10-year design life was expected from transportation department designers, many projects outperformed this nominal life expectancy. For example, 31 projects constructed after 1987 had not required overlays and were still performing well after 16 years. Conventional resurfacing usually requires a subsequent resurfacing within 10 years. In comparison, the average service life of CIPR projects is 12.9 years (Morian et al., 2004). Other reported values of CIPR treatment life are listed in Table 19.

Table 19: Cold In-Place Recycling Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Hicks et al., 2000	5 to 10	average treatment life in Ohio
Maher et al., 2005	6 to 8	expected treatment life
Maher et al., 2005	12 to 20	expected life with HMA overlay on CIPR
Morian et al., 2004	12.9	average treatment life in Pennsylvania

Nevada has also reported good performance of CIPR and FDR projects, both of which receive a 1.5 inch thin HMA overlay following the recycling action. The full life expectancy of 15 to 20 years is often realized due to Nevada's proactive pavement management system with regular crack sealing and 2-inch structural/functional overlays, as reported by Bemanian et al. (2006). The thin overlay placed on top of CIPR projects lasts about 10 years, thus a new overlay is required, but theoretically CIPR won't be needed on the same section of pavement again (Bemanian et al., 2006).

2.1.5.3 Cost

The cost of CIPR depends on a number of factors, including the mill depth and the properties of the existing pavement. General cost estimates were identified in the literature, and are summarized in Table 20. The majority of the cost estimates were obtained from Pennsylvania. Average costs in Pennsylvania are shown for most years between 1988 and 2000, with the year of expense shown to account for the time value of money. Prior to 1994, most of the Pennsylvania projects had mill depths of 3 to 4 inches. After 1995, milling depths of 2 inches have been most prevalent. Simply averaging the costs in Table 20 yields an approximate cost of $17,700 per lane mile.

Table 20: Cold In-Place Recycling Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
6,000 – 8,000	OH	1997	Hicks et al., 2000
24,600 – 28,200	None specified	2004	Maher et al., 2005
14,500	PA	1988	Morian et al., 2004
11,800	PA	1989	Morian et al., 2004
15,400	PA	1990	Morian et al., 2004
13,800	PA	1991	Morian et al., 2004
38,000	PA	1995	Morian et al., 2004
14,000	PA	1997	Morian et al., 2004
17,100	PA	1998	Morian et al., 2004
17,100	PA	1999	Morian et al., 2004
21,400	PA	2000	Morian et al., 2004

2.1.5.4 Individual Research Studies

MDT, 2001 and Abernathy, 2004

Montana has conducted several field experimental studies using cold in-place recycling. The first CIPR project was constructed during the summer of 1996. Two milling depths (2.4 in and 3.6 in) were investigated. Roughness, rutting, and cracking were measured five years after construction. Roughness for both CIPR sections was considered fair. Rutting was generally higher in the 3.6 inch milled section, and cracking was higher in the 2.4 inch milled section (MDT, 2001).

More recently (July 2001) a CIPR project was constructed which featured the Koch Pavement Solutions™ CIR-EE (cold in-place recycling - engineered emulsion) process. Six test sections were constructed using various mill depths and overlay thicknesses. Project evaluation will be based on crack mapping as well as roughness and rutting data. The final report for this project is expected in the summer of 2006 (Abernathy, 2004).

Forsberg et al., 2002

Minnesota Department of Transportation constructed test sections using the conventional CIPR and the new CIR-EE processes during summer 2000. The 5.75-mile section had an ADT of 580. While only a preliminary cost analysis has been performed, the construction cost for the conventional process was $42,300 per lane mile and 10% more (total of $46,600) for the engineered emulsion section. The authors note that these costs excluded the salvage value of the materials.

Many laboratory tests were performed comparing the conventional CIPR and new CIR-EE properties. The new CIR-EE material appears less susceptible to raveling, especially within the first two days after construction. The new material is also not predicted to thermally crack until the pavement temperature is -29°F, as opposed to -22°F for the conventional mix. Therefore, Forsberg et al. (2002) expect future performance evaluation of the test sections to indicate the 10% extra initial cost for CIR-EE is a worthwhile investment.

Jahren & Chen, 2005

Jahren & Chen (2005) are in the process of analyzing the performance of 22 sections of CIPR pavements in Iowa. Their preliminary report noted that past CIPR projects showed various levels of performance, even with projects constructed in the same region during the same season by the same contractors. Thus, the 22 projects selected for the current study represent sections of varying traffic levels, support structure condition, and age of CIPR project. The pavement performance for the CIPR projects will be based on pavement condition index (PCI) measurements as well as field and lab tests to determine the aged engineering properties of the CIPR materials. Results from this analysis will likely be applicable to regions outside of Iowa, but the project's final report was not published at the time of this literature review.

Bergeron, 2005

Bergeron (2005) used information from CIPR and FDR practices since the early 1990s to determine the difference in net present value and benefit cost ratio for several pavement management scenarios in Quebec Canada. Of the 930 miles of pavement in Quebec that received CIPR and FDR treatment, data from 264 miles were analyzed. FDR projects stabilized the overlay with a hydrocarbon binder before it was applied. Roughness and rutting data for the roads were used in the empirical analysis.

Bergeron (2005) compared three scenarios: bituminous resurfacing (BR), CIPR, and FDR. The conventional local practice consisted of BR with crack sealing every two years at the rate of approximately 10,500 feet of cracks per mile. With FDR and CIPR, crack sealing was assumed to occur every four years at a lower sealing rate of 6,600 feet of cracks per mile. The performance life considered for the BR scenario on highways was 11 years until a minor deficiency in roughness and 17 years until a major roughness deficiency occurred. However, these life spans were significantly decreased if the pavement condition was deficient prior to work: 7 and 11 years, respectively. In contrast, the CIPR scenario used a performance life of 12 and 18 years until the minor and major deficiencies occurred and the life spans of FDR were even higher at 15 and 20 years. These assumptions were based on the performance of BR, CIPR, and FDR in Quebec prior to 2005.

The additional performance of CIPR and FDR compared to BR resulted in higher benefit/cost ratios even though the net present values were higher for the former scenarios. The practice of FDR had a 45% higher net present value than conventional BR but its benefit/cost ratio was 4 times greater than that of BR. Even better was CIPR: its net present value was only 13% higher than BR, but its benefit/cost ratio was 8 times greater. Note that these net present values and benefit/cost ratios were for highways characterized with an AADT of 20,000. Bergeron (2005) found that the net present value for national and regional roads (AADT of 12,000 and 5,000 respectively) were less and had even higher benefit/cost ratio comparisons. The costs applied to the treatment scenarios included the cost of work (FDR, CIPR, BR, and crack sealing) as well as estimated costs associated with delays imposed on road users. Other phases of study are still in progress to better describe the cost-effectiveness of CIPR and FDR techniques and provide recommendations for their use.

2.1.5.5 Summary

Cold in-place recycling of pavements should be considered if an agency has experienced repeated problems of reflective cracking with other treatment methods. The primary advantage of this method is that fewer new materials are needed for the projects, thereby greatly reducing material costs. The primary disadvantage of this method is the extensive field and laboratory tests required prior to construction for proper mixture design. Workmanship and experience are generally recognized as important components contributing to the success of CIPR and FDR projects. Bemanian et al. (2006) indicates that the treatment life of CIPR can easily exceed 10 years. The benefit of long life expectancy and reduced crack treatment for CIPR projects is usually worth the higher treatment costs (Bergeron, 2005).

2.1.6 Ultrathin Friction Course

2.1.6.1 Description

An ultrathin friction course is a formulation of hot-mix asphalt with gap-graded aggregate placed on a polymer-modified asphalt emulsion tack coat. The total thickness of this wearing surface is only 0.375 to 0.75 inches. The application is typically used to seal the surface to minimize weathering, raveling, and oxidation. Candidate roads for an ultrathin friction course typically should have ruts less than ½ inch deep, moderate cracking to no cracking, and minor to no bleeding (Maher et al., 2005). The result is a smooth pavement with high frictional resistance (Wade et al., 2001). The NovaChip™ process (the original ultrathin friction course) was developed in France in 1986 and first used in the United States in 1992 in Alabama, Mississippi, and Texas (Maher et al., 2005 and Kandhal & Lockett, 1997). The treatment has been observed to be resistant to rutting for four years because of the strong "stone to stone skeleton" (Serfass et al., 1993). The advantages and disadvantages as reported by several sources are summarized in Table 21.

Table 21: Advantages and Disadvantages of Ultrathin Friction Course

Advantages	Disadvantages
• Very durable surface for high volume roads (Maher et al., 2005)	• Requires specialty equipment and license for installation (Peshkin et al., 2004)
• Fully open to traffic within an hour (McHattie & Elieff, 2001)	• Typically proprietary products, i.e. NovaChip^{TM} (Wade et al., 2001)
• Very good bonding to existing pavement (Kandhal & Lockett, 1997)	• Transportation limitation of 1.5 hours from mixing in plant to placement on the road (Maher et al., 2005)
• One machine used for installation (Kandhal & Lockett, 1997)	
• Can be fully recycled (Maher et al., 2005)	

2.1.6.2 Performance

The lifespan of ultrathin friction courses varies; several ranges are shown in Table 22. This is a relatively new technology; consequently, the state-of-knowledge is limited regarding the treatment life and the effect the treatment may have on extending the pavement life. Regardless, based on the information gathered as part of this study, a user can reasonably expect at least 7 years of service.

Table 22: Ultrathin Friction Course Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Gilbert et al., 2004	8 to 12	expected life in South Africa
Maher et al., 2005	10 to 12	typical serviceable life
Peshkin et al., 2004	7 to 10	generally reported range

The first NovaChip^{TM} experiment in Missouri occurred in 1998. The test section showed damage from snowplow activity and freeze-thaw damage during the first winter (MoDOT, 1999). Nevertheless, Novachip^{TM} projects are still being constructed in the north central district of Missouri (MoDOT, 2006).

2.1.6.3 Cost

Cost estimates for ultrathin friction course are listed in Table 23. The range of the three estimates is large and may be attributed to the fact that most costs are from experimental projects. Nonetheless, the average cost exceeded $40,000 per lane mile in 2004. Louisiana recently developed a non-proprietary version of the NovaChip^{TM} technology referred to as

Ultrathin HMAC Wearing Course (Cooper & Mohammad, 2004), but installation costs were not identified.

Table 23: Ultrathin Friction Course Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
42,200 – 47,200	None specified	2004	Maher et al., 2005
17,600 – 21,100	None specified	2001	Peshkin et al., 2004
27,500	SD (one project)	pre-2001	Wade et al., 2001

2.1.6.4 Individual Research Studies

The manufacturer of NovaChip™, Koch Industries (a worldwide company) indicated that NovaChip™ application has been used in several cold weather states, including Colorado, Michigan, New York, Ohio, Pennsylvania, and Wisconsin (Koch Industries, 2001). However, the only research studies that could be located in the literature were conducted in two southern states: Alabama and Louisiana.

