

Cost Effectiveness of the MDOT Preventive Maintenance Program Final Report

Prepared For:

Michigan Department of Transportation
Bureau of Field Services
Research Administration
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April 2013

providing engineering solutions to improve pavement performance

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16. Abstract

The Michigan Department of Transportation's (MDOT) pavement preservation program dates back to 1992. MDOT's pavement preservation strategy is primarily implemented through its capital preventive maintenance (CPM) program, in which preventive maintenance treatments are used to protect existing pavement surfaces, slow deterioration, and correct surface deficiencies. An overall objective of the CPM program is to postpone major rehabilitation and reconstruction activities by extending the service life of pavements.

This study evaluated the benefits and costs of various preventive maintenance treatments used in MDOT's CPM program. Defining the benefit as the percent increase in performance over a "do nothing" or untreated pavement performance curve, where data were available benefits were calculated for preventive maintenance treatments. Using unit costs, benefit-cost ratios were calculated, permitting the comparison of the cost-effectiveness of similar treatments. The overall performance of MDOT's CPM program was also examined by comparing the life-cycle costs (LCC) of a rehabilitation strategy to a preservation strategy using a simplified approach. The outcome showed that the preservation strategy results in agency cost savings of approximately 25 percent per lane-mile over the rehabilitation strategy.

Findings from this study can be used to help MDOT improve its CPM project selection, treatment selection, and performance monitoring and modeling practices.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

ACKNOWLEDGMENTS

This project could not have been conducted without the assistance and guidance provided by numerous MDOT employees. Their tireless efforts in providing data for this study, in reviewing and critiquing the research team's work approach, and in helping to establish values for use in the data analysis strongly contributed to a refined final product. The research team specifically acknowledges the contributions of the following MDOT staff:

- Pat Allen
- Andy Bennett
- Wendi Burton
- Erin Chelotti
- Andre Clover
- Kevin Kennedy
- Benjamin Krom

Dr. Tim Colling and Mr. Gary Schlaff of Michigan Technological University were responsible for working with various MDOT databases to generate a dataset that could be used for this analysis. Their contributions were instrumental in the completion of this project.

EXECUTIVE SUMMARY

Background

The Michigan Department of Transportation's (MDOT's) formal involvement in preventive maintenance activities dates back at least to 1992 with the development of the Capital Preventive Maintenance (CPM) Program. Since then, the use of various preventive maintenance treatments in Michigan has grown substantially. Where the program started with approximately $6 million in funding in the first year, by the end of the 1990s funding had grown to over $55 million and in recent years has fluctuated in a range from approximately $80 million to $100 million annually. This level of activity makes Michigan's CPM program one of the largest, and possibly most successful, in the United States.

MDOT employs a comprehensive pavement preservation strategy. This starts with a very broad range of treatments that are defined as preventive maintenance, shown in table ES-1.

Table ES-1. MDOT capital preventive maintenance treatments (MDOT 2010).

Pavement Seals	Functional Enhancements
• HMA Crack Treatment • Concrete Crack Treatment • Concrete Joint Resealing With Minor Spall Repair • Overband Crack Fill—Pretreatment • Chip Seals • Micro-surfacing • Ultra-Thin HMA Overlay—Low and Medium Volume (< 1 inch thick) • Paver Placed Surface Seal • Shoulder Fog Seal	• Non-Structural HMA Overlay (1.5 inches) • Surface Milling with Non-Structural HMA Overlay (1.5 inches) • HMA Shoulder Ribbons • Full Depth Concrete Pavement Repairs • Diamond Grinding • Dowel Bar Retrofit • Concrete Pavement Restoration* • Underdrain Outlet Clean Out and Repair

* Includes Joint Spall Repair, Surface Spall Repair, Joint/Crack Sealing, Full Depth Repairs and Diamond Grinding.

The primary intent of the CPM program is to postpone major rehabilitation and reconstruction activities by extending the service life of the original pavement. The MDOT CPM program uses pavement seals to target pavement surface defects primarily caused by the environment and pavement material deficiencies. Occasional structural deficiencies are also corrected by this program.

Study Purpose and Scope

In 2010 MDOT initiated a study of its CPM program, *Cost Effectiveness of the MDOT Preventive Maintenance Program* to evaluate the performance and cost benefits of their preventive maintenance treatments and evaluate the overall cost effectiveness of the CPM program. Specific project objectives included the following:

- *Determine the costs and benefits of each pavement preventive preservation option used by MDOT*: identify and document available cost information and appropriate measures of benefit for MDOT's preventive maintenance treatments.

- *Document the cost and benefits of the MDOT pavement preservation program*: based on the assessment of the individual preventive maintenance treatments and other information, evaluate the overall cost effectiveness of MDOT's CPM program.
- *Determine the variability in the costs and benefits of each pavement preservation option relative to the types of pavement distress and the timing of the treatment application*: characterize the effect of variables such as pavement condition and timing of treatment placement on the ultimate cost effectiveness of each treatment.
- *Establish a relational matrix for the selection of time, location, and pavement preservation option for a given pavement project and pavement surface distresses*: develop a tool that can be used to help MDOT to select the most cost effective preventive maintenance treatment based on the factors that affect treatment performance.

Summary of Research Findings

Preventive Maintenance Treatment Performance

Performance of the CPM treatments was analyzed by calculating the pavement service life extension, benefit area, and benefit-cost ratios. Analyses were only feasible for HMA-surfaced pavements, which were divided into flexible pavements (conventional HMA pavements) and composite pavements (HMA surface on an underlying portland cement concrete pavement). After examining performance by MDOT Region, analyses were also divided by climatic zone, where Zone 1 includes the Superior and North Regions and Zone 2 includes Grand, Bay, Southwest, University, and Metro Regions.

Overall, the microsurfacing and HMA mill and overlay treatments provide the longest service life extension (up to 12 years). HMA crack sealing was the most common treatment being used and it provides a service life extension of up to 3 years. In this study crack sealing is analyzed in two ways. First, it is addressed as a stand-alone CPM treatment in which its impact on pavement performance and its cost-effectiveness are discussed. However, crack sealing is commonly used as a planned, routine maintenance activity. As such, in discussion with MDOT it was decided not to treat crack sealing as a treatment that reset the treatment cycle. As shown in table ES-2, other treatments provided service life extensions ranging from 2 to 8 years.

The life extensions are computed using the performance models developed using Distress Index (DI) data. It is to be noted that average DI values at a given pavement age were used in the modeling efforts. The life extension values are driven by the pre-treatment pavement performance also, and the pre-treatment models are different for each zone and pavement type. The pre-treatment models are not treatment-specific and were developed using the entire data set to avoid any bias in the analysis and also to have a common reference for comparison.

In general, it was noted that the majority of the preventive maintenance treatments are placed on pavements that have DI values between 0 and 25, which generally represents pavements in *fair* or better condition. The data suggests that MDOT's CPM program is extending the service life of these pavements; however, care should be taken to select appropriate candidates for preservation in conjunction with the appropriate treatments to maximize the benefit.

Cost effectiveness was determined by calculating a benefit-cost ratio for each treatment, defined as the ratio of the percent area benefit obtained post-treatment compared to the pre-treatment performance divided by the unit cost of the treatment. The results are shown in table ES-3.

Table ES-2. Summary of pavement service life extensions.

Treatment	Pavement Type	Life Extension (Years)		
		All	**Zone 1**	**Zone 2**
Single Chip Seal	Flexible	4.3	2.7	6.6
	Composite			
Double Chip Seal	Flexible	6.9		
	Composite		1.9	
Double Microsurfacing	Flexible	3.5	7.8	1.8
	Composite	9.8		11.6
HMA Crack Seal	Flexible	2.8	2.8	0.6
	Composite	0.9	2.1	1.6
HMA Mill & Overlay	Flexible	7.9		7.8
	Composite	3.6	8.5	5.3
HMA Overlay	Flexible	3.6		4.0
	Composite	3.2		2.2

Table ES-3. Calculated benefit-cost ratios for selected treatments.

Treatment	Benefit-Cost Ratios					
	Flexible Pavements			**Composite Pavements**		
	All	**Zone 1**	**Zone 2**	**All**	**Zone 1**	**Zone 2**
Single Chip Seal	0.22	0.11	0.48			
Double Chip Seal	0.18			0.14		
Double Microsurfacing	0.09	0.26	0.10	0.24		0.21
HMA Crack Seal	0.46	0.46	0.15	0.19	0.80	0.19
HMA Mill and Overlay	0.11		0.18	0.06	0.16	0.08
HMA Overlay	0.10		0.14	0.03		0.06

For flexible pavements, HMA crack seals have the highest benefit-cost ratio when data from all the zones are considered together. Comparing single chip seals, double chip seals, and double microsurfacing, the single chip seals have the highest benefit-cost ratios for flexible pavements (overall and Zone 2). For Zone 1, microsurfacing has a higher benefit-cost ratio than single chip seals. Overall, the microsurfacing and HMA overlays (with and without milling) have the lowest benefit-cost ratios for flexible pavements.

For composite pavements, microsurfacing has the highest benefit-cost ratios, followed by crack seals, double chip seals, and HMA overlays when all the zones are considered together. Microsurfacing has a higher benefit-cost ratio when compared to HMA overlays in both Zones 1 and 2.

It should be noted that benefit-cost ratios, while a measure of the cost effectiveness of a preventive maintenance treatment, should not be used as the sole determining factor in selecting these treatments. For example, crack sealing has a relatively high benefit-cost ratio primarily because of its low costs. However, crack sealing serves a very specific purpose (i.e., it's most effective on transverse thermal cracks, longitudinal paving joints, and reflection cracks, and not very effective on alligator cracking). In treatment selection, considering benefit-cost ratios in conjunction with an assessment of the applicability of the treatment to the existing pavement condition is necessary to achieve a long lasting preventive maintenance treatment.

Performance of the MDOT CPM Program

The impact of the first CPM treatments placed after a major rehabilitation/reconstruction activity and the CPM treatments placed after the first application a CPM treatment (post-first CPM treatments) were analyzed separately. The post-first CPM treatments are not applied consistently; for example, a chip seal may be placed on a segment with an existing chip seal or on a segment that already has a thin HMA overlay. Since the existing surface conditions on which the post-first CPM treatments are placed vary significantly, the anticipated performance is also expected to vary considerably. Hence, only the overall performance of post-first CPM treatments was evaluated rather than evaluating the performance on a treatment-by-treatment basis.

The average pavement service life extension and the benefit area obtained from the MDOT CPM treatments are summarized in table ES-4. The CPM treatments (the combination of first applications and all subsequent [post-first] applications) increase the service life of flexible pavements by around 16 years, with an overall benefit "area" of around 70 percent over the pre-treatment pavement performance. For composite pavements, the CPM treatments (including first and post-first treatments) increase the pavement service life by around 15.5 years, with an overall benefit area of around 50 percent over the pre-treatment pavement performance.

The average DI of the pavements prior to the application of the preventive maintenance treatments ranges from 15 to 25, which is within the range of prescribed threshold values in the MDOT CPM manual. This suggests that a vast majority of the preventive maintenance treatments are being applied to pavements with the true intention of preserving the existing structure.

Table ES-4. Treatment benefit from CPM treatments.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
First CPM Treatments	Flexible	All	7.9	38
		Zone 1	7.6	31
		Zone 2	10.2	51
	Composite	All	8.9	32
		Zone 1		
		Zone 2	6.5	32
Post-first CPM Treatments	Flexible	All	8.0	35
		Zone 1		
		Zone 2		
	Composite	All	6.6	20
		Zone 1		
		Zone 2		

A simplified life-cycle cost analysis was conducted for both a rehabilitation strategy and a CPM strategy using the statewide average rehabilitation and CPM costs provided by MDOT. While this analysis is not rigorous, it does provide a simple way to compare the cost effectiveness of a rehabilitation strategy to that of a CPM strategy. The results show that MDOT's CPM program has generated an average savings of almost $310,000 per lane-mile for flexible pavements, and around $265,000 per lane-mile for composite pavements when compared to a rehabilitation-only strategy while providing service life extensions of around 16 years.

Conclusion

This study evaluated the performance and benefits of various preventive maintenance treatments used by MDOT as a part of its preventive maintenance program and the overall effectiveness of MDOT's Capital Preventive Maintenance Program. The findings show how MDOT's CPM program is helping to preserve MDOT's pavements and delaying the need for major rehabilitation or reconstruction activities. The findings support the contention that MDOT's practice of maintaining existing good roads in good condition is both economically and environmentally sustainable. However, care should be taken to select appropriate candidates for preservation in conjunction with the appropriate treatments to ensure maximum benefit and performance.

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1. INTRODUCTION

Background

The Michigan Department of Transportation's (MDOT's) formal involvement in preventive maintenance activities dates back at least to 1992 with the development of the Capital Preventive Maintenance (CPM) Program. Since then, the use of preventive maintenance in Michigan has grown substantially. Where the program started with approximately $6 million in funding in the first year, by the end of the 1990s funding had grown to over $55 million and in recent years has fluctuated in a range from approximately $80 million to $100 million annually. This level of activity makes Michigan's one of the largest, and possibly most successful, preventive maintenance programs in the United States.

At the same time, when it comes to preventive maintenance Michigan experiences some of the same issues that almost every other agency faces, including an incomplete understanding of the benefits of preventive maintenance and difficulty in documenting those benefits. A range of approaches may be used to extract the best performance from Michigan's preventive maintenance actions. These include considering average extended service lives (ESLs) for each treatment, the individual's experience in using treatments in the past, what can be learned from other Regions, and so on. But in general, while MDOT's Regions tend to have a good understanding of the initial costs of their preventive maintenance activities, there is little objective information available on the benefits provided by the various treatments or, for that matter, the long-term costs associated with obtaining those benefits.

There is broad interest in knowing where and when treatments should be applied to generate the greatest "bang for the buck." MDOT, like several other agencies, has tried to answer this question several times. For example, Larry Galehouse, one of the architects of MDOT's preventive maintenance program, specifically addressed this issue (1998), noting that over the first 5 years of Michigan's CPM Program, the $80 million that was spent on preventive maintenance was approximately fourteen times less than the amount that would have been spent had rehabilitation and reconstruction been performed on the same pavements. This has been interpreted by some to mean that preventive maintenance is fourteen times more cost effective than rehabilitation, even though the results indicate nothing of the sort. Galehouse also estimates a cost savings of $700 million over that same 5-year period, suggesting by some simple math that preventive maintenance provides a cost-effectiveness benefit of 9 to 1. Again, the results do not explicitly support that interpretation.

Bellner and Associates (2001) also considered this issue of the cost effectiveness of MDOT's pavement preservation practices in *Effectiveness of the Capital Preventive Maintenance Program*. In their extensive review of MDOT's program, Bellner and Associates make several very useful observations of the performance of selected preventive maintenance treatments placed between 1995 and 2000. Most of the observations of effectiveness were related to the average ESL in the CPM program guidelines, individual performance measures, or comparisons of one type of treatment or treatment variation to another. It is not known where these average ESLs came from, and again comparing actual ESLs to average expected ESLs does not constitute an analysis of cost effectiveness. As such, despite the implication in its title, Bellner's study does not go so far as to permit a true analysis of CPM cost effectiveness.

Peshkin et al. (2004) examined the cost effectiveness of MDOT's chip seal and crack seal efforts as part of an NCHRP study on optimal timing of preventive maintenance. As a case study, MDOT provided the NCHRP study team with the same data that Bellner and Associates examined in 2001, and the results were analyzed to determine the most cost effective time to apply those treatments. However, the study did not consider all of MDOT's treatments, nor did it address whether the treatments were cost effective, but rather when they were most cost effective.

MDOT CPM Program

The Michigan Department of Transportation employs a comprehensive pavement preservation strategy. This starts with a very broad range of treatments that are defined as preventive maintenance. There are two subgroups of treatments in the CPM program: *Pavement Seals* and *Functional Enhancements* (MDOT 2010). The current list of treatments is presented in table 1.1.

Table 1.1. MDOT capital preventive maintenance treatments (MDOT 2010).

Pavement Seals	Functional Enhancements
• HMA Crack Treatment • Concrete Crack Treatment • Concrete Joint Resealing With Minor Spall Repair • Overband Crack Fill—Pretreatment • Chip Seals • Micro-surfacing • Ultra-Thin HMA Overlay—Low and Medium Volume (< 1 inch thick) • Paver Placed Surface Seal • Shoulder Fog Seal	• Non-Structural HMA Overlay (1.5 inches) • Surface Milling with Non-Structural HMA Overlay (1.5 inches) • HMA Shoulder Ribbons • Full Depth Concrete Pavement Repairs • Diamond Grinding • Dowel Bar Retrofit • Concrete Pavement Restoration* • Underdrain Outlet Clean Out and Repair

* Includes Joint Spall Repair, Surface Spall Repair, Joint/Crack Sealing, Full Depth Repairs and Diamond Grinding.

MDOT's CPM program is intended to protect existing pavement surfaces, slow deterioration, and correct surface deficiencies. Deterioration caused by the environment or material deficiencies are more likely targets than those caused by traffic loadings, although occasional structural deficiencies may be addressed by the program. An overall objective of the CPM program is to postpone major rehabilitation and reconstruction activities by extending the service life of the original pavement.

Study Purpose and Scope

The purpose of this study is to evaluate the performance and cost benefits of the various preventive maintenance treatments being used by MDOT and make observations regarding the overall cost effectiveness of the CPM program. This study responds to a very important need for MDOT that has not been adequately addressed in the past. The results of this research study will help MDOT in determining which treatments are cost effective, when they are cost effective, and when they should not be used.

Project Objectives

The objectives of the study are identified in the MDOT research problem statement and are summarized below, with an elaboration of each objective:

- *Determine the costs and benefits of each pavement preventive preservation option used by MDOT*: identify and document available cost information and appropriate measures of benefit for MDOT's preventive maintenance treatments.
- *Document the cost and benefits of the MDOT pavement preservation program*: based on the assessment of the individual preventive maintenance treatments and other information, evaluate the overall cost effectiveness of MDOT's CPM program.
- *Determine the variability in the costs and benefits of each pavement preservation option relative to the types of pavement distress and the timing of the treatment application*: characterize the effect of variables such as pavement condition and timing of treatment placement on the ultimate cost effectiveness of each treatment.
- *Establish a relational matrix for the selection of time, location, and pavement preservation option for a given pavement project and pavement surface distresses*: develop a tool that can be used to help MDOT to select the most cost effective preventive maintenance treatment based on the factors that affect treatment performance.

Research Approach

The flowchart in figure 1.1 illustrates the overall research approach. Details on each task shown in the flowchart are also presented in this section.

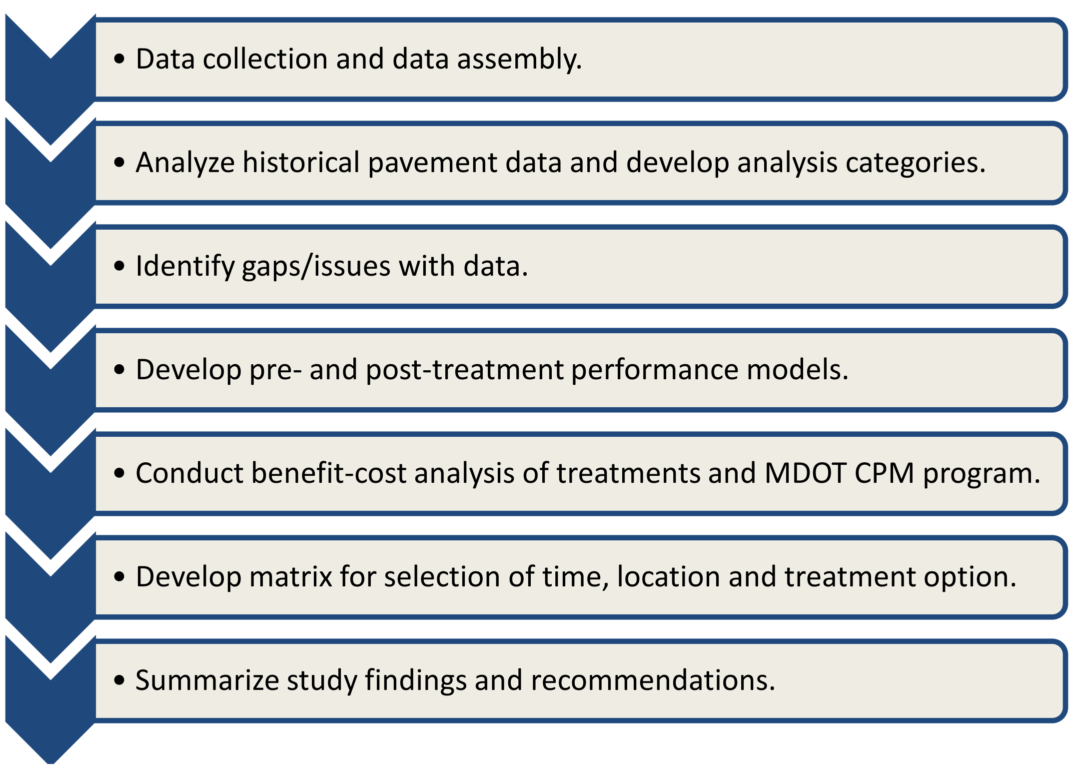

Figure 1.1. Flowchart describing the research approach.

Data Collection and Data Assembly

The first step was to identify the key data that would be used in the analysis and compile those data in a database. The following data elements were eventually identified:

- Pavement inventory information:
    - Route name, type, number, and MDOT region.
    - Beginning and End Mile Points of each project included in this study.
    - Pavement Functional Classification (Interstates/Other Freeways, Other Principal Arterials, Minor Arterials, Major and Minor Collectors).

- Pavement type (Flexible, Composite, Rigid).

- Work history:
    - Rehabilitation and/or reconstruction dates.
    - Preventive maintenance treatment dates.

- Historical pavement performance data:
    - Distress Index (DI).

- Traffic Data.
    - Annual Average Daily Traffic (AADT).

This data request was submitted to the MDOT and then Michigan Technological University (MTU) collected the raw data provided by MDOT and compiled it in an Access® database. Detailed information on the data collection and data assembly efforts is provided in Chapter 3.

Analyze Historical Pavement Data and Develop Analysis Categories

Once all available pavement data were provided by MDOT, researchers conducted a detailed analysis of the data to sort through and identify information relevant to the scope of this study. Those results were then used to develop a project-specific database for easy data access and retrieval.

The analysis categories included the following: pavement type (flexible, composite, or rigid), MDOT Region (used as a pseudo-variable to capture the effects of climatic zones), and functional classification (Interstates/Other Freeways, Other Principal Arterials, Minor Arterials, Major and Minor Collectors). Traffic (AADT) was included as an analysis category in the initial matrix, but since no reasonable trends could be discerned, it was omitted from the final analysis matrix.

Develop List of Gaps in Data

The initial review of the collected data indicated there were gaps in the dataset. A list of those was developed and ways to address these gaps in the analysis were proposed to MDOT. Most of the gaps were due to insufficient data available for a few preventive maintenance types. A list of treatments that were excluded from this study (after discussion and approval from MDOT) is discussed in Chapter 3.

Develop Performance Models

Using the data collected in the tasks discussed above, pavement performance models were developed that address the application of surface treatments commonly used by the MDOT. The following treatments were initially included in this study: single chip seals, double chip seals, HMA crack seal/treatment, ultra-thin HMA overlay, double microsurfacing, paver placed surface seal, HMA mill and overlay, HMA overlay, concrete pavement rehabilitation, and concrete joint/crack seal. In this study crack sealing is analyzed in two ways. First, it is addressed as a stand-alone CPM treatment in which its impact on pavement performance and its cost-effectiveness are discussed. However, crack sealing is commonly used as a planned, routine maintenance activity. As such, in discussion with MDOT it was decided not to treat crack sealing as a treatment that reset the treatment cycle.

Where there were sufficient data, performance of treated pavements was compared to performance of the pavement prior to the placement of the treatment to establish the impact of each type of treatment and also to characterize the improvements to the pavement condition and the service life extension as a result of the treatment. The modeling efforts are described in detail in Chapter 4.

Benefit-Cost Analysis

APTech established the benefits and cost associated with each of the pavement preservation treatments investigated in this study. Unit costs were used in the benefit-cost analysis, which is described in Chapter 4. The benefit-cost ratio associated with each pavement preservation treatment was computed and used to determine the most cost-effective treatment. In addition to assessing the benefits associated with each individual treatment, the overall cost effectiveness of the MDOT CPM program was also examined and is described in Chapter 5.