Kandhal & Lockett, 1997

The first NovaChip™ application in the United States was constructed on US 280 (ADT = 13,000) in Alabama in October 1992. Traffic lanes in the opposite direction functioned as the experimental control section because they had been constructed just two months prior with a conventional dense-graded granite aggregate wearing course. Likewise, the eastbound section had also just received a new overlay. Thus, the NovaChip™ ultrathin friction course could be evaluated in terms of its performance as a wearing surface on new pavement. Problems during installation rendered this test section invalid. Therefore, two new NovaChip™ test sections, labeled granite section and gravel section, were constructed on US 280. The sections are briefly described as follows:

1. Granite section – 1.75 miles long with 75% ⅜-inch coarse granite, 20% granite screenings, and 5% mineral filler
2. Gravel section – 0.95 miles long with aggregate composed of 70% ⅜-inch crushed gravel, 27% sand, and 3% mineral filler

During construction, flushing was moderate in the traveling lane and slight in the passing lane of the granite section. Therefore, the application rate was adjusted so that no flushing was observed in the passing lane and was slight in the traveling lane of the gravel section. Based on these trends in flushing, the authors noted that future construction should have lower tack coat application rates in the traveling lane.

Measurements of friction on the two NovaChip™ sections and the control indicated similar values in the traveling lane. The passing lane of the NovaChip™ sections had higher friction than the passing lane of the control.

One month after the NovaChip™ installation on US 280, 3 miles of Alabama Highway 21 (AL 21) received a NovaChip™ overlay. The two-lane highway had an ADT of 7,500 in 1996. The mix was 72% coarse ⅜-inch granite, 22% granite screenings, and 6% aggregate lime mineral filler. Prior to receiving the overlay, the road was slightly raveled with partially sealed transverse cracks. Significantly higher friction numbers were measured two and a half years after construction compared to the untreated sections. Almost four years after construction, the NovaChip™ section did not exhibit any raveling or loss of aggregate.

These primary applications of NovaChip™ in Alabama were considered successful and the overlay has since been applied to I-65 in Cullman and I-29 in Birmingham, which have ADT levels of 60,000 and 165,000, respectively (Koch Industries, 2001).

Cooper & Mohammad, 2004

In 1997, 5.25 miles of Route LA 308 received a ¾-inch NovaChip™ overlay. In 1998, a 3 mile section of the highway located east of the NovaChip™ section underwent a 2-inch mill and a 3.5-inch HMA overlay, while a 6.5 mile long section located west of the NovaChip™ section received a 1.5 inch mill and 3.5-inch HMA overlay. All three treatments were constructed by the same contractor. The highway had an ADT of approximately 4800 in 1996, the first year of the monitoring period.

These three sections were monitored until 2002 at which time Cooper & Mohammad (2004) evaluated roughness, alligator cracking, random cracking, transverse cracking and rutting data. Post construction measurements indicated that roughness in the NovaChip™ section increased at a faster rate than the mill and overlay sections. However, the average roughness values were all considered "good" by Louisiana DOT's pavement management system. The observed alligator cracking was blamed on moisture infiltration into the base and/or subgrade as a result of unimproved shoulders. In 2002, the lowest alligator cracking was on the NovaChip™ section. Random cracking and transverse cracking were highest in 2002 for the NovaChip™ section. The rut depth for all sections was 0.1 inches in 2002, much less than the 0.4 to 0.5 inches measured before the treatments.

A simplified life cycle cost comparison for the three treatments was calculated based on the actual construction cost of each treatment. The mill and overlays were assumed to have a 20 year life. The authors assumed two NovaChip™ treatments would be needed for a 20-year life cycle evaluation. Other assumptions included neglecting additional maintenance costs, salvage value, rehabilitation costs, and increases in construction costs (for the second NovaChip™ application at ten years). The result was a present worth of \$7.34/yd^2 for the NovaChip™ and \$10.68/yd^2 for the mill and overlay (average of costs for 1.5- and 2-inch milling).

2.1.6.5 Summary

Ultrathin friction course is a new preventive maintenance treatment offering reportedly good performance for a period of at least 7 years. It may be more appropriate for high volume roads in which longevity and faster construction is a high priority in reducing impacts to travelers. The performance of ultrathin friction course in cold climates needs to be carefully examined, particularly the effects of snowplow activity and freeze/thaw conditions.

2.1.7 Fog Seal

2.1.7.1 Description

A fog seal is an asphalt emulsion diluted with water (typically 1:1 ratio). The emulsion is applied directly to the pavement surface without the addition of aggregate. A fog seal can be considered a candidate treatment to address raveling, oxidation, and low-severity fatigue cracking. However, it is only considered a temporary fix because a fog seal generally lasts only one to two years (Wade et al., 2001 and Hicks et al., 2000). Primary advantages and disadvantages of fog seal treatments are summarized in Table 24. Fog seals are used for applications ranging from short-term repair of minor surface defects to a combination treatment with chip seals to reduce aggregate loss.

Table 24: Advantages and Disadvantages of Fog Seals

Advantages	Disadvantages
• Good treatment performance in all climates (Peshkin et al., 2004)	• Usually slow-setting emulsions are used, resulting in longer traffic delays (Wade et al., 2001)
• Inexpensive treatment to address raveling (Wade et al., 2001)	• Reduces surface friction immediately after application (Wade et al., 2001)
• Reduces aggregate loss when applied over a chip seal (Caltrans, 2003 and Wade et al., 2001)	• Increased wear occurs from studded tires (Peshkin et al., 2004)
• Seals small cracks (Maher et al., 2005)	• Short life expectancy (Maher et al., 2005)

2.1.7.2 Performance

A fog seal is often applied when there is only a relatively minor amount of surface defects. Generally, rutting should be less than ⅜ inch and cracking should be minimal (Hicks et al., 2000). As summarized in Table 25, the effective life of a fog seal is reported in the literature as ranging from less than 1 year to as much as 4 years.

Table 25: Fog Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	2 to 4	for ADT < 100
Bolander, 2005	1 to 3	for ADT 100 to 500
Hicks et al., 2000	2, 3, 4	min, average, max (respectively)
Hicks et al., 2000	1 to 2	average life in Ohio
Peshkin et al., 2004	1 to 2	generally reported range
Wade et al., 2001	1 to 2	generally reported range

2.1.7.3 Cost

Estimated costs for fog seal applications are shown in Table 26. Most of the cost estimates are greater than five years old. Average cost (calculated from Table 26) is approximately $2,200 per lane mile.

Table 26: Fog Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
1,000 – 3,200	None specified	1999	Bolander, 2005
3,200	None specified	2000	Hicks et al., 2000
1,400 – 1,700	OH	1997	Hicks et al., 2000
700 – 1,400	None specified	1999	Johnson, 2000
1,400 – 3,500	None specified	2004	Maher et al., 2005
2,100 – 3,200	None specified	2001	Peshkin et al., 2004
3,200	None specified	2000	Wade et al., 2001

2.1.7.4 Summary

A fog seal is an application of slow or medium setting diluted asphalt emulsion applied directly on a pavement surface, with no aggregate. Fog seals typically are used on roadways that exhibit minor surface defects, such as raveling, oxidation, and some small cracking. The treatment is relatively inexpensive. Similarly, its life expectancy is low (typically, less than four years). A fog seal may also be applied on a new chip seal to prevent aggregate loss subsequent to construction. No information was found to substantiate any extension of the life of the pavement receiving a fog seal treatment.

2.1.8 Slurry Seal

A slurry seal is a cold-mix combination of slow-setting asphalt emulsion, fine aggregate (well-graded), mineral filler, and water (Hicks et al., 2000). The mineral filler is an inert mineral added to improve the strength and density of the slurry seal; the fine filler completely passes through a 0.002 inch sieve (USDOT, 2006).

The effective life of a slurry seal is reported in the literature to range anywhere from 1 to 7 years, as summarized in Table 27. Some of the advantages of a slurry seal include its versatility and smooth surface (Maher et al., 2005). One of the primary disadvantages of slurry seals is that the emulsion requires a relatively long curing time, resulting in potential traffic delays (Hicks et al., 2000).

Table 27: Slurry Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	5 to 10	for ADT < 100
Bolander, 2005	5 to 8	for ADT 100 to 500
Geoffroy, 1996	1 to 6	according to NCHRP
Geoffroy, 1996	3 to 5	according to FHWA
Geoffroy, 1996	3 to 6	according to US Corps of Engineers
Hicks et al., 2000	2 to 5	average life according to Ohio DOT
Hicks et al., 2000	3, 5, 7	min, average, max (respectively)
Hicks et al., 2000	3 to 4	life expectancy from Caltrans
Maher et al., 2005	3 to 8	expected treatment life

The pavement life extension has been studied less, but some estimates are available. A paper survey by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies. Respondents indicated that the minimum increase in pavement life was 2 to 4 years, the maximum increase was 7 to 8 years, and the most repeated selection by the 13 respondents was 5 to 6 years.

Reported cost estimates for slurry seals are summarized in Table 28. Average costs from four studies range from $4,900 to $10,600 per lane mile, calculated using dollar values prior to the year 2001.

Table 28: Slurry Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
5,300 – 10,600	None specified	1999	Bolander, 2005
4,900 – 7,000	None specified	2001	Peshkin et al., 2004
6,300	None specified	2000	Hicks et al., 2000
5,000 – 7,000	OH	1997	Hicks et al., 2000

2.1.9 Cape Seal

A cape seal is the combination of a slurry seal on top of a chip seal (Hicks et al., 2000). The slurry seal is used to enhance a new chip seal by reducing chip loss after construction. The disadvantage of this combination application is the slurry seal requires longer curing time than just a conventional chip seal, resulting in additional traffic delays (Maher et al., 2005). As shown in Table 29, the approximate treatment life of a cape seal ranges from about 6 to 15 years. Reported cost estimates for cape seal application are shown in Table 30.

Table 29: Cape Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	6 to 8	for ADT 100 to 500
Bolander, 2005	8 to 15	for ADT < 100
Maher et al., 2005	7 to 15	typical serviceable life

Table 30: Cape Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
12,300 – 17,600	None specified	1999	Bolander, 2005
15,800 – 21,100	None specified	2004	Maher et al., 2005

2.1.10 Scrub Seal

A scrub seal is a variation of a chip seal, in which a polymer-modified asphalt emulsion is sprayed on the pavement and then broom-scrubbed. Sand or small aggregate is then applied and also possibly broom-scrubbed before the aggregate layers are embedded with a pneumatic tire roller (Bolander, 2005). The sweeping process tends to fill cracks that are greater than ⅛ inch wide, and is somewhat effective in sealing cracks (Maher et al., 2005).

As shown in Table 31, the approximate treatment life of a scrub seal ranges from about 1 to 6 years. Reported cost estimates for scrub seal application are shown in Table 32. Traditional chip seals are described in greater detail in section 2.1.3 of this report.

Table 31: Scrub Seal Treatment Life as Reported by Various Sources

Reference	Treatment Life (years)	Notes
Bolander, 2005	2 to 8	for ADT < 100
Bolander, 2005	2 to 6	for ADT 100 to 500
Maher et al., 2005	2 to 6	for ADT < 1,500
Peshkin et al., 2004	1 to 3	generally reported range
Wade et al., 2001	3 to 4	typically reported range

Table 32: Scrub Seal Costs per Lane Mile

Cost per Lane Mile (12-ft width), $	Location	Year Data Taken	Reference
4,200 – 9,200	None specified	1999	Bolander, 2005
3,500 – 9,200	None specified	2004	Maher et al., 2005
5,300 – 8,800	None specified	2001	Peshkin et al., 2004
2,800 – 3,500	None specified	2000	Wade et al., 2001

2.2 Comparisons of Preventive Maintenance Techniques

The individual performance of preventive maintenance treatments was discussed in previous sections of this report. Each subsection described key aspects of the treatment and included tables compiled of information regarding the treatment life and cost. To provide a head-to-head comparison, the minimum, average, and maximum values of treatment life are summarized in Table 33. The average cost was also computed in a simplified method neglecting the time value of money (the range of average reported costs spans the years 1995 to 2002). The most expensive treatments, in order of highest unit price cost, are ultrathin friction course, cold in-place recycling, and cape seal, and these also correspond to the highest average treatment life reported.