Develop Preventive Maintenance Treatment Selection Matrix

APTech summarized the results of the analysis conducted in this project in the form of a treatment selection matrix in which the cost effectiveness of each treatment is presented over the available range of conditions. The matrix can be used to assist those who are involved in the selection of the time of application, location, and the treatment option for a given set of conditions. This is discussed in further detail in Chapter 5.

Summarize Study Findings and Recommendations

The results of the analysis efforts and the recommendations for MDOT are presented in detail in this report. The findings from this study can be incorporated into MDOT's CPM manual or other appropriate document.

Report Organization

This report consists of six chapters (including this one) and three appendices, as summarized below:

- Chapter 2: Literature Review.
- Chapter 3: Data Collection and Data Assembly.
- Chapter 4: Preventive Maintenance Performance and Cost Analysis.
- Chapter 5: MDOT Capital Preventive Maintenance Program
- Chapter 6: Conclusions, Recommendations, and Implementation.

- Appendix A: Annotated Bibliography.
- Appendix B: Treatment Benefit Calculations.
- Appendix C: Implementation Plan.

This chapter presented a brief history on the use and benefits of preventive maintenance treatments in Michigan, purpose and scope of this study, and the research approach. The following chapter presents a review of literature focusing on performance and benefits of various preventive maintenance treatments.

2. LITERATURE REVIEW

Introduction

The cost effectiveness of preventive maintenance is an important issue to many highway agencies and researchers. The particular issue of costs and effectiveness has been studied by many agencies, including Michigan (Bausano et al. 2004; Galehouse 2002), Texas (Chang et al. 2005; Chen et al. 2003), Indiana (Labi et al. 2005; Labi et al. 2006; Labi et al. 2007), Arizona (Peshkin 2006; Smith et al. 2005), Ontario (Wei and Tighe 2004) and Utah (Romero and Anderson 2005). At the national level, there have also been several wide-ranging studies analyzing some aspect of maintenance treatment cost-effectiveness. These include the following: case studies by Baladi et al. (2002), a synthesis of preventive maintenance treatment practice by Cuelho et al. (2006), Geoffroy's ground-breaking work on cost-effective preventive maintenance (1996), a study by Hicks et al. of preventive maintenance versus reconstruction (2001), Mamlouk and Zaniewski's work on optimizing pavement preservation, the SPS-3 and SPS-4 studies performed as part of SHRP and reported on by Morian et al. (1997), and Peshkin et al.'s work on optimal timing (2004).

Michigan's involvement in preventive maintenance activities dates back to the early 1990s, and as such Michigan is one of the few states that has generated sufficient data to carry out a cost-effectiveness analysis. The literature shows that many aspects of Michigan's preventive maintenance program have been studied, including treatment life (Bausano et al. 2004), life cycle cost analysis practices (Chan et al. 2008), treatment options (Galehouse 2002), warranties (Kennedy 2005), and thresholds for treatment selection (Lee and Chatti 2001). Michigan has also been included or highlighted in several national studies, including the NCHRP study of optimal timing conducted by Peshkin et al. (2004).

A large number of the reports included in the annotated bibliography (Appendix A) address treatment effectiveness and/or costs. For the most part, these terms, and especially the combined term "cost effective," are used loosely without a broadly accepted definition. In some instances the term is part of the research or title of a report in which the concept is never actually addressed. Others seem to focus either on treatment performance or treatment life only (i.e., an element of effectiveness) or on costs (such as life-cycle costs), but not on properly combining the two. However, in their work on optimal timing of preventive maintenance Peshkin et al. (2004) do address the cost effectiveness of preventive maintenance and present a rational methodology for assessing cost effectiveness.

The literature review summarizes the experiences of various state and federal agencies on the performance benefits and effectiveness of various preventive maintenance treatments applied on hot-mix asphalt (HMA) and portland cement concrete (PCC) pavements. In addition, the National Cooperative Highway Research Program (NCHRP) 523 Study (Peshkin et al. 2004) that investigated the optimal timing and benefits associated with preventive maintenance treatments, the Long Term Pavement Performance (LTPP) Specific Pavement Study-3 (SPS-3) which focused on the performance monitoring of selected preventive maintenance treatments since 1990, and a study that used a life-cycle cost technique to compare benefits of pavement preservations are also discussed in this chapter.

Literature Review

In addition to findings from state and federal agencies, this literature review focuses on the following studies which are particularly relevant to this project:

- National Cooperative Highway Research Program (NCHRP) 14-14 Study – *Optimal Timing of Pavement Preventive Maintenance Treatment Applications*. (Peshkin et al. 2004)
- Long Term Pavement Performance (LTPP) Specific Pavement Study -3 (SPS-3) – *Analysis of Completed Monitoring Data for the SPS-3 Experiment*. (Morian et al. 2011)
- *Life Cycle Cost-Based Pavement Preservation Treatment Design.* (Pittenger et al. 2011)

The studies listed above are discussed in the following sections.

Optimal Timing of Pavement Preventive Maintenance Treatment Applications (NCHRP 14-14)

The primary objective of NCHRP 14-14 was to develop a framework for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements. The developed methodology considered a variety of treatments and different ways of monitoring their performance. The research focused on developing a methodology that would assist agencies in placing the right treatment on the right pavement at the right time. A systematic procedure to identify optimal timing of preventive maintenance treatments was developed during the study, a summary of which is provided below: (Peshkin et al. 2004).

- Identification of specific objectives of the preventive maintenance program: overall agency expectations need to be clearly defined.
- Selection of treatments and definition of guidelines on their appropriate use: since each treatment provides unique benefits, or can be placed subject to different constraints, guidelines should be developed on the selection, use, and performance of treatments specific to local/regional conditions (such as traffic and climatic conditions).
- Definition of typical performance of pavements when no treatment is applied, as well as the expected performance for different treatments: analysis of historical data available should be conducted to develop pavement performance models with and without treatment application.
- Identification and tracking of appropriate performance measures for different treatments and analysis of data and calculation of optimal timing of treatments: treated sections should be monitored periodically to keep track of performance over time.

The benefit associated with a treatment was defined as the difference in condition over time between the treated pavement and the performance of the same pavement if no treatment had been applied. An illustration of the benefit associated with the application of a preventive maintenance treatment is shown in figure 2.1 (Peshkin et al. 2004).

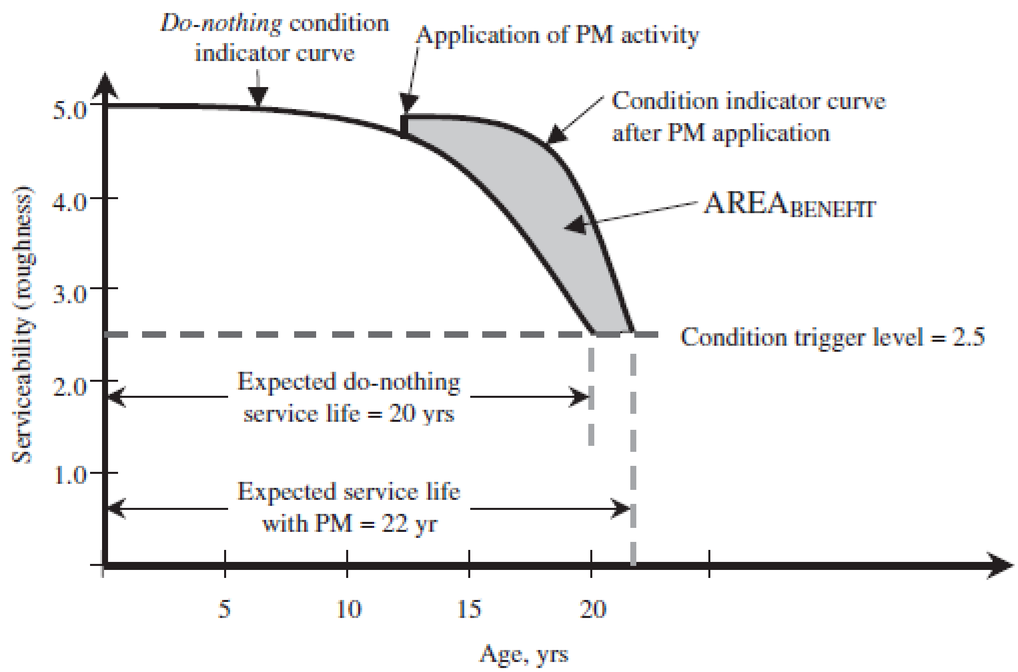

Figure 2.1. Illustration of benefit associated with a preventive maintenance treatment (Peshkin et al. 2004).

The study also developed general guidelines on designing experiments to determine the optimum timing of various preventive maintenance treatments, a few of which are listed in table 2.2. To determine the optimal treatment timing for a particular surface treatment, it recommended that a number of untreated sections be retained in the experimental matrix so that surface treatments can be applied at different times in the life of the pavement. For example, if a chip seal is applied 2 years after construction, a sufficient length of untreated test section should be left available to allow chip seal applications at later ages (e.g., 3, 4, or 5 years). The actual timing of the treatment depends on the type and purpose of the treatment.

Table 2.1. Suggested timing cycles for monitoring different preventive maintenance treatments (Peshkin et al. 2004).

Treatment	Recommended year of Initial Treatment	Treatment Monitoring Cycle
Bituminous-Surfaced Pavements		
Crack Sealing	1 to 3	Annually
Slurry Seals	2 to 6	Annually
Micro-surfacing	3 to 7	2 years
Chip Seals	2 to 5	Annually to 2 years
Thin HMA overlay	5 to 8	2 years
Ultrathin Overlay	2 to 6	2 years
Portland Cement Concrete Pavements		
Joint and Crack Sealing	4 to 10	2 years
Diamond Grinding	5 to 10	3 years

It should be noted that the timing cycles shown in table 2.1 are influenced by other factors such as climate, traffic, and construction quality (Peshkin et al. 2004). In addition to these guidelines, a Microsoft® Excel-based tool was developed to make the methodology easy to apply. This tool provides agencies with the flexibility of investigating many "what if" scenarios if relevant data are not available. A plan for the design and data collection efforts required to obtain the necessary data was also detailed as a part of this study.

Analysis of Completed Monitoring Data for the SPS-3 Experiment

The performance monitoring of selected maintenance treatments (thin HMA overlays, slurry seals, crack sealing, and chip seals) constructed as a part of the SPS-3 experiment began in 1990. This study focused on the life of each treatment (based on a threshold Pavement Rating Score [PRS][1] value of 50) in conjunction with the structural contribution (based on normalized Falling Weight Deflectometer [FWD] deflections under a 40 kN load) of the treatments in the SPS-3 experiment to determine their performance (Morian et al. 2011).

Survival curves were developed that relate survival probability to the age of treatment for each of the treatments in the SPS-3 experiment. The life expectancy at three levels of survival probability (0.8, 0.6 and 0.5) was computed for each of the four treatment types along with the control section. A summary of the statistical results of the survival analysis is shown in table 2.2.

Table 2.2. Statistical results for survival analysis (Morian et al. 2011).

Treatment Type	**Estimated Life (years) at given Survival Probability**		
	0.80	**0.60**	**0.50**
Thin HMA Overlay	7.0	9.1	10.0
Slurry Seal	4.7	7.4	8.6
Crack Seal	3.6	6.3	7.4
Chip Seal	5.9	9.3	10.7
Control Section	3.2	6.1	7.5

From table 2.2, the following observations can be made:

- At high survival probabilities (> 0.7), thin HMA overlays exhibit the highest service life, followed in order by chip seals, slurry seals, crack seals, and the control section.
- At a 50 percent survival probability, the chip seals and thin HMA overlay exhibited relatively high estimated service lives of 10.7 and 10.0 years, respectively. The life of slurry seals was estimated to be around 8.6 years, while the crack seals did not exhibit any apparent improvement in service life when compared to the control section.
- Even at higher survival probabilities, crack seals showed only marginal increase in the estimated service life over the control section.