Table 33: Summary of Expected Lives and Costs for Preventive Maintenance Treatments

Preventive Maintenance Treatment	Treatment Life (years)			Cost per Lane Mile (12-ft width)
	Min	Average	Max	
Crack Sealing	2	4.4	10	$5,300
Thin Overlay	2	8.4	12	$14,600
Chip Seal (Single)	1	5.9	12	$7,800
Chip Seal (Double)	4	7.3	15	$12,600
Microsurfacing	4	7.4	24	$12,600
Cold In-Place Recycling	5	10.6	20	$17,700
Ultrathin Friction Course	7	9.8	12	$31,100
Fog Seal	1	2.2	4	$2,200
Slurry Seal	1	4.8	10	$6,600
Cape Seal	6	9.8	15	$16,700
Scrub Seal	1	3.7	8	$5,800

From all of the literature reviewed, two main studies specifically compared multiple preventive maintenance treatment alternatives simultaneously (Hall et al., 2003 and Jahren et al., 2003a). A study conducted by Morian et al., (1997) was also useful, but predates the more recent analysis conducted by Hall. Many others conducted studies that considered multiple treatment types, yet their data was not specifically used to make head-to-head comparisons between treatments (Bausano et al., 2004; Cooper & Mohammed, 2004; Jackson et al., 2005; Romero & Anderson, 2005; Smith & Tighe, 2004; Temple et al., 2002; and Wade et al., 2001). Many of these research efforts only made comparisons between various types of chip seals (i.e., chip, slurry, fog, cape and scrub). Yet other researchers conducted studies based on literature reviews and/or surveys (Bolander, 2005; Geoffroy, 1996; Gransberg & James, 2005; Hicks et al., 2000; Smith & Beatty, 1999; and Wade et al., 2001). Some of these research projects considered multiple treatments and others single treatments. In addition, three main studies used their research to develop guidelines for preventive maintenance activities (Cook et al., 2004; Peshkin et al., 2004; and Yichang et al., 2006). Finally, there were multiple studies conducted where only a single treatment was considered (Abernathy, 2004; Bemanian et al., 2006; Bergeron, 2005; Chong, 1989; Cuelho & Freeman, 2004; Davis, 2005; Forsberg et al., 2002; Gransberg & Musharraf, 2005; Joseph, 1992; Kazmierowski et al., 1993; Labi et al., 2006; Morian et al., 2004; Outcalt, 2001, Salomon & Newcomb, 2000; Sebaaly et al., 2004; and Smith & Beatty, 1999). A table in Appendix A summarizes each of these studies in terms of: which preventive maintenance treatments were studied, how many test sections were used, what type of study was conducted, what quantitative parameters were considered (if any), and what type of results were produced.

2.2.1 Jahren et al., 2003a

Jahren et al. (2003a) conducted a study on thin maintenance surfaces for the Iowa Department of Transportation. Field test sections were constructed for the study to examine thin overlays, single and double chip seals, fog seals, cape seals, slurry seals and microsurfacing as compared to control sections. Data for surface condition index (SCI), skid resistance, and roughness index (RI) were measured before and after construction. Further detail on these measurements can be found in Section 2.1.2.4 of this report. The experiments were conducted on three highways in Iowa: US 30 (constructed in 1997), US 151 (constructed in 1997), and US 69 (constructed in 1998).

Based on a SCI and RI, the thin overlay outperformed all other treatments on all highways in both years. However, other treatments showed greater improvement with respect to skid resistance. Even though the microsurfacing test section exhibited the lowest SCI by the end of the monitoring period, its skid resistance was higher than the other treatments. Based on the experiments constructed on US 151, preventive maintenance treatments are more effective and perform better when they are applied to a pavement that is in good condition compared to when they are applied to a pavement that is already in poor condition (Jahren et al., 2003a).

2.2.2 Hall et al., 2003 (Long-Term Pavement Performance SPS-3 Experiment)

The Strategic Highway Research Program initiated a study of Long-Term Pavement Performance (LTPP). Under this project, the Specific Pavement Studies SPS-3 Experiment focused on the effects of routine preventive maintenance for flexible pavements. Four treatments were studied: crack sealing, slurry seals, chip seals, and thin HMA overlays. Several variables were also considered, specifically:

- climate (wet-no freeze, wet-freeze, dry-no freeze, and dry-freeze),
- subgrade type (fine and coarse grained),
- traffic volume (low and high),
- pretreatment pavement condition (good, fair, and poor), and
- structural number (adequate and inadequate).

Most of the construction took place in 1990 and 1991 at 81 sites in the United States and Canada. The chip seals and slurry seals were placed by the same contractor within each of the four regions, North Central, North Atlantic, Southern, and Western. Material specifications were identical across all regions, but the materials were obtained from a different source for each region. The crack sealing material was the same for all regions, but placed by a different installation crew. The thin overlays had the greatest variation in construction. Although they were nominally 1.5 inches thick, they were placed by state and provincial highway agencies under their standard material and installation procedures (Morian et al., 1997 and Hall et al., 2003).

Hall et al. (2003) statistically analyzed SPS-3 data to assess initial and long-term effects of the four treatments on the pavement (crack seals, slurry seals, chip seals, thin HMA overlays). Roughness, rutting, and fatigue cracking were the performance measures used for each treatment and control section. They also established the condition of pavements prior to conducting their study (in terms of traffic, climate, and timing of application) to study whether its condition had an effect on the performance of preventive maintenance treatments.

Only the thin HMA overlay test sections were found to have significantly less roughness and rutting than the control sections in both the initial and long-term periods following construction. Qualitatively, the thin HMA section also exhibited less fatigue cracking. Chip seals performed the second best, followed by slurry seals. In terms of roughness, rutting and cracking, crack sealing did not provide any initial or long term benefit to the pavement. Cost effectiveness of each of these treatments was not considered in this study.

2.2.3 Summary

Comparisons between various preventive maintenance treatments should be carefully made. Generally, specific studies have been conducted to determine how various construction alternatives, climates, traffic levels, etc. affect the life and effectiveness of preventive maintenance treatments. Few of these studies, however, considered the effect these treatments had on the life of the pavement. Most often, studies focused their attention on how long the treatment itself lasts. Therefore, very few life-cycle cost analyses have been conducted with respect to the pavement as a whole.

The two studies that compared the effects of various treatments on pavement condition or distress had similar results. Overall, according to Hall et al. (2003), thin HMA overlays appear to offer the greatest benefit, followed by chip seals, and slurry seals. Similarly, Jahren et al. (2003a) concluded that thin overlays also performed well.

3 SURVEY DESIGN AND RESULTS

The purpose of this survey was to investigate the state-of-the-practice of preventive maintenance treatments applied to pavements. The survey was distributed using an email listserv maintained by the AASHTO RAC (the American Association of State Highway and Transportation Officials Research Advisory Committee). The results of this analysis will be used to enhance the Montana Department of Transportation's preventive maintenance program. This chapter provides details of the survey design and analysis, and a summary compilation of the results.

3.1 Survey Design

In general, the objectives of the survey were to solicit U.S. states and Canadian provinces to determine: 1) the types of pavement preventive maintenance systems they currently use, 2) their use of materials and techniques, and 3) how preventive maintenance systems are evaluated in their respective programs. A copy of the survey can be found in Appendix B. The various sections of the survey solicited the following types of information:

- details about their job as it relates to preventive maintenance of pavements,
- information related to the preventive maintenance program within their state/province, and
- information related to specific preventive maintenance treatments or techniques.

Three types of responses were solicited throughout the survey: multiple choice, ordinal ratings and open-ended. For the rated responses, survey participants were instructed to select one of five values they felt best represented their behavior or opinion regarding a particular topic. The ordinal nature of such a scale allows conclusions to be drawn on a relative basis only. Differences between response values cannot be quantified because each respondent's assessment of the intervals between the response categories will vary. In general, results from specific questions on this survey are qualitative and are intended to make general conclusions regarding preventive maintenance practices within individual states and provinces. More specific details and recommendations would need to come from additional investigations.

3.2 Survey Administration

The survey was designed to target individuals within state or provincial departments of transportation that had intimate knowledge about preventive maintenance practices and procedures within their state. The listserv maintained by AASHTO RAC was well suited in this regard and was therefore used. The managers of research programs within each state were asked to forward the request to areas within their agency involved with preventive maintenance or pavement preservation. The survey was first distributed on December 13, 2005 and responses were due December 30, 2005. Many of those sought to participate did not respond by the first deadline; consequently, a reminder was sent out in early January with a revised response deadline by January 27, 2006. Again, due to lack of participation, a third reminder was sent out, but specifically targeted to those states/provinces that had similar climate, geography, or resources as Montana. This last appeal for participation had a final due date of March 17, 2006. Altogether there were 47 individual responses to the survey from 34 states and 5 provinces, as shown in Figure 1. Numbers within individual states/provinces indicate the number of responses received. This translates into a response rate of 62.9 percent by state/province.

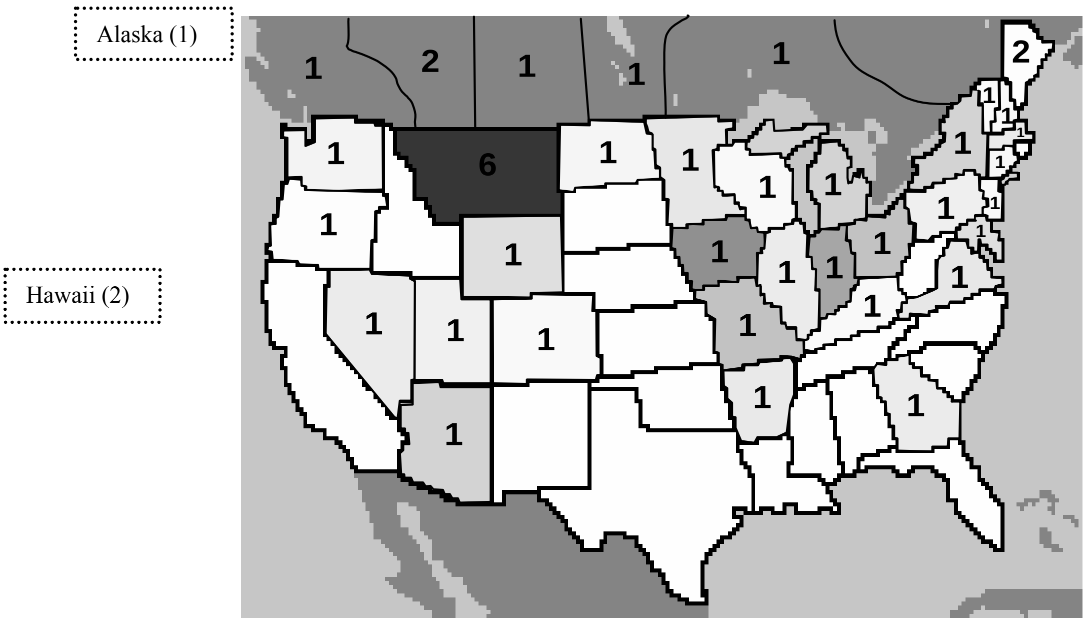

Figure 1: Map showing number of survey respondents from each location.

3.3 Survey Analysis

Survey responses were analyzed using various summary statistics, including percentages, frequencies, and means. Tabular results are summarized within the following sections. Respondents were able to skip any question on the survey. Percentages are based on total responses obtained for each question, as opposed to the total number of survey respondents, thereby eliminating the need for an “unknown” or “no response” category for each question. If a particular state/province did not answer more than the first four questions of the survey, they were not considered a respondent, since the information from the first four questions did not provide data useful to accomplishing the objectives of the survey.

3.4 Section I: Employment Demographics

Employment demographics were needed from each respondent to determine where participants worked, their level of job experience, and a brief description of their job responsibilities with respect to preventive maintenance of pavements. This information was used to characterize certain data sets as explained in subsequent sections.

3.4.1 Residence

The survey was distributed to all 50 states, Washington D.C. and all Canadian provinces for a total of 62 recipients. The first question simply asked respondents to indicate their current state or province of residence. As previously mentioned, participation in the survey was only considered when a particular state/province answered more than the first four questions of the survey. In all, there were 47 individual responses to the survey from 34 states and 5 provinces, as previously shown in Figure 1. Appendix C contains a complete list of participating states and provinces, and the number of surveys received from each agency.

3.4.2 Years of Experience

The second question asked how many years of experience the respondent had with respect to preventive maintenance of pavements. The response options were 0-1, 1-2, 3-5, 6-10 and 10 or more. A summary of the data from this question is listed in Table 34. Most of the survey respondents indicated that they had greater than six years of experience. The symbol "*" indicates the number of respondents that skipped this question.

Table 34: Years of Experience of Survey Respondents

Years Experience	Count	Percent[1]
* [2]	1	---
0-1	3	6.5
1-2	5	10.9
3-5	11	23.9
6-10	9	19.6
10+	18	39.1
Total	47	100.0

*Notes: [1] Percent of respondents that selected the range (out of 46 total); [2] * indicates question skipped*

3.4.3 Description of Job Activities

The last question in this section asked respondents to clarify their job activities as they relate to preventive maintenance of pavements. This question required an open-ended response, so no two responses were alike. Actual responses to this question are provided in Table D-1 in Appendix D. Many of those who responded to the survey were generally responsible for managing some aspect of preventive maintenance within their state or province; therefore, most respondents generally described their managerial job duties. Active terminology such as, approve, coordinate, engineer, design, manage, oversee, review, prioritize, develop, promote, select and specify were used to describe their job activities. Others action words that were frequently used included collect, determine, evaluate, maintain, monitor, recommend, and research.

3.5 Section II: Preventive Maintenance Program

Questions within the second section of the survey were used to determine the type of pavement preventive maintenance efforts or programs currently in place in individual states and provinces. Of specific interest was information related to how preventive maintenance treatments are selected and prioritized, who selects them, what types of funding are available, how much time it takes to apply treatments, whether formal guidelines are used, and more.

3.5.1 Existence of Preventive Maintenance Program

The first question within this section asked survey participants whether their state/province currently has a preventive maintenance program for pavements. The majority of those that responded (91.3 percent) indicated that their state/province currently has a preventive maintenance program for pavements, leaving 8.7 percent that indicated there wasn't a program. No one utilized the "Don't Know" option to this question. In 1999 the Lead States Team on Pavement Preservation of the American Association of State Highway and Transportation Officials (AASHTO) surveyed the United States, District of Columbia, and Puerto Rico. Of the 41 responses, 36 referred to an established preventive maintenance program and 2 were developing programs. However, all 41 noted that preventive treatments were used, regardless of a dedicated program (AASHTO, 2000).

3.5.2 Program Funding

This question was asked to determine whether preventive maintenance activities are paid out of a dedicated budget, and if so, what level of annual funding is available. Respondents indicated that 67.4 percent had dedicated budgets, 28.3 percent did not, and 4.4 percent didn't know. For the affirmative response to the question, the range of responses varied quite dramatically – from $2 million to $150 million (see Table D-2 in Appendix D). Some respondents were unable to provide this information or indicated that it varied from year to year. On average, respondents indicated that the amount dedicated per year for preventive maintenance activities was approximately $40 million.

3.5.3 Manual or Guidelines

The third question within this section asked survey participants whether their state currently has a manual or written guidelines for their pavement preservation program, and if so, whether the document was available and in what format. Respondents indicated that 69.6 percent had a manual, 30.4 percent did not have a manual, and no one utilized the "Don't Know" option to this question. Respondents that answered "Yes" were asked to provide more details regarding the availability and format of their guidelines. The open-ended responses to the affirmative portion of this question are summarized in Table D-3 in Appendix D. Approximately one-third of the respondents left the open-ended portion of the question blank. Another quarter indicated that an electronic document was available. Others stated that a hard copy was available, or that they used internal policy, decision trees, or toolbox to make these decisions. Two respondents indicated that a document was not available, and three stated that their document was under development. Responses to this and the previous question also reveal that most states that have dedicated funding also have a manual or guidelines.

3.5.4 Responsible Position

This open-ended question attempted to determine who or what position within the organization determines the need for preventive maintenance projects. As expected, responses varied, but still revealed apparent trends. Most respondents indicated that these decisions are managed on a district or regional level. Many also indicated that their decision making process utilized a combined approach, in which a pavement management system was used in combination with district, state, maintenance, planning, and upper management personnel. Individual responses to this question are listed in Table D-4 in Appendix D.

3.5.5 Selection Process

Survey participants were asked to indicate how pavements are identified for preventive maintenance treatments. Respondents were able to select applicable responses from the following list:

a. when funds are available;
b. they are regularly scheduled, regardless of pavement performance;
c. when pavement damage reaches a certain level;
d. a system combining timing, cost, treatment and performance is used (e.g., decision tree); and
e. other.

Individual tallies of the responses to this question are summarized in Table 35, and generally indicate that most agencies utilize a combined approach (option "d") as the primary method of determining where to apply preventive maintenance treatments. Closely following are methods that utilizes pavement damage inputs. Many respondents also indicated that funding information is used, but only a few said that treatments are applied merely on a time schedule. Since respondents were able to choose multiple responses to this question, a more detailed analysis was conducted to determine potential cross links between certain methods. Most participants responded with a single response of option "d" (the combination system), followed by a single response of option "c", then a combination of options "a" and "c", etc. Results of this analysis are summarized in Table 35.

Table 35: Tabulated Values of Selection Process

Method	Count	Percent[(1)]	Rank
a. when funds are available	20	42.6	3
b. regularly scheduled regardless of performance	6	12.8	4
c. based on pavement damage	23	48.9	2
d. combination system	25	53.2	1
e. other	11	23.4	---
Only a	2	4.3	5
Combination a+b	0	0.0	---
Combination a+c	5	10.6	3
Combination a+d	4	8.5	4
Only b	0	0.0	---
Combination b+c	0	0.0	---
Combination b+d	0	0.0	---
Only c	7	14.9	2
Combination c+d	4	8.5	4
Only d	9	19.1	1
Only e	4	8.5	4
Other multiple combinations	12	25.5	---

Notes: [(1)] Percent of respondents (out of the 47 total) that selected the method(s)

Survey participants were also given the option to input any other alternative in addition to those already provided. Only four respondents utilized this option exclusively. Others used this category to provide additional information related to their other choices. Responses to the "Other" category for this question are summarized in Table D-5 in Appendix D.

3.5.6 Timing

The ninth question on the survey asked participants to estimate how long it takes for a project to be funded, designed and constructed in their state or province. This question was open-ended, therefore responses varied greatly. Nevertheless, and as expected, the least amount of time was reported for funding, more for design and the most for construction. Average, minimum and maximum values calculated from the responses to this question are reported in Table 36. A complete list of the individual responses to this question is provided in Table D-6 in Appendix D.

Table 36: Summary of Time from Project Identification to Funding, Design and Construction

Factor	…funding (mo.)	…design (mo.)	…construction (mo.)
Average	7.8	9.2	14.7
Minimum	0	0	2
Maximum	42	24	42
Standard Deviation	8.8	6.4	8.2
Count	33	31	37

3.5.7 Warranties

The final question in this section of the survey was worded to determine whether state or provincial agencies require warranties on preventive maintenance treatments. If affirmative, survey participants were asked to provide additional information; namely, which treatments are warranted, how long they are warranted and whether warranty bonds are required. Of those who responded, 69.6 percent indicated that warranties are not required for preventive maintenance treatments, and 30.4 indicated that they are required. Of those who responded positively, many indicated that warranties are required for microsurfacing, and that these are generally for one to two years. Others indicated that they currently require warranties for chip seals (usually for one to two years) or are developing specifications. Only a few stated that they require warranties for all treatments. There was no clear trend for those who require warranty bonds. Open-ended responses to the affirmative response to this question are listed in Table D-7 in Appendix D.

3.6 Section III: Preventive Maintenance Treatments

The third section of this survey asked specific questions about preventive maintenance treatments themselves. Questions included how often certain treatments are used, how performance is measured, and how the personnel decide which treatment is appropriate.

3.6.1 Frequency of Use of Specific Preventive Maintenance Treatments

To determine how frequently preventive maintenance treatments are used in certain states or provinces, survey participants were asked to rate how often they use the treatments listed on the survey. The ordinal response options were "Never", "Not Very Often", "Often", "Very Often", and "Always", which had the numerical values 1, 2, 3, 4, and 5 assigned to them, respectively. These values were used to determine a mean response, which was ultimately used to rank how often specific treatments are utilized by those who responded. Response options also included "Never Heard of It" and "Don't Know". A summary of the responses to this question is listed in Table 37. In general, the respondents indicated that crack sealing is the most frequently used preventive maintenance treatment, followed by thin overlays, chip sealing, drainage features, and microsurfacing, respectively. The least used treatment was scrub sealing, followed by cape sealing, PCCP diamond grooving, PCCP undersealing, and slurry sealing, respectively. Scrub seals and cape seals were the least *familiar* treatments of all the treatments listed.