[1] Pavement Rating Score (PRS) is an analysis approach developed for the LTPP SPS-3 sections by Morian et al. (1998). It is a single distress condition indicator which includes other individual distress parameters such as cracking, patching, and others. This method is based on a scale of 0 to 100, with 100 indicating a pavement in perfect condition, and 0 indicating a failed pavement section. Deduct values are assigned to individual distress and severity levels to aid in the computation of the PRS based on the distress data collected.

From a practical standpoint, the results of the SPS-3 experiment indicate that the expected performance of treatments can be related to the agency's level of risk associated with a roadway classification. For critical roadways where the objective is to minimize the risk associated with under-achieving the expected performance, using life predictions based on high probability rankings may be appropriate. On the other hand, for relatively lower-priority roadways where a higher risk of performance may be acceptable, the lower probability rankings may be suitable.

From a structural benefit standpoint, this study concluded that the relative reduction in the FWD deflections (under a normalized 40 kN load) as compared to the control section for the treatments are 9 percent for crack seal, 11 percent for chip seals, 17 percent for slurry seals, and 29 percent for thin HMA overlays. This runs counter to the common perception that maintenance or preservation treatments provide no tangible structural benefit.

Life Cycle Cost-Based Pavement Preservation Treatment Design

This study by Pittenger et al. (2011) aimed to compare the benefits for three pavement preservation treatments (thin HMA mill and inlay, open graded friction course [OGFC], and chip seals) using a LCC technique. The service life of each of these treatments was based on preset threshold limits for micro-texture, macro-texture, and also included the pavement engineer's experience based on observed historical trends.

An Equivalent Uniform Annual Cost (EUAC) based LCC model that specifically addressed the nature of the pavement preservation treatment was developed. The model was also capable of incorporating the expertise of the pavement engineer's experiences into the LCC estimates. The results of this study showed that the Oklahoma DOT Standard 5/8-inch chip seal has the lowest EUAC (for a 5-year analysis period) when compared to OGFC and thin overlays (which had a 10-year analysis period). This research also highlighted how the new EUAC-based model could be used to assist a pavement engineer in selecting the most economically efficient pavement preservation treatment.

Summary of Pavement Preservation Treatment Performance in Selected States

This section highlights the performance of various pavement preservations treatments in selected states in the mid-western United States. The estimated service lives and performance trends from these studies discussed below may be used to fill the gaps in the data set for this research study.

Indiana

The performance of chip seals, joint and crack seals, microsurfacing and thin hot mix asphalt overlays in Indiana are discussed in this section.

Chip Seal

Labi et al. (2005) reported that Indiana spends about 10 percent of its pavement maintenance budget on chip seals. Chip seals are reported to increase the resistance to skidding, oxidation, raveling, spalling, and permeability. From the comparative analysis and tests on road stretches, it was seen that the pavement life was considerably extended with the use of chip sealing. However, a chip seal is not considered viable for pavements subjected to high volumes of traffic owing to lose chips and relatively short life. Chip seals are expected to extend pavement life by 3 to 4 years in Indiana (Labi et al, 2005).

HMA Joint and Crack Sealing

A comprehensive review of HMA joint and crack sealing in Indiana revealed little quantitative evidence to demonstrate the cost-effectiveness of HMA crack/joint sealing practices (Hand et al. 2000). Cost-effectiveness of preventive maintenance strategies, rather than treatments was investigated by Labi et al. (2005) and the best strategy for asphalt surfaced pavements was crack sealing every 4 years and thin HMA overlays every 8 years.

Microsurfacing

From 1994 to 2001, about 173 lane-miles of Indiana's roadways were microsurfaced. Labi et al. developed a method to determine the long-term effectiveness of microsurfacing in Indiana using the data collected from these areas. The study assessed performance based on three measures of effectiveness: the service life, increase in average pavement condition, and area bound by the performance curve. The indicators used for each measure of effectiveness included pavement condition rating (PCR)[2] , rutting, and surface roughness. A matrix was developed based on the measures of effectiveness and indicators providing various results of performance for each of the treatments considered. The average service life of microsurfacing was estimated to be between 5 and 10 years (Labi et al. 2006).

Thin HMA overlays

Labi et al. (2005) conducted a comprehensive literature review on the long-term effectiveness of thin (approximately 1.5 inches) HMA overlay treatments for the Indiana DOT using three measures of effectiveness: treatment service life, increase in average pavement condition, and area bounded by the performance curve. It was shown that depending on levels of weather severity, traffic, and route type, the service life of thin overlay treatments is approximately 3 to 13 years when the International Roughness Index (IRI) is used as the performance indicator, 3 to 14 based on rutting, and 3 to 24 for Pavement Condition Rating (PCR); the wide range of effectiveness is indicative of the sensitivity of the different measures of performance to traffic loading, weather severity levels, and route type.

The researchers also reported that increased severity of either weather or traffic effects is sufficient to cause a drastic reduction in the treatment service life and that the effect of increased traffic on service life reduction appears to be greater than the effect of increased weather severity. Under the influence of traffic and weather, the service life of thin HMA overlays is between 3 and 13 years.

Irfan et al. (2009) estimated the service life for Indiana pavements by using performance curves and probability analysis. The service life of thin HMA overlays was estimated using a range of threshold values for various performance indicators. The life extension for thin HMA overlays was noted to vary from 9 to 12 years based on IRI, 8 to 11 years based on PCR, and 9 to 14 years based on the rutting threshold values defined for the state.

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[2] The Pavement Condition Rating (PCR) is based on a scale of 0 to 100, with 100 indicating a pavement in perfect condition, and 0 indicating a failed pavement section. Deduct values are assigned to individual distress and severity levels to aid in the computation of the PCR based on the distress data collected.

Kansas

The performance of chip seals, slurry seals, and thin HMA overlays in Kansas is discussed in this section.

Chip Seals

A study by Liu et al. (2010) included the performance evaluation of various preventive maintenance treatments in Kansas. It was noted that the service life of a chip seal varied from 1 to 9 years. In addition, before and after comparisons of Pavement Condition Index (PCI) ratings were conducted to examine the effectiveness of preventive maintenance treatments in mitigating important distresses on pavement sections. Two sections of Kansas state highway were used to conduct the before and after comparisons in terms of rutting condition and roughness of the pavement. The study indicated that chip seals had a minimal effect on decreasing pavement roughness. Chip seals were also observed to mitigate a majority of transverse cracks and fatigue cracking. A majority of the chip seals were found to have an average treatment life of about 4 years.

Slurry Seal

The average service life of slurry seals in Kansas was approximately 5 years. The distresses considered during this study include roughness, rutting, transverse cracking, and fatigue cracking. The before and after analysis of PCI ratings for each of the segments under study indicated that while slurry seals improved the performance of pavements by mitigating rutting, transverse cracking, and fatigue cracking, they were relatively ineffective in decreasing the effects of roughness (Liu et al. 2010).

Thin HMA overlays

The service life of thin HMA overlays was observed to vary from 2 to 10 years, with an average life of 6 years. Based on the before and after analysis, the study indicated that thin HMA overlays were successful in reducing a majority of the distresses (Liu et al. 2010).

Michigan

A study conducted for the Michigan Department of Transportation (MDOT) analyzed the life expectancy of various preventive maintenance treatments based on reliability-based analysis using pavement management system data gathered since 1992. MDOT’s Distress Index (DI) was incorporated as a primary factor in analyzing the performance of various preventive maintenance treatments. The life expectancy of each preventive maintenance treatment was determined by plotting the average DI for each treatment over time. The results of this analysis indicated that the overall life extension for a thin HMA overlay was 5 to 10 years. In addition, single layer chip seals exhibited an extension of about 3 years (Bausano et al. 2004).

As discussed in the previous chapter, Michigan implements a comprehensive pavement preservation strategy. The strategy identifies a broad range of preventive maintenance treatments which are classified into two categories: *Pavement Sealing* and *Functional Enhancements*. Table 2.3 summarizes the service life extensions obtained from the various preventive maintenance treatments used by MDOT (MDOT 2010).

Table 2.3. Life extensions for various preventive maintenance treatments (MDOT 2010).

CPM Treatment	Flexible Pavement Life Extension (years)	Composite Pavement Life Extension (years)	Rigid Pavement Life Extension (years)
Non-Structural HMA Overlay	5 to 10	4 to 9	N/A
Surface Milling w/ Non-Structural HMA Overlay	5 to 10	4 to 9	N/A
Single Chip Seal	3 to 6	N/A	N/A
Double Chip Seal	4 to 7	3 to 6	N/A
Regular Single Microsurfacing	3 to 5	N/A	N/A
Multipe or Heavy Single Microsurfacing	4 to 6	N/A	N/A
Double Microsurfacing	N/A	Unknown	N/A
Crack Treatment	0 to 3	0 to 3	N/A
Overband Crack Filling	0 to 2	0 to 2	N/A
Ultra-thin HMA Overlay	3 to 6	3 to 6	N/A
Paver Placed Surface Seal	4 to 6	3 to 5	N/A
Full Depth Concrete Pavement Repair	N/A	N/A	3 to 10
Concrete Joint Resealing	N/A	N/A	3 to 5
Concrete Crack Sealing	N/A	N/A	0 to 3
Diamond Grinding	N/A	N/A	3 to 5
Dowel Bar Retrofit	N/A	N/A	2 to 3
Concrete Pavement Restoration	N/A	N/A	7 to 15

Note: While the majority of the life extensions reported herein are based on historical pavement performance trends, the life extensions for Ultra-thin HMA overlay and Paver Placed Surface Seals are estimated values.

Minnesota

The performance of chip seals, HMA crack sealing, microsurfacing, and thin HMA overlays in Minnesota are discussed in this section.

Chip Seal

Single chip seals in Minnesota are recommended in moderate temperatures and low rainfall to increase the friction of the surface, and provide an expected life of about 3 to 6 years. The average life extension from double chip seals is approximately 7 to 10 years (Johnson 2000).

HMA Crack Sealing

Crack sealing is recommended on HMA pavements that exhibit low- to medium-severity longitudinal or transverse cracking (< 0.75 inch) to prevent infiltration of moisture into the pavement. Various types of crack sealant and filler materials like asphalt cement, asphalt emulsion, crumb rubber, and rubberized asphalt are allowed for use by the Minnesota Department of Transportation (MnDOT). The typical crack sealing techniques provide a service life of approximately 3 years. The saw and seal method is also used by MnDOT where the newly placed asphalt is sawn to create a reservoir and is filled with the sealant at a typical spacing of 40 feet. This technique provides an anticipated service life of about 10 years (Johnson 2000)

Microsurfacing

The MnDOT handbook recommends the use of microsurfacing when the rut depth exceeds ¾ inches. The use of microsurfacing is noted to extend the service life of pavements by about 7 to 10 years (Johnson 2000).

Thin HMA Overlays

The MnDOT handbook defines the use of thin HMA overlays for functional improvements and specifies that these can be dense-graded, open-graded, or gap-graded. Pavements with a good surface condition, stable base, and visible surface distresses such as extreme raveling or longitudinal cracking qualify for this treatment. The life expectancy of a thin HMA overlay is estimated to be from 5 to 8 years (Johnson 2000).

Ohio

The performance of chip seals, HMA crack sealing, microsurfacing, and thin HMA overlays in Ohio are discussed in this section.

Chip Seal

The Ohio Department of Transportation (ODOT) guidelines indicate the use of a single layer chip seal application as a maintenance measure on low volume roadways, as it eliminates raveling, reduces the infiltration of water, and retards oxidation along with sealing cracks. According to ODOT, chip seal applications are most effectively used on low volume roads with traffic levels less than 2,500 ADT or 250 ADTT. The expected service life of a chip seal is about 5 to 7 years (ODOT 2001). A study conducted by Rajagopal (2010) evaluated the performance of chip seals and microsurfacing practices in Ohio. The study focused on two issues: (a) optimal timing and treatment placement and, (b) cost effectiveness, based on 225 chip seal and 214 microsurfacing projects. The study concluded that chip seals provide an average service life extension of 7 years when placed on pavements whose PCR is in the range of 66 to 80.

HMA Crack Sealing

Crack sealing is considered to be an effective method of preventing infiltration of water, resisting crack deterioration, and preventing erosion of the pavement by ODOT. Crack seals are considered to be most effective when the pavement temperatures are cool; the estimated pavement life extension is about 2 to 3 years (ODOT 2001).