Table 37: Frequency of Use of Specific Preventive Maintenance Treatments

Treatment	Count	*(1)	Percent(2)	Mean	St. Dev.	Don't Know	Never Heard of It	Rank
Crack Seal	43	4	91.5	3.67	0.808	0	0	1
Fog Seal	43	4	91.5	1.77	0.718	0	0	11
Cape Seal	44	3	93.6	1.25	0.508	5	7	15
Chip Seal	44	3	93.6	3.20	1.286	0	0	3
Ultrathin Friction Coarse	43	4	91.5	1.92	0.784	2	3	9
Slurry Seal	44	3	93.6	1.74	0.621	1	0	12
Scrub Seal	43	4	91.5	1.24	0.435	1	9	16
Thin Overlay (with or without mill)	44	3	93.6	3.66	0.805	0	0	2
Microsurfacing	44	3	93.6	2.46	0.926	0	0	5
Hot In-Place Recycling	43	4	91.5	1.81	0.824	0	0	10
Cold In-Place Recycling	44	3	93.6	1.98	0.902	0	0	8
PCCP Diamond Grinding	44	3	93.6	2.38	1.011	2	0	6
PCCP Diamond Grooving	43	4	91.5	1.54	0.600	4	0	14
PCCP Undersealing	44	3	93.6	1.69	0.863	4	1	13
PCCP Dowel Retrofit	43	4	91.5	2.10	1.020	2	0	7
Maint. of Drainage Features	44	3	93.6	2.63	0.952	1	0	4

Notes: (1) Number of respondents that skipped this treatment; (2) Percent of respondents (out of the 47 total) that responded to the treatment option

3.6.2 Other Preventive Maintenance Treatments or Methods

This open-ended question was asked as a follow-on to the previous question. This question ascertained whether states or provinces were using any innovative or new preventive maintenance treatments that were not listed in Question 11. Of those who responded, 73.3 percent indicated that their state/province does not use any other or new preventive maintenance treatments for pavements, leaving 26.7 percent that indicated using other treatments. A list of the open-ended responses to the affirmative answer to the question is provided in Table D-8 in Appendix D. Most alternative treatments listed were related to crack maintenance, followed by microsurfacing and chip sealing, and to a lesser extent, alternate methods of using recycled materials.

3.6.3 Performance Monitoring

This question was asked to determine how preventive maintenance treatments are monitored and their performance measured. Respondents were able to choose any or all of the predetermined responses or utilize the "Other" response and fill in an open-ended response. Fixed responses included:

a. by measuring the life of the treatment (i.e., how long the treatment lasts),
b. by measuring the life of the pavement,
c. visual performance data is collected and interpreted (e.g., thermal cracking, fatigue cracking, raveling, bleeding),
d. measured performance data is collected and interpreted (e.g., rutting, friction, IRI),
e. don't know, or
f. other (please specify).

Overall, respondents indicated that visual and measured performance data are most commonly used to monitor the performance of preventive maintenance treatments (see Table 38). The next most common method is to measure the life of the treatment itself. The least common method is to measure the life of the pavement. Since respondents were able to choose multiple responses to this question, a more detailed analysis was conducted to determine potential cross links between certain measurement methods. Most participants responded by indicating that they use all of the suggested methods, followed by a combined response of option "c" and "d". These and other combinations are listed in Table 38. Most of the respondents that selected the "Other" option indicated that their state/province does not have a formal evaluation process. The open-ended responses are listed in Table D-9 in Appendix D.

Table 38: Tabulated Summary of Monitoring Methods

Method	Count	Percent[(1)]	Rank
a. treatment life	20	42.6	3
b. pavement life	12	25.5	4
c. visual performance data	30	63.8	1
d. measured performance data	29	61.7	2
e. don't know	0	0.0	---
f. other	8	17.0	---
Only a	1	2.2	6
Combination a+b+c+d	8	17.8	1
Combination a+c	4	8.9	3
Combination a+c+d	3	6.7	4
Combination a+d	2	4.4	5
Only b	1	2.2	6
Combination b+c+d	2	4.4	5
Only c	4	8.9	3
Combination c+d	7	15.6	2
Only d	4	8.9	3
Only e	0	0.0	---
Only f	5	11.1	---
Other multiple combinations	4	8.9	---

Notes: [(1)] Percent of respondents (out of the 45 total) that selected the monitoring method(s)

3.6.4 Deciding Factors

Survey participants were asked to rate the level of importance of specific factors with respect to selecting a preventive maintenance treatment. The five ordinal responses to each factor were "Not Important", "Somewhat Important", "Neutral", "Important", and "Very Important", which had the numerical values 1, 2, 3, 4, and 5 assigned to them, respectively. These numerical values were used to determine a mean response, which was ultimately used to rank their relative importance. Details of the responses are summarized in Table 39. In general, most respondents use their previous experience with a particular treatment to determine whether to continue using it, followed by ADT or number of trucks, location (urban or rural), and availability of contractors, equipment and materials, respectively. Those least used were weather; availability of design standard or design manual; availability of state equipment and workforce; and decision tree, respectively.

Table 39: Tabular Summary of Decision Factors

Factor	Count	*(1)	Percent(2)	Mean	St. Dev.	Rank
ADT or number of trucks	45	2	95.7	3.93	0.809	2
Location (urban/rural)	45	2	95.7	3.87	0.842	3
Weather (e.g., average rain or snowfall)	43	4	91.5	2.91	1.065	13
Conclusive research in the United States	45	2	95.7	3.07	0.863	9
Conclusive research in your state	45	2	95.7	3.62	1.007	5
Availability of contractors, equipment, and materials	45	2	95.7	3.84	0.852	4
Availability of state equipment and workforce	44	3	93.6	2.98	1.303	11
Availability of design standard or design manual	45	2	95.7	2.96	0.976	12
Life-cycle costs	44	3	93.6	3.39	1.017	7
Technique is easier to implement or install	44	3	93.6	3.34	0.963	8
Previous success or failure of a particular treatment	45	2	95.7	4.20	0.869	1
Method supported by FHWA, State DOT	45	2	95.7	3.58	1.177	6
Decision tree (combination of options)	44	3	93.6	3.00	0.988	10

Notes: (1) Number of respondents that skipped this factor; (2) Percent of respondents (out of the 47 total) that responded to the decision factor

4 SUMMARY AND CONCLUSIONS

4.1 Summary

An extensive literature review was conducted to synthesize past and ongoing research related to highway pavement maintenance and preservation techniques. The literature review was augmented with a web-based email survey that was distributed to all 50 US states, Washington D.C. and 11 Canadian provinces for a total of 62 recipients. The literature review and survey results provide interesting qualitative overviews of the state-of-the-practice of preventative maintenance treatments, and how these treatments are instigated, managed, and accessed by transportation department personnel throughout North America.

The literature review focused on treatment systems that are most commonly used in North America, including: crack sealing, thin overlays, chip seals, microsurfacing, cold in-place recycling, ultrathin friction courses, fog seals, slurry seals, cape seals, and scrub seals. Approximately 40 reports and technical papers were reviewed to explore the state-of-knowledge of these surface treatment measures with respect to treatment life and pavement life extension. Most of the studies were very site and material specific, and were usually based on relative comparisons between two or three different treatments. This report summarizes the most recent research results on treatment life and pavement life extension for the treatment systems. For most of the systems, there appears to be data available in terms of treatment life; however, there is very limited data available for quantifying the effects a treatment has on extending the pavement life.

Generally, specific studies have been conducted to determine how various construction alternatives, climates, traffic levels, etc. affect the life and effectiveness of preventive maintenance treatments. Few of these studies, however, considered the effect these treatments had on the life of the pavement. Most often, studies focused their attention on how long the treatment itself lasts. Therefore, very few life-cycle cost analyses have been conducted with respect to the pavement as a whole. Two main studies compared the effects of various treatments had on pavement condition or distress. Overall, according to Hall et al. (2003), thin HMA overlays appear to offer the greatest benefit, followed by chip seals, and slurry seals. Similarly, Jahren et al. (2003a) concluded that thin overlays also performed well. The most expensive treatments, in order of highest unit price cost, are ultrathin friction course, cold in-place recycling, and cape seal, and these also correspond to the highest average treatment life reported. The survey results generally parallel the information found in the literature.

In all, there were 47 individual responses to the survey from 34 US states and 5 Canadian provinces. The majority of respondents indicated they had greater than six years of experience, and most were generally responsible for managing some aspect of preventative maintenance within their state or province. Based on the responses that were received between December 13, 2005 and March 17, 2006, it appears the survey was successful in obtaining a significant percentage of respondents (47 respondents out of 62 jurisdictions) and the survey was successful in targeting individuals that are closely involved with the management of preventative maintenance systems. It appears the management of preventative maintenance systems is most often conducted at an agency's district or regional level with input from other areas or departments including maintenance, headquarters, planning, and upper management.

From a programmatic viewpoint, over 90% of North American states/provinces have a preventative maintenance program for pavements. Over half of these programs (~67%) are funded through a dedicated budget item, which reportedly varies over a large range from $2 million to $150 million. The average annual budget for preventative maintenance was about $40 million.

The survey results clearly indicate there is no standardized 'one size fits all' approach for selecting an appropriate preventative maintenance measure for a given roadway. About 70% of the jurisdictions have a written manual or decision tree that provides guidelines for preventative maintenance activities. The guidelines apparently provide a form of recommendations based most often on a combination of performance (pavement damage), timing, and cost in selecting the appropriate system for a given application. Pavement maintenance appears to be more of a remedial stopgap measure rather than a proactive or preventative function. Only 6 of the 47 respondents said that treatments were applied merely on a time schedule regardless of pavement performance.

Overall, respondents indicated that visual or measured data is collected to monitor the performance of treatments. These include measures such as: qualitative evaluation of thermal cracking, fatigue cracking, raveling, and bleeding or quantitative measures of rutting, friction, and roughness (IRI). However, once the decision is made to implement a treatment, it appears that most respondents base their selection of a particular system on their previous experience, followed by ADT or number of trucks, location (urban or rural), and availability of contractors, equipment, and materials. Information from the literature review supports the survey results, in that there are few, if any, well-documented and reliable quantitative approaches for selecting the optimum treatment system and for determining when the optimum time occurs for implementing a system. Consequently, this lack of quantifiable metric necessitates a heavy reliance on the experience of personnel and rules of thumb.

Interestingly, about 70% of the respondents indicate they do not require warranties for preventative maintenance treatments. Of the jurisdictions that require warranties, most are used for either microsurfacing or chip seals, and they are usually one to two years in duration.

There are numerous preventative maintenance treatments available; 16 were listed in the survey. The top five most frequently used systems were, in order:

1. crack sealing,
2. thin overlays,
3. chip sealing,
4. drainage features, and
5. microsurfacing.

Based on the survey results it appears that scrub, cape, and slurry seals are used much less frequently than the top five treatments listed above. This trend was indirectly confirmed in the course of the literature review, based on the lack of quantifiable field performance data.

4.2 Conclusions

Large amounts of money are expended annually by DOTs on highway preventative maintenance systems. Based on the extensive literature review and survey of transportation personnel conducted in this study, it is apparent that state- or region-specific research is critically important to ensure that funds are wisely used for extending the life of a pavement section or for repairing ailing pavement surfaces. An applied research program is recommended that includes the use of full scale highway test sections. It is suggested that the research program be structured to address the following critical aspects of treatment applications with a specific focus on Montana's rural, northern, and mountainous conditions:

1. What is the best treatment system for a given application (including climate, traffic volume, pavement surface condition, future plans for the system)?
2. When is the correct time in a pavement life to apply the treatment system?
3. For planning purposes, what is the expected useful life of the treatment, and what effect does the treatment have on the useful life of the original pavement surface/section?
4. What mix designs and construction practices work best for conditions typically encountered in Montana?

In conclusion, there is a scarcity of quantitative data and applicable information in the literature on research specifically conducted to examine the field performance and the effects that treatments have on pavement life expectancy. The ranges of reported life expectancies vary widely for these treatments, as does reported unit costs. This lack of conclusive data is attributed to variations in the many aspects of treatment systems, including: construction practices; emulsion types and concentrations; mix designs; climatic conditions; traffic volumes; aggregate type, texture and gradation; and the condition of the receptor pavement. There is clearly a need for additional research to quantify and enhance our understanding of the short and long-term effects that treatment systems have on highway pavement surfaces.

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Appendix A – Summary of Research Projects

Reference	Preventive Maintenance Treatment											No. of Test Sections or Type of Research	Parameters Considered					Type of Result		
	Crack Seal	Chip Seal	Slurry Seal	Thin Overlay	Fog Seal	Cape Seal	Scrub Seal	Ultrathin Friction Course	Microsurfacing	HIPR	CIPR		Roughness	Cracking	Rutting	Raveling	Other	Treatment Life Span	Pavement Life Span	Cost Information
Abernathy, 2004											x	6		x	x					
Bausano et al., 2004	x	x							x			240						x		
Bemanian et al., 2006											x	Statewide Study	x	x	x	x		x		x
Bergeron, 2005											x	195	x		x			x	x	x
Bolander, 2005		x	x	x	x	x	x		x			Lit. Review						x		x
Chong, 1989	x											37		x						x
Cook et al., 2004	x	x	x		x	x		x	x	x	x	Guide								
Cooper & Mohammad, 2004				x			x					3	x	x	x			x		x
Cuelho & Freeman, 2004	x											84		x			FWD	x	x	x
Davis, 2005		x										7		x						x
Forsberg et al., 2002											x	6		x		x				

(cont'd)	Preventive Maintenance Treatment											No. of Test Sections or Type of Research	Parameters Considered					Type of Result		
Reference	**Crack Seal**	**Chip Seal**	**Slurry Seal**	**Thin Overlay**	**Fog Seal**	**Cape Seal**	**Scrub Seal**	**Ultrathin Friction Course**	**Microsurfacing**	**HIPR**	**CIPR**		**Roughness**	**Cracking**	**Rutting**	**Raveling**	**Other**	**Treatment Life Span**	**Pavement Life Span**	**Cost Information**
Geoffroy, 1996	x	x	x	x					x			Survey						x	x	x
Gransberg & James, 2005		x										Lit. Review & Survey						x		
Gransberg & Musharraf, 2005		x										342	x	x	x	x				x
Hall et al., 2003 (SPS-3)	x	x	x	x				x				81	x	x	x			x		
Hicks et al., 2000	x	x	x	x	x	x			x			Lit. Review		x	x	x		x		x
Jackson et al., 2005	x	x	x		x			x				5				x	x			x
Jahren et al., 2003a		x	x	x	x	x		x	x			38	x	x	x	x		x		
Joseph, 1992	x											37								x
Kazmierowski et al., 1993									x			3	x	x	x	x			x	

(cont'd)	**Preventive Maintenance Treatment**											**No. of Test Sections or Type of Research**	**Parameters Considered**					**Type of Result**		
Reference	**Crack Seal**	**Chip Seal**	**Slurry Seal**	**Thin Overlay**	**Fog Seal**	**Cape Seal**	**Scrub Seal**	**Ultrathin Friction Course**	**Microsurfacing**	**HIPR**	**CIPR**		**Roughness**	**Cracking**	**Rutting**	**Raveling**	**Other**	**Treatment Life Span**	**Pavement Life Span**	**Cost Information**
Labi et al., 2006									x			56	x	x	x	x		x		
Morian et al., 1997 (SPS-3)	x	x	x	x								57	x	x	x		x	x		
Morian et al., 2004											x	44		x				x		x
Outcalt, 2001		x										4		x	x		FWD		x	x
Peshkin et al., 2004	x	x	x	x	x		x	x	x			Guide						x		x
Romero & Anderson, 2005	x	x	x	x								72	x				x	x		
Salomon & Newcomb, 2000											x	Lit. Review								
Sebaaly et al., 2004											x	3	x	x	x			x		

(cont'd)	Preventive Maintenance Treatment											No. of Test Sections or Type of Research	Parameters Considered					Type of Result		
Reference	Crack Seal	Chip Seal	Slurry Seal	Thin Overlay	Fog Seal	Cape Seal	Scrub Seal	Ultrathin Friction Course	Microsurfacing	HIPR	CIPR		Roughness	Cracking	Rutting	Raveling	Other	Treatment Life Span	Pavement Life Span	Cost Information
Smith & Beatty, 1999									x			Lit. Review			x		x			
Smith & Tighe, 2004				x				x				40	x					x		
Temple et al., 2002		x							x			Statewide Study	x	x	x		x	x		x
Wade et al., 2001		x			x	x						12		x	x	x	x			
Wade et al., 2001		x	x	x	x		x	x	x	x		Lit. Review	x	x	x	x	x			
Yichang et al., 2006												Guide		x	x	x	xx	x		x

Appendix B – Survey Instrument

Exit this survey >>

Montana Department of Transportation

Western Transportation Institute

Pavement Preventive Maintenance Survey

Introduction

This national survey is being conducted by the Western Transportation Institute for the Montana Department of Transportation to determine:
1) what type of pavement preventive maintenance efforts are currently in place in your state, and
2) how specific materials and techniques are being used and evaluated in your preventive maintenance program.

Your participation in this survey is important, so please take the time to complete it before the December 30, 2005 deadline. (The survey will take approximately 10 to 12 minutes to complete.)

All results are confidential and will be treated as such.

Thank you in advance for your time.

Next >>

Montana Department of Transportation

Western Transportation Institute

Exit this survey >>

Pavement Preventive Maintenance Survey

Page 1 of 3: Questions Regarding Your Personal Information

1. What state/province do you live in?

☐

2. How many years of experience do you have working with preventive maintenance of pavements?

0-1 ○ 1-2 ○ 3-5 ○ 6-10 ○ 10 or more ○

3. Briefly describe how your job activities relate to preventive maintenance of pavements.

<< Prev Next >>

Exit this survey >>

Montana Department of Transportation

MONTANA STATE UNIVERSITY

Western Transportation Institute

Pavement Preventive Maintenance Survey

Page 2 of 3: Questions Regarding Preventive Maintenance Program for Your State

4. Does your state currently have a preventive maintenance program for pavements?

Yes No Don't know

5. Does your state have a dedicated budget for its preventive maintenance program, and if so, what is the level of annual funding?

- Don't Know
- No
- Yes (please enter dollar amount)

6. Does your state have a manual or guidelines for their pavement preservation program?

- Don't Know
- No
- Yes (please specify if document is available and in what format)

7. Who or what position identifies the need for a preventive maintenance project (e.g., district, maintenance, design, local officials)?

8. How are pavements in your state identified for preventive maintenance treatments? (check all that apply)

- ☐ When funds are available
- ☐ They are regularly scheduled, regardless of pavement performance
- ☐ When pavement damage reaches a certain level
- ☐ A system combining timing, cost, treatment and performance is used (e.g., decision tree)
- ☐ Other (please specify)

9. What is the average time (in months) from nomination or project identification to...

...funding?

...design?

...construction?

10. Does your state require a warranty on preventive maintenance treatments?

- ○ No
- ○ Yes (list treatments warranted, for how long, and whether warranty bonds are required)

<< Prev **Next >>**

Montana Department of Transportation

MONTANA STATE UNIVERSITY
Western Transportation Institute

Pavement Preventive Maintenance Survey

Page 3 of 3: Questions Regarding Preventative Maintenance Treatments/Techr

11. How often are the following preventive maintenance treatments or methods used?

	Never heard of it	Don't know	Never	Not Very Often	Often	Very Often	Always
Crack Seal	○	○	○	○	○	○	○
Fog Seal	○	○	○	○	○	○	○
Cape Seal	○	○	○	○	○	○	○
Chip Seal	○	○	○	○	○	○	○
Ultra-thin Friction Coarse	○	○	○	○	○	○	○
Slurry Seal	○	○	○	○	○	○	○
Scrub Seal	○	○	○	○	○	○	○
Thin Overlay (with or without mill)	○	○	○	○	○	○	○
Microsurfacing	○	○	○	○	○	○	○
Hot In-Place Recycling	○	○	○	○	○	○	○
Cold In-Place Recycling	○	○	○	○	○	○	○
PCCP Diamond Grinding	○	○	○	○	○	○	○
PCCP Diamond Grooving	○	○	○	○	○	○	○
PCCP Undersealing	○	○	○	○	○	○	○
PCCP Dowel Retrofit	○	○	○	○	○	○	○
Maintenance of Drainage Features	○	○	○	○	○	○	○

12. Are there any other or new preventive maintenance treatments or methods (not listed above) currently being used in your state?

○ No
○ Yes (please list)

13. How are preventive maintenance treatments monitored and their performance measured? (check all that apply)

- [ ] By measuring the life of the treatment (i.e., how long the treatment lasts)
- [ ] By measuring the life of the pavement
- [ ] Visual performance data is collected and interpreted (e.g., thermal cracking, fatigue cracking, raveling, bleeding)
- [ ] Measured performance data is collected and interpreted (e.g., rutting, friction, IRI)
- [ ] Don't Know
- [ ] Other (please specify)

14. How important are the following factors when deciding whether to use a particular preventive maintenance technique?

	Not Important	Somewhat Important	Neutral	Important	Very Important
ADT or number of trucks	○	○	○	○	○
Location (urban/rural)	○	○	○	○	○
Weather (e.g., average rain or snowfall)	○	○	○	○	○
Conclusive research in the United States	○	○	○	○	○
Conclusive research in your state	○	○	○	○	○
Availability of contractors, equipment, and materials	○	○	○	○	○
Availability of state equipment and workforce	○	○	○	○	○
Availability of a design standard or design manual	○	○	○	○	○
Life-cycle costs	○	○	○	○	○
Technique is easier to implement or install	○	○	○	○	○
Previous success or failure of a particular treatment	○	○	○	○	○
Method supported by FHWA, State DOT	○	○	○	○	○
Decision tree (combination of options)	○	○	○	○	○

15. May we contact you for further information? If so, please list your contact information below. (We will not use your contact information for anything beyond the purposes of this survey)

Name	
Position Title	
Employer	
Phone Number	
Email Address	

Thank you for your participation!

<< Prev **Click here when finished**

Appendix C – Survey Participants

Numbers following each state or province indicate the number of surveys received.