Microsurfacing

ODOT guidelines recommend the use of microsurfacing to reduce ruts, retard raveling, improve surface friction, and remove irregularities. Minor rehabilitation with regards to potholes and excessive cracking is performed prior to the application of microsurfacing. This technique is suitable for all traffic conditions; a double layer can be used for greater ADT of traffic. The expected service life is about 5 to 8 years (ODOT 2001). Rajagopal (2010) reported that microsurfacing on two-lane state routes provided an average service life extension of 9 years when placed pavements with a PCR in the range of 61 to 70, and microsurfacing treatments on priority systems (consisting of four lanes or more) provided an average service life extension of 8 years when placed on pavements with a PCR in the range of 61 to 70.

Thin HMA overlays

ODOT indicates that thin HMA overlays are one of the most effective methods of rehabilitation, improving ride quality when performed with milling or scratching to achieve a uniform lift. The service life of the pavement depends on its condition and the pre-overlay repairs. The expected service life of a structurally sound pavement after overlay is around 8 to 12 years (ODOT 2001). Another study conducted by ODOT to determine the effectiveness of thin HMA overlays on pavement ride and condition performance concluded that the service life of a thin HMA overlay system is between 4 and 9 years, with an average service life of 6.6 years. The life extension was defined in terms of age of the existing pavement and service life of the overlay treatment. The study also focused on assessing the performance of thin HMA overlays based on the area under the performance curve and on the improvement in IRI for the pavement sections considered (Chou et al. 2008).

FHWA Study

A study was conducted by FHWA to highlight the degree to which pavement preservation treatments extend the service life of pavements. The study summarized the current state practices and performance results of six target states: California, Kansas, Michigan, Minnesota, Texas, and Washington. These states were evaluated for various performance factors such as timing of application, distress types, extended pavement service life, and cost per lane mile (Wu et al. 2010). The results of the study are summarized in table 2.4.

Table 2.4. Summary of various pavement preservation treatments (Wu et al. 2010).

Treatment	Timing of Application (years)	Service Life Extension (years)
Asphalt Surfaced Pavements		
Chip Seal	2 to 13	3 to 8
Crack Sealing	1 to 38	0 to 4
Thin HMA Overlay	4 to 24	3 to 23
Microsurfacing	1 to 11	3 to 8
Slurry Seal	7 to 13	4 to 7
PCC Pavements		
Diamond Grinding	13 to 42	4 to 17
Dowel bar Retrofit	1 to 41	2 to 16
Full Depth Repair	4 to 25	3 to 14
Joint Sealing	6 to 12	4
HMA Overlay without slab fracturing	10 to 36	1 to 20

Summary

This chapter includes a review of relevant research focusing on the life extensions and performance benefits obtained from preventive maintenance treatments. This review shows that most states are moving towards a policy of pavement preventive maintenance and away from the worst-first approach (where pavements are allowed to deteriorate to a highly distressed condition before any rehabilitation is performed). This is likely due to the shrinking budgets and newer policies that advocate financial and environmental sustainability of existing assets. The literature review also indicates that almost all preventive maintenance treatments are helping to extend the service life of pavements. Table 2.5 summarizes some of the primary benefits provided by the different preventive maintenance treatments (Peshkin et al. 2004).

Table 2.5. Primary benefits of different preventive maintenance treatments (Peshkin et al. 2004).

Treatment	Roughness	Friction	Noise	Life Extension	Moisture Reduction
Asphalt Surfaced Pavements					
HMA – Chip Seal	✓✓	✓✓		✓✓	✓
HMA – Crack Sealing				✓	✓✓
HMA – Thin HMA Overlay	✓✓	✓✓	✓✓	✓✓	✓✓
HMA – Microsurfacing	✓✓	✓✓	✓✓	✓✓	✓
HMA – Slurry Seal	✓✓	✓✓	✓✓	✓✓	✓
PCC Pavements					
PCC – Diamond Grinding	✓✓	✓✓	✓✓	✓✓	
PCC – Dowel bar Retrofit	✓✓		✓✓	✓✓	
PCC – Full Depth Repair	✓✓			✓✓	✓
PCC – Joint and Crack Sealing				✓	✓✓

✓ - Minor effect. ✓✓ - Major effect.

Certainly one conclusion that can be drawn from the recent literature is that the issues associated with determining the cost effectiveness of preventive maintenance have not been adequately resolved. There are several explanations for this, including a general lack of detailed treatment performance information and a surprisingly poor grasp (or at least a general lack of consensus) of what is meant by cost effectiveness. In contrast, Michigan’s experience in performing preventive maintenance and collecting information on performance provides an excellent opportunity to make a significant contribution to Michigan’s CPM program in terms of studying the cost-benefits associated with the various treatments typically used by Michigan.

The following chapter summarizes the data collection and data assembly efforts undertaken in this study.

3. DATA COLLECTION AND DATA ASSEMBLY

Introduction

This chapter presents details of the data collection and data assembly efforts undertaken in this study. As a part of this project, a comprehensive database on preventive maintenance projects was compiled from electronic documents received from the MDOT Construction Field Services Division. The data set required for the analysis included the following:

- Project inventory information for reconstruction and rehabilitation (R&R) and capital preventive maintenance projects (CPM).
- Pavement performance data.
- Traffic information.

All the information pertinent to this study was assembled into a common electronic format (Microsoft Excel® and Microsoft Access®). The assembled data sets were then merged to develop the project database for use in the analyses. The data collection and data assembly efforts were led by MTU with input from APTech and MDOT. Specific details on the data collection and data assembly efforts are described in the following sections.

Data Collection

This section provides specifics on the data collected in order to develop the project database. The key data fields used to complete the project inventory dataset are:

- List of R&R and CPM projects
- Control Section (CS), Job Number (JN), Beginning and End Mile Points (BMP and EMP), direction, number of lanes, and geographic location of the pavement section (MDOT Region).
- Pavement type (flexible, rigid, and composite).
- Historical Distress Index (DI) data.
- Traffic data – annual average daily traffic (AADT) and percentage of trucks and commercial vehicles.

Table 3.1 presents a summary of the data source files that were used to compile the project database. The source of the data, file names, and the specific data extracted from each of the available source are also highlighted in table 3.1. It should be noted that some of the sensor data for the earlier years (early 1990s) were not available in a usable format for this study; only the data that were in a format consistent with the current data collection standards were used. The data sources were approved by MDOT before they were used for compiling the project database and conducting the analysis.

Table 3.1. Data sources and information extracted.

Data	File Name(s)	MDOT Source	Data used
CPM Treatments	MDOT CPM Treatments 1992 to 2009.xlsx	Kevin Kennedy	CPM treatment type, date, and location
DI Data – tenth-mile segments	21211015 MDOT DI 1992 through 2009.csv	Ben Krom	DI data for analysis segments
Sufficiency Data	Sufficiency.zip (1986 through 2009)	Pat Allen	Pavement type, number of lanes, other physical road parameters, R&R type, date and location

Data Assembly

The steps involved in the data assembly are discussed in this section. The data assembly was performed by MTU with input from APTech and MDOT. The assumptions that were made to address gaps in the data are presented below:

- The "Fiscal Year" in which the R&R projects are let was used as the year of project completion (or the "zero year") when analyzing the pavement performance trends. A similar assumption was made for the year of CPM treatment. A couple of issues result from this assumption. First, when a pavement condition survey is conducted just before the placement of a CPM treatment in the same year, the improvement in pavement condition immediately after the placement of the treatment will not be captured. Therefore, the condition at age zero will not be considered for these pavement sections. Also if a significant improvement in pavement condition is observed during the following condition survey cycle, the low condition of the pavement prior to treatment placement will be noted as the pre-treatment condition. If the distress data was collected one year before or after the year in which the treatment was placed, the last DI value reported before the treatment placement was used as the pre-treatment DI value. It is understood that while this may not be the actual pre-treatment DI value, it is the best estimate of it. Furthermore, since the DI is generally not expected to drop significantly in one year because the CPM treatments are generally applied to pavements in fair to good condition, it is believed that this is a reasonable value to use in the analysis.
- The DI data are not always historically calculated on the same 0.1-mile segments. An assumption was made that the 0.1-mile segments are approximate and it is not critical to have the exact continuity as long as the overall segmentation error is low.
- The MDOT regions (Superior, North, Grand, Bay, Southwest, University, and Metro) were used to model the impact of climatic variations on pavement performance. The MDOT regions were compared to the United States Department of Agriculture (USDA) hardiness zones (see figure 3.1) to develop climatic zones for this study.

On comparing the Michigan hardiness zones (average annual minimum winter temperatures) to the MDOT regions, it was seen that the climatic zones in Michigan could be grouped into two general categories. Superior and North regions were observed to have similar climates and they were categorized as "Zone 1" for analysis purposes; the remainder of the MDOT regions (Grand, Bay, Southwest, University, and Metro) were grouped together and categorized as "Zone 2."

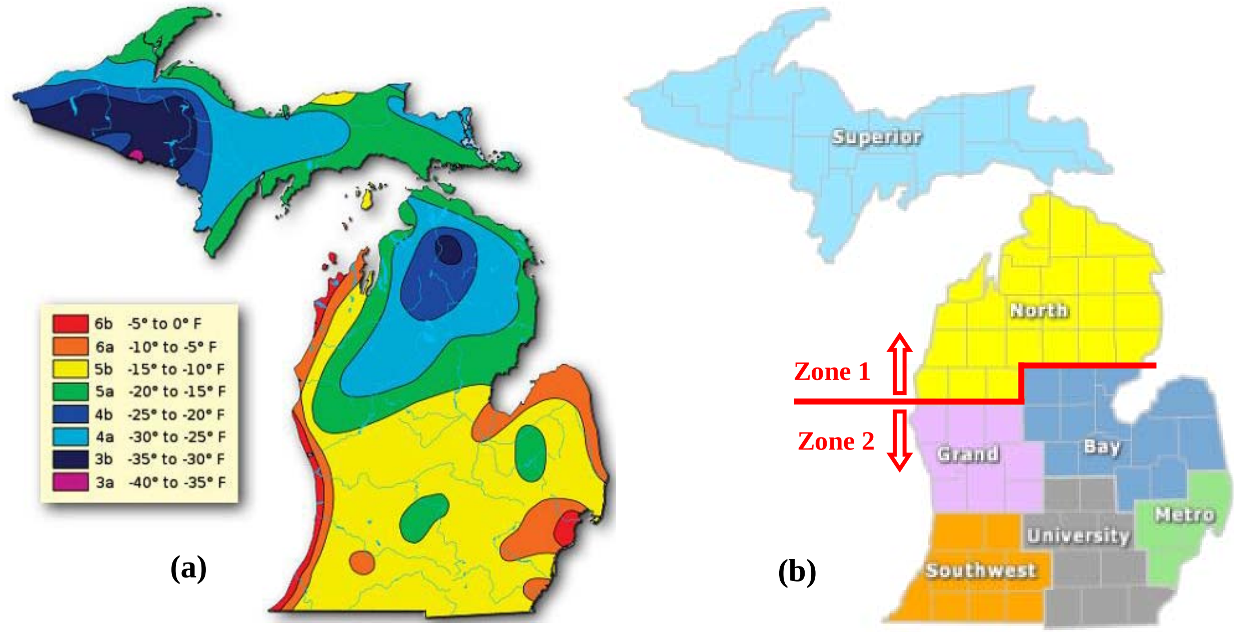


Figure 3.1. (a) Michigan hardiness zones (USDA) and (b) MDOT Regions.

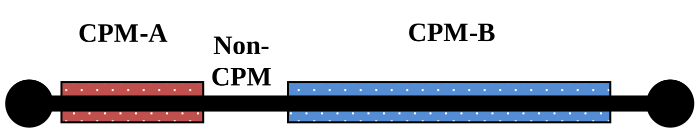
Process Flow

A summary of the process flow involved in the data assembly is summarized in the following steps:

Step 1: A list of all contiguous pavement segments that had been reconstructed or rehabilitated was generated and labeled as “R&R Segments.” The construction date of the segment was assumed to be the “Start date” or “Year 0 date.” Data exists for R&R Segments as far back as 1980, but distress data and CPM data records do not start until 1992. The rehabilitation date was also stored in the database as the year of the project work (e.g., 1990). Historical data back to 1980 was used to determine the boundaries of the R&R segments with “resurfacing, reconstruction, and restoration and rehabilitation” all signaling the occurrence of an R&R segment. Not only were the rehabilitation dates used to set the “Year 0 date,” but they were also used to signify the end of the range of Distress Index (DI) data that applies to the previous pavement section. A schematic of an R&R segment is shown below:

R&R Segment

Step 2: All CPM projects that overlap at least one R&R segment and postdate the Year 0 of the R&R segment were located. Each “CPM segment” became an individual analysis unit as indicated by “CPM-A” and CPM-B” in the schematic below.