Alabama (0)
Alaska (1)
Arizona (1)
Arkansas (1)
California (0)
Colorado (1)
Connecticut (1)
Delaware (1)
Florida (0)
Georgia (1)
Hawaii (2)
Idaho (0)
Illinois (1)
Indiana (1)
Iowa (1)
Kansas (1)
Kentucky (1)
Louisiana (0)
Maine (2)
Maryland (1)
Massachusetts (1)
Michigan (1)
Minnesota (1)
Mississippi (0)
Missouri (1)
Montana (6)
Nebraska (0)
Nevada (1)
New Hampshire (1)
New Jersey (1)
New Mexico (0)
New York (1)
North Carolina (0)
North Dakota (1)
Ohio (1)
Oklahoma (0)
Oregon (1)
Pennsylvania (1)
Rhode Island (0)
South Carolina (0)
South Dakota (0)
Tennessee (0)
Texas (0)
Utah (1)
Vermont (1)
Virginia (1)
Washington (1)
Washington D.C. (0)
West Virginia (0)
Wisconsin (1)
Wyoming (1)

Alberta (2)
British Columbia (1)
Manitoba (1)
New Brunswick (0)
Newfoundland and Labrador (0)
Nova Scotia (0)
Ontario (1)
Prince Edward Island (0)
Quebec (0)
Saskatchewan (1)

Appendix D – Summary Data from Survey Responses

Table D-1: Open-Ended Responses to Question 3

State/Province	Years Exp.	Briefly describe how your job activities relate to preventive maintenance of pavements.
Montana	10+	prioritize roadway maintenance needs within the Division, develop repair strategy, manage or oversee repair
Montana	10+	I am the Field Operations Manager for the Maintenance Division. My position involves overseeing maintenance operations on a statewide basis. Part of this oversight is reviewing and approving preventive maintenance treatments for MDT state maintenance projects.
Montana	10+	I help to develop on provide oversight over prev. maintenance programs.
Montana	3-5	I oversee Road Design activities, and currently review/approve the field review reports that are sent out for distribution at the start of the design process. Additionally, I expect to be involved in the revision of the 'Guidelines for Nomination and Development of Pavement Projects' which includes the process for preventive maintenance projects.
Montana	10+	As the Billings Area Maintenance Chief it is my responsibility to develop a pavement maintenance program for my area. A preventive maintenance program is a essential part of my overall pavement maintenance program
Manitoba	3-5	Manager of Asset Management Responsibilities include collecting and modeling pavement and treatment performance data related to provincial pavement preservation program.
North Dakota	10+	Our section handles the Pavement Preservation Program for the DOT
Alaska	10+	I recommend and approve preventive maintenance activities.
Arkansas	10+	I am a Staff Maintenance Engineer. I have worked as an engineer in the Maintenance Division for almost 33 years. I am involved in Maintenance Management and all phases of highway maintenance work.
Utah	10+	As Deputy Engineer for Maintenance, I help to manage the program of pavement preventive maintenance. This includes allocating budget to the various Regions/Districts, and overseeing the tracking of expenses on projects. Previously, as Pavement Management Engineer, I worked with the Engineer for Maintenance to develop recommendations for funding the preventive maintenance program, and made the case for preventive maintenance to our senior management and Transportation Commission.
Vermont	0-1	I am the Paving Program Manager, recently assigned. My program is responsible for the preventive maintenance program for the State Highway system.
New Jersey	10+	Responsible for pavement design and pavement management at NJDOT.

State/Province	Years Exp.	Briefly describe how your job activities relate to preventive maintenance of pavements.
Hawaii	1-2	Bituminous Engineer - responsible for asphaltic concrete and related materials, i.e. quality control, specifications. Also, Pavement Maintenance Task force leader involving implementation of preventive maintenance program - project prioritization, treatment selection, etc.
Washington	6-10	State Pavement Design Engineer. I provide and evaluate pavement rehab recommendations.
New Hampshire	0-1	I am the head of the Pavement Management Section at NHDOT. I provide the pavement recommendations for new construction projects as well as rehabilitation/resurfacing projects. The pavement management section is also responsible for collecting the condition data on the NH Roadway system and maintaining the Department's Pavement Management System (PMS).
Kansas	6-10	I am responsible for the pavement management system. The system uses optimization techniques to select locations and scopes of pavement projects including preventive maintenance activities. Kansas does not have a specific budget or mileage allotment for PM, but rather allows the system to trade between PM and rehab.
Oregon	3-5	I am the Pavement Management Engineer for ODOT. Out shop makes recommendations for sections to include for resurfacing in our surface preservation program. We also assist Districts with candidate selection for chip seal program.
Maine	3-5	1. I work as a Contracts Engineer developing Bid Documents including Specifications. 2. Work as part of a team evaluating roads within Maine that will receive a preventative maintenance treatment. 3. I am the project Manager of the Interstate system in Maine and I use preventative maintenance treatments.
Minnesota	6-10	I was the Pavement Preventive Maintenance Engineer for the department from 1/2003 to 10/2005.
Montana	10+	Responsible for Federal oversight of State DOT administration of the Federal Aid Highway program. Implementation of Federal Policy, determination of eligibility and compliance with regulations.
Alberta	3-5	I promote the use of preventive maintenance treatments for pavements. Provide information to staff through presentations and make myself available for questions. I also coordinate the selection of preventative maintenance projects for the department at the present time.
Colorado	3-5	My program has been charged with integrating preventive maintenance into the Pavement Management System. Part of this task is creating a Preventive Maintenance Manual that would include standard practices, specifications, etc... We are trying to promote uniformity and understanding throughout the state.

State/Province	Years Exp.	Briefly describe how your job activities relate to preventive maintenance of pavements.
Indiana	6-10	Evaluate effectiveness of and give guidelines on in-house crack and chip sealing, evaluate pavement deterioration and recommend appropriate treatments.
Ontario	10+	Pavement design & evaluation, materials engineering
Arizona	0-1	Manager of the section that is responsible for maintenance on a statewide basis.
Missouri	3-5	In my current position, I provide more information to my customers relating to new pavement design or rehabilitations. I am responsible for PM as a resource since I used to perform research on preventive maintenance treatments in my previous job.
Delaware	6-10	My job responsibility is to manage an approximate $40 million dollar paving list, $1.5 million dollar surface treatment list, and a $2 million dollar conversion list. I am also responsible for managing the consultant who performs our road rating collection of approximately 5772 miles of state-maintained segments. This data is then analyzed and researched to form a paving list of locations to be resurfaced or provided with a preventative maintenance technique to prolong the life of the segment and enhance the performance.
Pennsylvania	10+	My staff monitors and verifies project candidates for preventive maintenance programs, and issues design approvals. Also, through Pavement Management concepts, we determine roadway needs and appropriate treatments, including preventive maintenance.
Maine	6-10	I am the Assistant Program Manager of the Program that administers all of the pavement preventive maintenance project.
Hawaii	1-2	Bituminous engineer - develop specifications for asphalt related preventive maintenance treatments. Assigned to chair Statewide Pavement Maintenance Task Force - evaluate roads to prioritize and select projects.
Iowa	10+	Have overall coordination responsibility for contract maintenance funds. Any preventive maintenance projects come from these funds.
Illinois	1-2	I am responsible for revising special provisions on the various treatments we recently added to our preventive maintenance efforts. Project selection is handled by the individual districts.
Wisconsin	6-10	I am the pavement maintenance engineer
Kentucky	3-5	I work in the Pavement Management Section. We evaluate all Interstate and Parkway pavements and selected sections from all other roads. We determine treatment type and year needed. We also coordinate the Maintenance Rating Program.

State/Province	Years Exp.	Briefly describe how your job activities relate to preventive maintenance of pavements.
Saskatchewan	3-5	Responsible for Asset Management and Preservation Policies, Standards and Practices
British Columbia	10+	Provide advice and set standards
Alberta	6-10	Part of our PMS work activity is to identify pavement Rehab and Maintenance projects. Those maintenance subjects are further categorized into 3 levels of maintenance, of which some are preventive and some corrective.
Maryland	3-5	My job activities encompass the pavement management and pavement design aspects of preventative maintenance of pavements.
Virginia	1-2	I work in a research office where we study the effects of different maintenance options on pavement performance.
Georgia	10+	Responsible for annual evaluation of all state route pavement. Develop statewide pavement preservation program. Train personnel on preventive maintenance activities.
New York	10+	Pavement Preservation Engineer working in the Office of Operations Management in our Main Office.
Nevada	10+	We have a program with our Maintenance Division to perform preventive maintenance and a program for pavement preservation.
Wyoming	10+	Manage the WYDOT Pavement Management System, advise districts on maintenance applications, application selection, recommend materials for applications, write specifications for applications.
Ohio	1-2	I am monitoring performance of past preventive maintenance projects and approving future projects that meet our criteria.
Massachusetts	3-5	As the Pavement Rehabilitation Engineer in the Pavement Management Section, I am responsible for the selection of pavement preservation projects and their treatments.
Connecticut	*	*
Michigan	6-10	I am currently the Preventive Maintenance Engineer for the Michigan Department of Transportation. I have held this position for 3 years. Prior to that I worked in our pavement management unit. I have work a total of 14 years for the Department.

Table D-2: Open-Ended Responses to the Affirmative Response to Question 5

Does your state have a dedicated budget for its preventive maintenance program, and if so, *what is the level of annual funding*?
$77,000,000
$15,000,000 on the maintenance side
varies
Don't know
$35,000,000 - $55,000,000
$20,000,000 CDN [Canadian]
$16,000,000
$15,000,000
We do not have a dedicated budget, but expend about $40-$45,000,000 per year.
$2,000,000
$3,000,000
Approx. $20,000,000
$7,000,000
$70,000,000 plus depending on funding levels
established by SHA
approximately $10,000,000 [Canadian]
Minimum of 5% of Surface Treatment Program and $5,000,000 of maintenance dollars are to be used for preventive treatments. Approx. $12,000,000 minimum currently.
$150,000,000
$5,000,000
varies from year to year based on funding availability

Does your state have a dedicated budget for its preventive maintenance program, and if so, *<u>what is the level of annual funding</u>*?
$50,000,000 for Interstate/Expressways
$3,000,000
$87,000,000
varies
$100,000,000 [Canadian]
It is part of the overall system preservation program and the specific budget is dictated by the network condition, optimization inputs/constraints and the overall system budget.
$60,000,000
$8,000,000
$20,000,000
$40,000,000
Approximately $89,000,000

Table D-3: Open-Ended Responses to the Affirmative Response to Question 6

State/Province	Does your state have a manual or guidelines for their pavement preservation program?
Alaska	*
Alberta	Currently have a pavement preservation toolbox. This document is in word format
Alberta	A Pavement Preservation Guideline in pdf format, which is being revised.
Arizona	Materials Preliminary Engineering and Design Manual
Arkansas	*
British Columbia	*
Colorado	We have guidelines that were developed for individual treatments. They are not available in one location. We are developing a manual but it is not completed.
Connecticut	*
Delaware	We have a manual for our pavement management section which provides details involving preventative maintenance.
Georgia	electronic
Hawaii	Not sure
Hawaii	Word document
Illinois	Our Preventive Maintenance Guidelines may be found at the following link: http://www.dot.il.gov/desenv/pdf/pm47_05.pdf
Indiana	*
Iowa	*
Kansas	*
Kentucky	Pavement Management in Kentucky (Hard copy)
Maine	Not available. More of a compilation of experience, documents received at training and other handouts.
Maine	*
Manitoba	currently under development

State/Province	Does your state have a manual or guidelines for their pavement preservation program?
Maryland	*
Massachusetts	*
Michigan	A hard copy is available through our publications division. The manual is a little outdated but still has a lot of useful information.
Minnesota	Guidelines are in MSWord.
Missouri	*
Montana	contact PvMS
Montana	Guidelines for nomination and Development of Pavement Projects Preventative Maintenance>>>Reconstruction
Montana	Document available in word
Montana	'Guidelines for Nomination and Development of Pavement Projects' available on our intranet site, in the annual Pavement Conditions Report, and has been distributed to appropriate design, maintenance, and materials bureau personnel.
Montana	MDT has pavement preservation guidelines and is part of our agreement with FHWA
Montana	Policy signed between FHWA and MDT available on MDT website.
Nevada	In a Word file
New Hampshire	We maintain a Pavement Management System for this function. We also have a Pavement Review Committee which field reviews the candidate sections and selects the 'right' treatment.
New Jersey	Operations Bulletin in process of being adopted
New York	Chapter 10 of the Comprehensive Design Manual. This is available in pdf format from the Department's web site: www.dot.state.ny.us
North Dakota	Information is included in the Maintenance Operations Manual
Ohio	Available at: http://www.dot.state.oh.us/pavement/publications.htm
Ontario	Decision trees in pavement management system
Oregon	*