Example of CPM segments that fall within an R&R Segment.

In addition to the "CPM segments," data that can be used as a "Non-CPM sections" were also captured in the database. These data, along with the data on pavement sections before the placement of the first CPM treatment, were used to model the pre-treatment pavement performance.

CPM projects with boundaries outside an R&R segment were either truncated or became part of an adjacent R&R Segment, if present.

R&R Segment with CPM. Example of CPM segments extending beyond R&R segment limits.

For several CPM segments, the corresponding R&R segments did not have the R&R type specified in the sufficiency database. However, based on recommendation by MDOT, these sections were still included in the project database since the pavement type of the R&R treatment and the historical pavement condition data were available. A few CPM segments could not be linked to an R&R segment due to project identification inconsistencies between the CPM and R&R databases – these segments were not included in the analysis.

Step 3: CPM project segments were compared to determine if there was an overlap of a successive CPM or R&R Segment; either of these events was used to indicate the "end" date range for the segment. If there was no overlap, the end date was the last year for which the pavement condition information was collected for that particular segment. It should be noted that crack sealing was not used to trigger the end of service of the previous CPM treatment.

Step 4: DI data for each CPM project segment and sufficiency pavement characteristics were queried and added to the record for the CPM project boundaries as necessary.

Pre-Treatment Pavement Segments Included in this Study

As described in the previous section, to model the "do-nothing" pavement performance data on R&R sections that did not receive any CPM treatment and the performance data on R&R segments prior to the first CPM treatment placement were compiled. Figure 3.2 shows the number of pre-treatment pavement segments used in the analysis. The data are categorized by climatic zone (Zone 1 and 2), functional class (interstates and other freeways, principal arterials, minor arterials, and collectors), and pavement type (flexible, rigid, and composite).

Figure 3.2 shows that the majority of the analysis segments fall under the "Principal Arterials" functional classification. The number of analysis segments in the "Interstates, Other Principal Arterials: functional class in Zone 1 is very low, which is expected since the total mileage of interstate pavements in this zone is also low. The number of analysis segments in the "Collectors" functional class is low in both Zones 1 and 2.

CPM Treatments Included in this Study

The CPM project list provided by MDOT was evaluated to determine which could be included in this analysis. As discussed in Chapter 1 (Table 1.1), MDOT identifies 17 CPM work types. However, in the list of CPM projects provided by MDOT there were around 4000 projects with

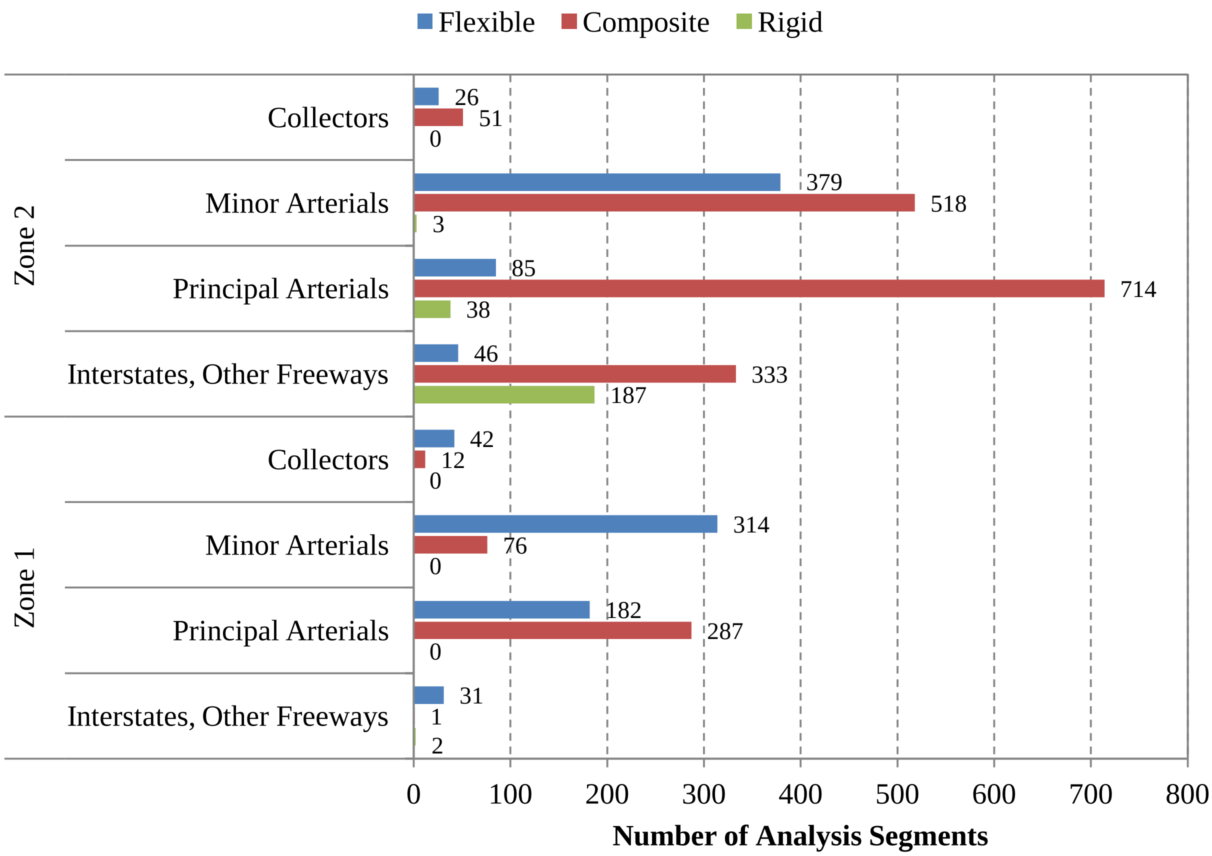


Figure 3.2. Number of pre-treatment pavement segments used in the analysis by zone and functional classification.

over 500 different work types. Of these 500 work types, obviously many were not truly unique. It appeared that subtle differences in treatment names, spellings and abbreviations, and suffixes were given to treatments that were similar in nature. To address this, assumptions were made to group similar work types into a single work type that coincided with MDOT's CPM work type descriptions (listed in table 1.1). These proposed groupings were then verified with MDOT. Table 3.2 shows the finalized list of CPM treatments included in this study, along with the number of projects identified in the CPM project list. It should be noted that a single project may be a part of one or more analysis segments based on the segmentation performed according to the rules described earlier in this chapter (under the Process Flow section). However, as noted earlier not all projects in the CPM project list could be included in the analysis matrix due to the lack of performance data and/or absence of an R&R segment to which the CPM treatment could be linked.

The following treatments were not included in this study either because of insufficient data or the incapability to assess treatment performance:

- Concrete crack treatment: eight segments were identified in the CPM project list, which is not sufficient to assess treatment performance.
- Shoulder fog seal: condition data does not exist for shoulder pavements and hence this treatment is not included in this study.

Table 3.2. Final list of CPM treatments included in the study.

CPM Treatment	Number of Projects
Single Chip Seal	233
Double Chip Seal	87
HMA Crack Seal/Treatment*	1109
HMA Mill and Overlay	743
HMA Overlay	263
Ultra-Thin HMA Overlay	72
Double Microsurfacing	541
Paver Placed Surface Seal	38
PCC Joint and Crack Seal	72
Concrete Pavement Rehabilitation	331

* As discussed earlier, also analyzed as a stand-alone CPM treatment; crack sealing does not reset treatment cycle for other treatments.

- HMA shoulder ribbons: as above, condition data does not exist for shoulder pavements and hence this treatment is not included in this study.
- Overband crack fill pre-treatment: MDOT indicated that this treatment is almost always covered up with a subsequent treatment soon after placement, which makes it difficult to evaluate performance. Based on MDOT's recommendation this treatment was removed from the experimental matrix.
- Diamond grinding: three projects were identified in the CPM project list and this is not sufficient to assess treatment performance.
- Dowel bar retrofit: three projects were identified in the CPM project list and this is not sufficient to assess general treatment performance. MDOT also noted that diamond grinding and dowel bar retrofit may be performed as a part of Concrete Pavement Restoration and it may be difficult to evaluate the benefits of these treatments as a stand-alone strategy.
- Under-drain outlet clean out and repair: one project was identified in the CPM list and this is not sufficient to assess general treatment performance.

Approximately 55 percent of CPM treatment segments identified were the first CPM treatments placed after reconstruction or a major rehabilitation event. These could be used to evaluate the performance of the specific treatment as a stand-alone activity. Of the remaining 45 percent that were not the first CPM treatment, approximately 70 percent were the second CPM treatments with the remaining 30 percent being the third through the seventh CPM treatment being placed on an R&R segment. To get a clearer picture on the treatment performance, the analysis of the first CPM activity was separated from the rest of the CPM treatments (referred to as post-first CPM treatment in the remainder of this report).

Figures 3.3 and 3.4 show the number of first and post-first single chip seal segments used in the analysis.

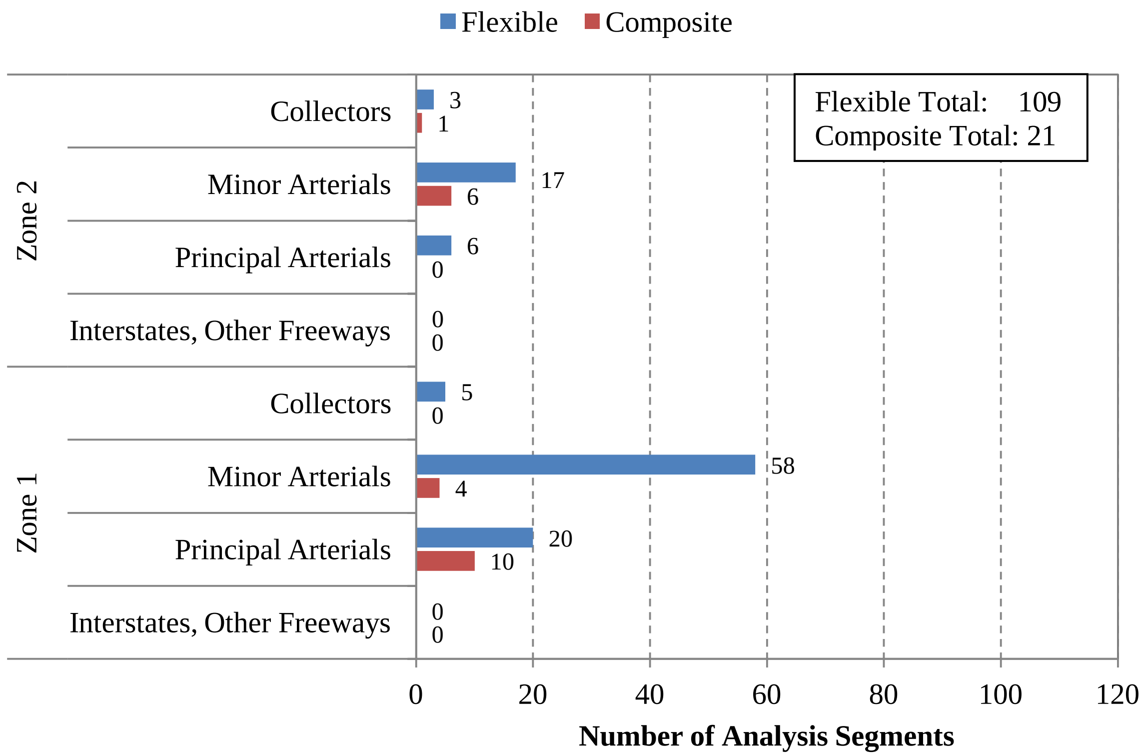


Figure 3.3. Number of single chip seal segments used in the analysis (first treatment).