State/Province	Does your state have a manual or guidelines for their pavement preservation program?
Pennsylvania	PennDOT Publication 242
Saskatchewan	Not in great detail but Decision Matrix
Utah	UDOT's Pavement Management and Pavement Design Manual is available on the UDOT web page at http://www.dot.utah.gov/download.php/tid=120/PavementDesignManual.pdf. Appendix 3E, Pavement Life Strategy (page 3-79) is particularly pertinent to pavement preservation. UDOT is also in the process of developing additional guidance for internal use.
Vermont	*
Virginia	Not available
Washington	WSDOT Pavement Guide Interactive. Volume 1 is our Pavement Policy - PDF. Vol. 2 is an interactive DVD.
Wisconsin	*
Wyoming	*

Table D-4: Open-Ended Responses to Question 7

State/Province	Who or what position identifies the need for a preventive maintenance project (e.g., district, maintenance, design, local officials)?
Alaska	State Maintenance & Operations Director State Pavement Engineer District Maintenance & Operations Managers
Alberta	District staff identify the need for preventive maintenance project.
Alberta	Regional operation engineers identify the needs, including where when and activity. Head office staff helps ranking the projects.
Arizona	Multi-level. Districts are budgeted maintenance funds and Pavement Management has statewide funds
Arkansas	District
British Columbia	Three Regional Pavement Managers cover the Province.
Colorado	Many positions make this determination. The Pavement Management Program recommends potential projects in conjunction with the Region Materials Engineers and Region Maintenance personnel. Some projects come from recommendations and others from regional priorities.
Connecticut	In general, the District Maintenance Directors will identify and select project type and locations.
Delaware	A joint effort of our pavement management section, construction, materials and research, and maintenance.
Georgia	Combination of district and state maintenance
Hawaii	Currently statewide task force comprised of district representatives. Each district identifies own needs.
Hawaii	Statewide Maintenance Task Force comprised of District maintenance and design personnel.
Illinois	Currently we have a dedicated amount of funding for each fiscal year. The districts then select projects to meet the funding target.
Indiana	Combination of Maintenance (in-house treatments), Districts (resurface and thin overlays), and Central Office (overall system condition).
Iowa	District engineering staff.
Kansas	The project selection process is distributed. PMS identifies candidate project locations, but district personnel subselect from this list. The subselected list is then reviewed by upper managers.
Kentucky	District and Central Office
Maine	A combination of Regional/District Managers, Planning, Project Managers and myself.

State/Province	Who or what position identifies the need for a preventive maintenance project (e.g., district, maintenance, design, local officials)?
Maine	Combination of Pavement Management (Planning) and Region Staff (Project Development Personnel).
Manitoba	Asset Management Section together with regional maintenance staff
Maryland	District maintenance. We have a goal to develop preventative maintenance guidelines through the input of District maintenance, statewide maintenance, pavement management, and pavement design. Efforts have not been initiated to date.
Massachusetts	The Pavement Management Section selects the preventive maintenance candidates with the assistance and cooperation of District maintenance or design staff.
Michigan	Projects are selected by our local offices based on selection guidelines. The guidelines are based on pavement management data. Once selected the projects are reviewed by a larger group (including myself) to make sure they are meeting guidelines.
Minnesota	PMS annually identifies candidate projects. Districts (material sections)select the projects to be done. The candidate project greatly exceeds money available.
Missouri	
Montana	PvMS and/or Maintenance Chief
Montana	For maintenance, the field maintenance chiefs work with the District engineering staff to identify projects that can be performed by maintenance either by in house workforce or contracted out.
Montana	Includes district design, const and maint.
Montana	District Administrator, District Engineering Services (design), and District Maintenance work together with the annual pavement conditions report and knowledge of last work completed/next work needed. Our planning and pavement analysis people provide input and approval. For urban projects, local officials identify the projects.
Montana	District personnel which includes maintenance, construction, preconstruction, and lab personnel
Montana	District and Maintenance. Also could be local official proposal on eligible route.
Nevada	Our District's submit requests and they are prioritized by our Maintenance Division.
New Hampshire	The majority of our resurfacing projects are identified by the District Offices.
New Jersey	Pavement Management identifies candidate projects
New York	The Resident Engineer who is responsible for the maintenance of all state roads in a particular county.
North Dakota	District Engineer
Ohio	district

State/Province	Who or what position identifies the need for a preventive maintenance project (e.g., district, maintenance, design, local officials)?
Ontario	Regional design, district, & maintenance
Oregon	Collaborative effort between the District and the Pavement Management Engineer. Pavement Management Engineer suggests candidate projects. Districts utilize list or nominate others. Pavement Management Engineer must agree with all projects.
Pennsylvania	All
Saskatchewan	Asset Management, Preservation, Area and Section staff
Utah	Region/District Engineering Teams, led by the Region Pavement Management Engineer and receiving substantial input from the Region/District Maintenance Engineer, and input to a lesser extent from Region Materials Engineer, Region Director, and others.
Vermont	The Pavement Management Engineer - Mike Fowler
Virginia	District based on visual survey and video distress collection
Washington	Regional Offices - Program Management and Maintenance Offices.
Wisconsin	Maintenance and districts
Wyoming	District Until recently each of the 5 districts were allotted $2,000,000 for preservation and maintenance activities. The majority was usually spent on pavements. The dedicated funds are no longer available, but pavement preservation projects are still being programmed from other funds.

Table D-5: Open-Ended Responses to the "Other" Response to Question 8

Other (please specify)**
Pavements in poor condition are excluded from preventive maintenance, although in some cases a treatment intended for preventive maintenance is used in a corrective situation.
Traffic Volumes
nomination by district
All are being used depending on Region and program performing work. It is not done uniformly on a statewide basis.
Districts review segments annually for preventative maintenance treatments
When District staff identifies a need.
At request from District
Asset Management
District maintenance decision
Informal decision process involving pavement condition, timing, traffic changes, and cost.
Demonstration projects and cost effectiveness

***italicized responses are from respondents that answered "other" as their only response*

Table D-6: Open-Ended Responses to Question 9

What is the average time (in months) from nomination or project identification to...		
...funding?	**...design?**	**...construction?**
10 mo	24 mo	12 mo
0	1	2
2-3 years	few months	2-3 years
6	9	12 to 36
3 months	4 months	1 year
immediate	6 months	6 months
6	6	9
1-3months	1-3 months	3-6 months
<6	<2	12-Aug
funding already in place	varies 1 to 12 months	6 to 12 months
varies	*	1 year +
3-4 years	2 years	3-4 years
3	6	18
*	*	24
15 months	22 months	27 months
districts typically have money in a PM 'fund'	projects are identified in fall/winter.	Built in the following construction season.
SHA dependant	SHA dependant	SHA dependant
1 - 5 months	3 - 8 months	4 - 16 months
Anywhere from 3 months to two years depending on budget and whether engineering or maintenance is performing the work.	Immediately after funding approved depending on staffing.	Typically, funding is distributed in November for engineering and the projects begin the following spring. For maintenance, the projects are selected and constructed within the same Fiscal Year.
1	5	12

What is the average time (in months) from nomination or project identification to...		
...funding?	**...design?**	**...construction?**
0-12	0--12	0-12
4	4	4
6 months	9 months	12 months
up to 2 years	less than a year from programming	within a year of design
16	18	20
varies	approx one year	approx 18 mos
3	6	15
< 12 months	< 12 months	up to 18 months
?	?	12
3 Months	NA	9 Months - 1 Year
1 year	1 year	1 year
12 ?	18 ?	24 ?
7	7	10
*	*	12 -18 months
8 to 12	6 to 12	10 to 12
6 months	12 months	24 months
1 to 2	2 to 10	3 to 18
12	12	24
6 Months	N.A.	6 to 12 Months
funding is in place at time of selection	3 to 12 months	1 year

Table D-7: Open-Ended Responses to the Affirmative Response to Question 10

State/Province	Yes (list treatments warranted, for how long, and whether warranty bonds are required)
Montana	Not currently on the Maintenance side of the house but Engineering does utilize a warranty for Seal and Cover projects
Montana	moving toward warranty on chip seals
Manitoba	microsurfacing 2 years
Maine	We require that the project perform well for a year. after one year the DOT takes on the risk. The warranty is usually limited to raveling, de-bonding etc.
Minnesota	Two year warranty on some rout and seal contracts, with a performance bond.
Indiana	Only 1 - Microsurfacing. Spec requires a 3 year warranty, warranty bond is required for 100% of contract cost.
Ontario	one year or two year warranties on microsurfacing are sometimes used
Delaware	Districts and Construction could provide more details. It also depends on the product used and specifications of the contract.
Saskatchewan	just on Microsurfacing (1 year)
British Columbia	1 year, no bond
Virginia	We are investigating the use of warranties for HMA overlays of existing HMA pavements, but do not have it implemented yet.
New York	Chip seal - 1 year
Ohio	All PM treatments warranted for 2-3 years. Warranty bonds are required.
Michigan	generally two years for pavement sealing (chip seals, micros, etc.) and 3 years for one course hma overlays. warranty bonds are required.

Table D-8: Open-Ended Responses to the Affirmative Response to Question 12

Are there any other or new preventive maintenance treatments or methods (not listed above) currently being used in your state?
High Float Surface Treatment 'Banding' - HMA patching of large cracks
Open Graded Surface Course Bonded Wearing Course (Novachip) Stone Matrix Asphalt Asphalt Surface Rejuvenation Lane Leveling Concrete Joint Sealing and Joint Spall Repair
slab jacking with urethane grout
surface recycling (that I included as hot in place above)
Summer of 2006 we are planning on trying Nova Chip which may be considered a thin friction coarse.
Developing a 'flexible' micro-surface. To replace tight blade leveling.
Crack Filling - Fill crack without routing Spray patch
We utilize partial and full depth concrete pavement repair as a preventive treatment if repair of isolated slabs will prevent additional damage to surrounding pavement that is still in good/fair shape.
PCCP cross-stitching
Depressed Transverse Crack Machine, developed in SK, fixing DTCs.
Rubberized Chip Seal will be tried for the first time this year.
crack relief layers

Table D-9: Open-Ended Responses to the "Other" Response to Question 13

Other (please specify)
We have worked very hard to develop the PM program and specifications. A detailed statistical research evaluation of performance has not been done.
Items checked are done regularly but we do not currently have a good process of documenting findings.
No specific measurement method is used.
Illinois' dedicated preventive maintenance program is only two years old and only includes chip seals, slurry seals, micro-surfacing, cape seals, and a treatment we call Half SMART (a 3/4 inch leveling binder lift followed by a chip seal). Currently we are just conducting visual surveys of the projects.
We're not monitoring, we should be.
It is done within the confines of network monitoring. There is not any specific evaluation of preventative maintenance treatments.
No formal evaluation process
Cost
***italicized responses are from respondents that answered "other" as their only response*

150 copies of this public document were produced at an estimated cost of $2.15 each, for a total cost of $322.50. This includes $127.50 for postage and $195.00 for printing.