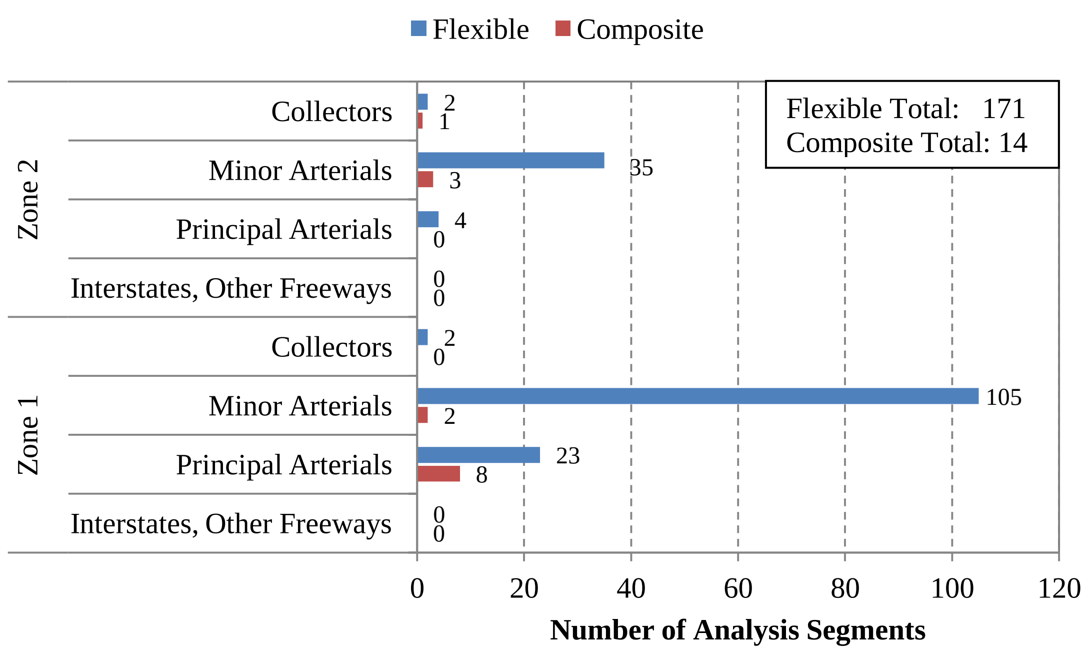


Figure 3.4. Number of single chip seal segments used in the analysis (post-first treatment).

Figures 3.5 and 3.6 show the number of first and post-first double chip seal segments used in the analysis.

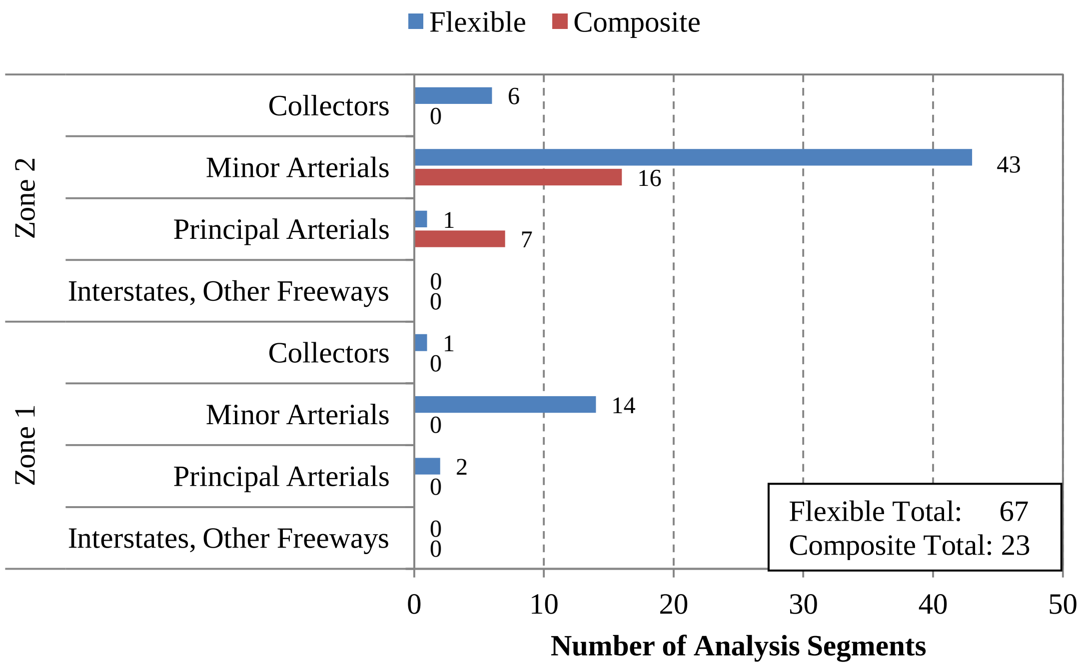


Figure 3.5. Number of double chip seal segments used in the analysis (first treatment).

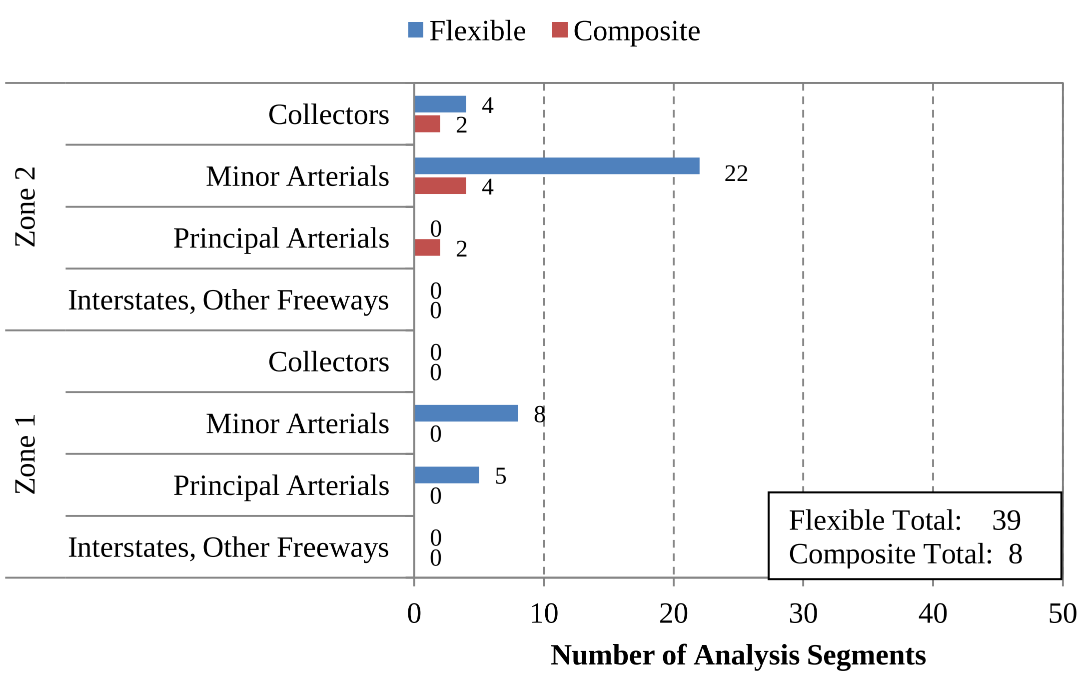


Figure 3.6. Number of double chip seal segments used in the analysis (post-first treatment).

Figures 3.7 and 3.8 show the number of first and post-first double microsurfacing segments used in the analysis.

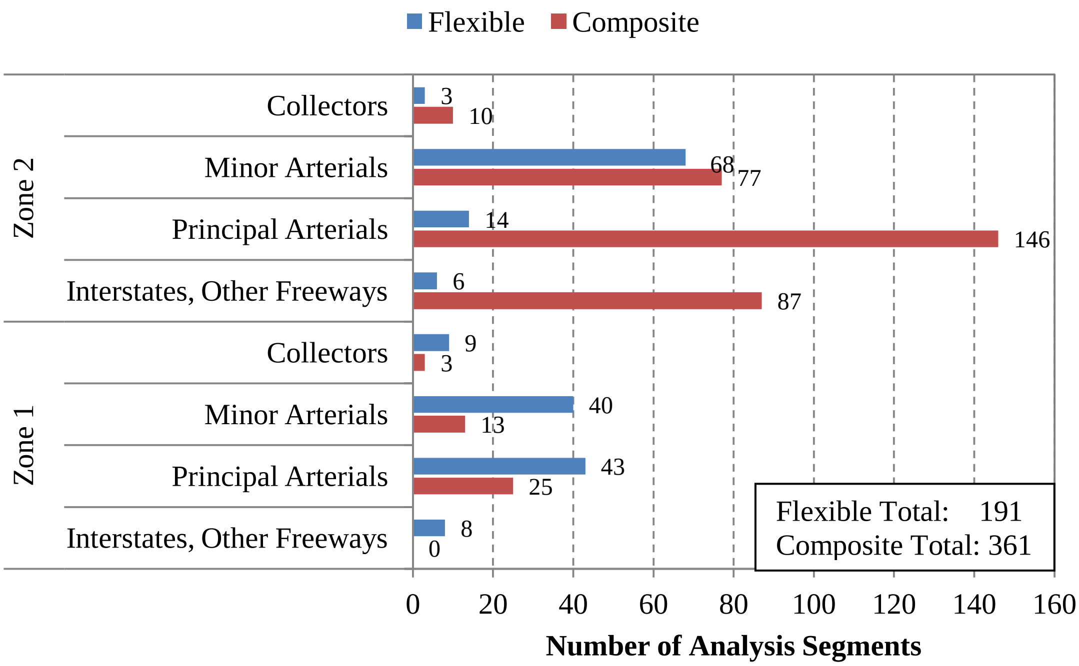


Figure 3.7. Number of double microsurfacing segments used in the analysis (first treatment).

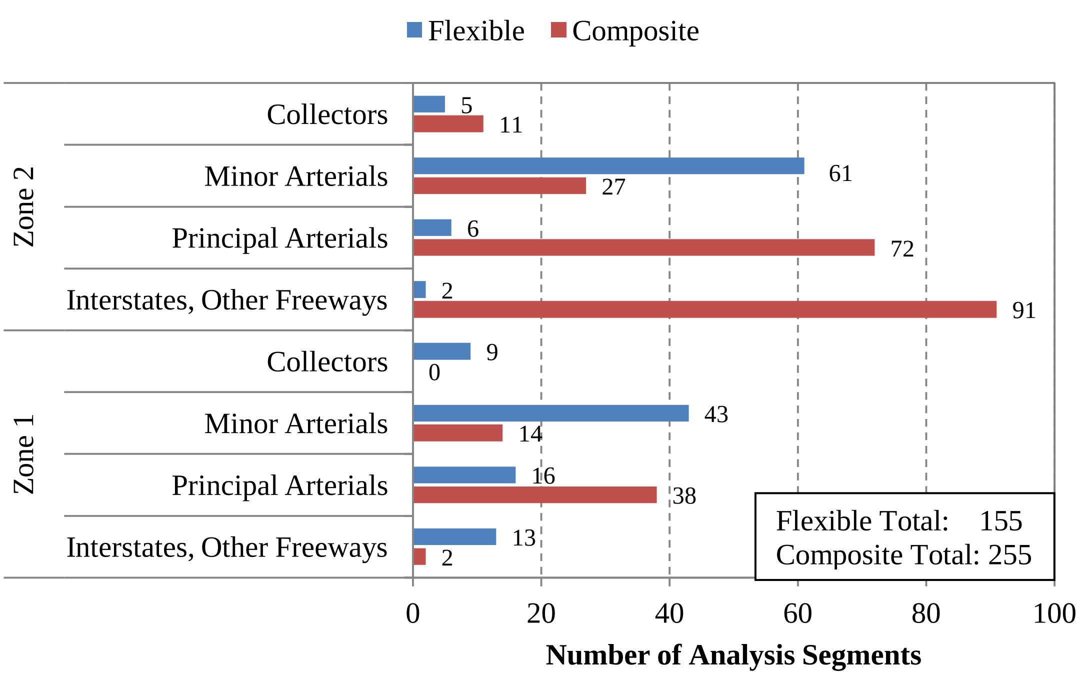


Figure 3.8. Number of double microsurfacing segments used in the analysis (post-first treatment).

Figures 3.9 and 3.10 show the number of first and post-first paver placed surface seal (PPSS) segments used in the analysis.

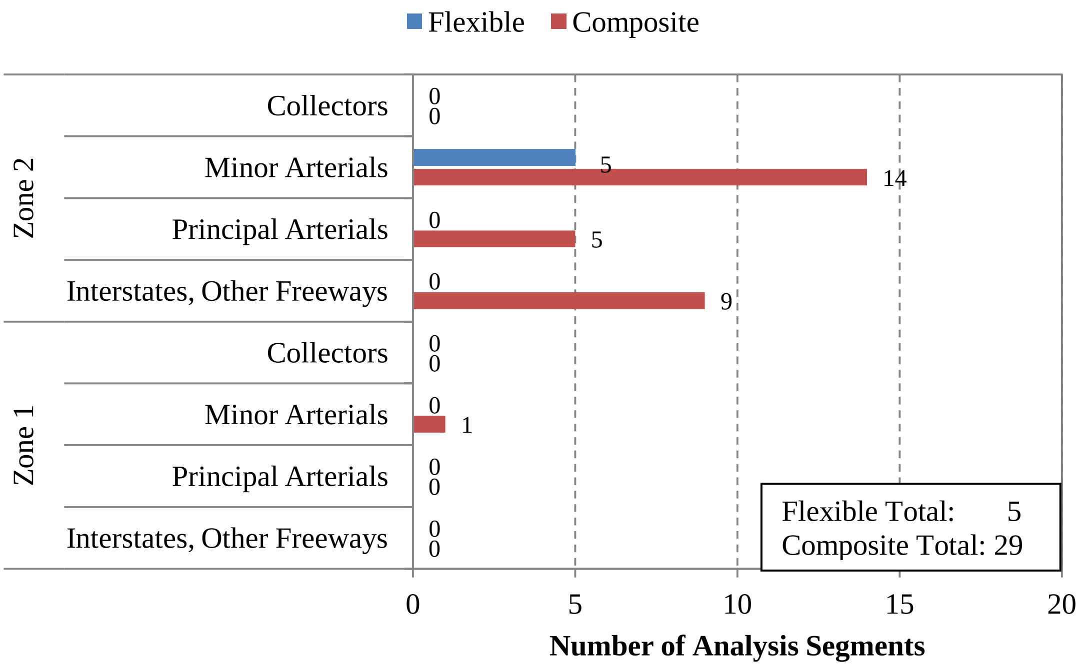


Figure 3.9. Number of PPSS segments used in the analysis (first treatment).

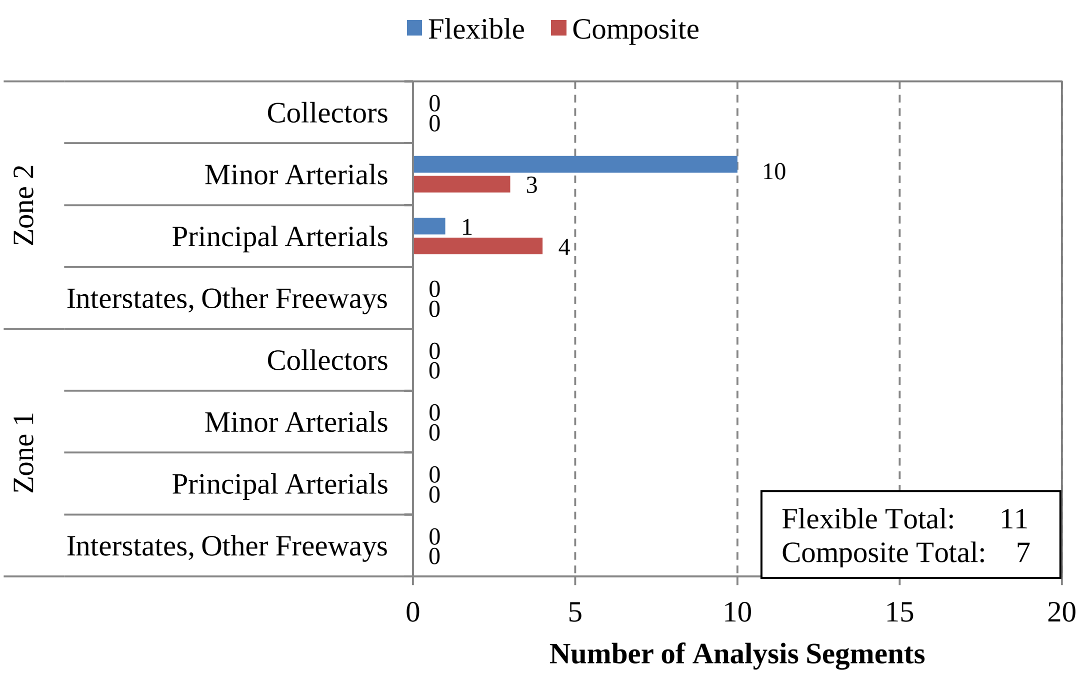


Figure 3.10. Number of PPSS segments used in the analysis (post-first treatment).

Figures 3.11 and 3.12 show the number of first and post-first HMA crack seal segments used in the analysis.

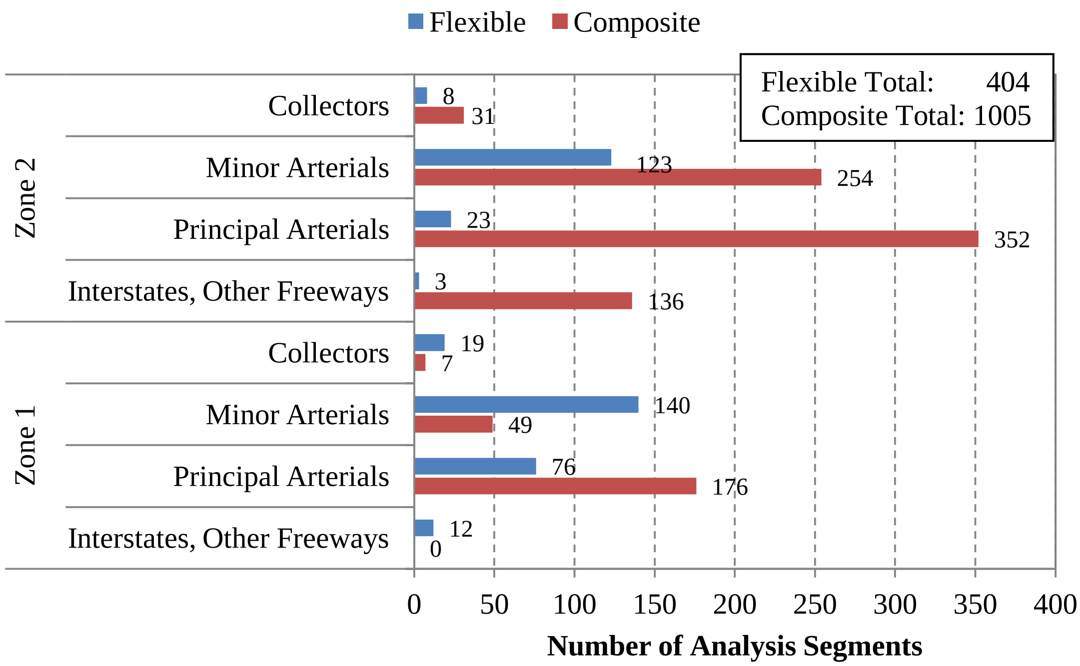


Figure 3.11. Number of HMA crack seal segments used in the analysis (first treatment).

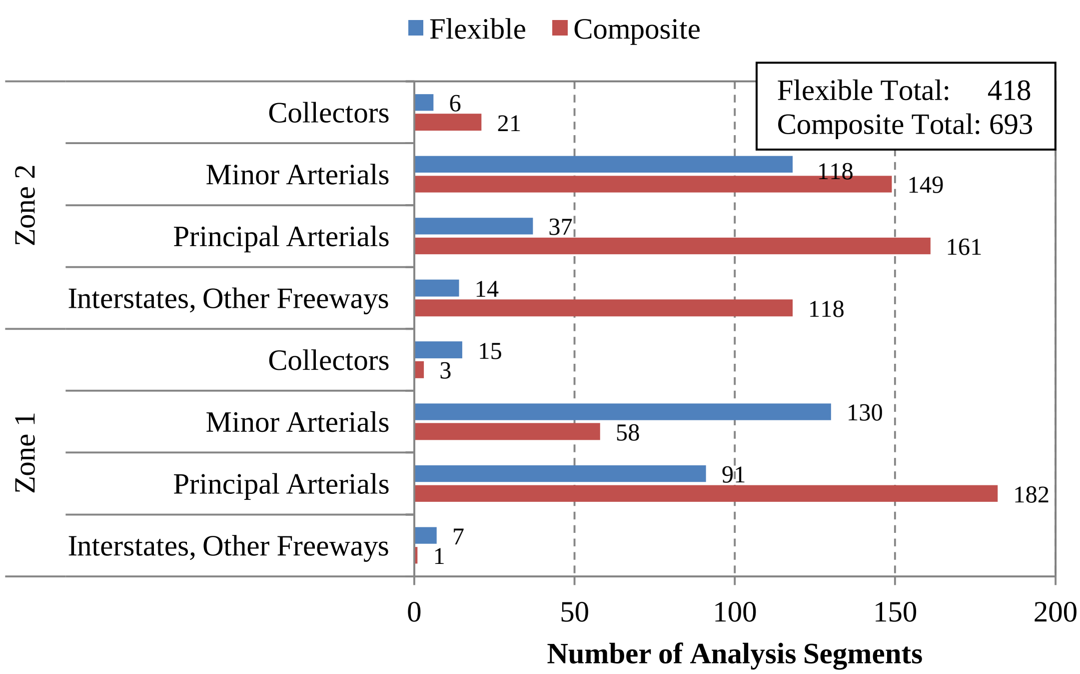


Figure 3.12. Number of HMA crack seal segments used in the analysis (post-first treatment).

Figures 3.13 and 3.14 show the number of first and post-first ultra-thin HMA Overlay (HMA OL) segments used in the analysis.

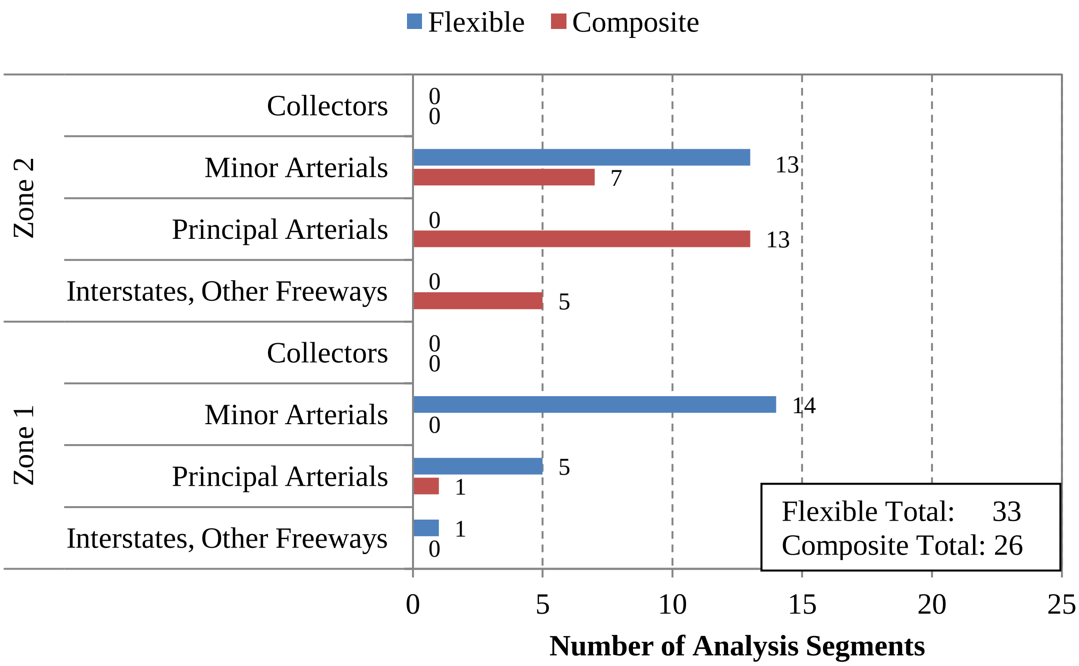


Figure 3.13. Number of ultra-thin HMA OL segments used in the analysis (first treatment).

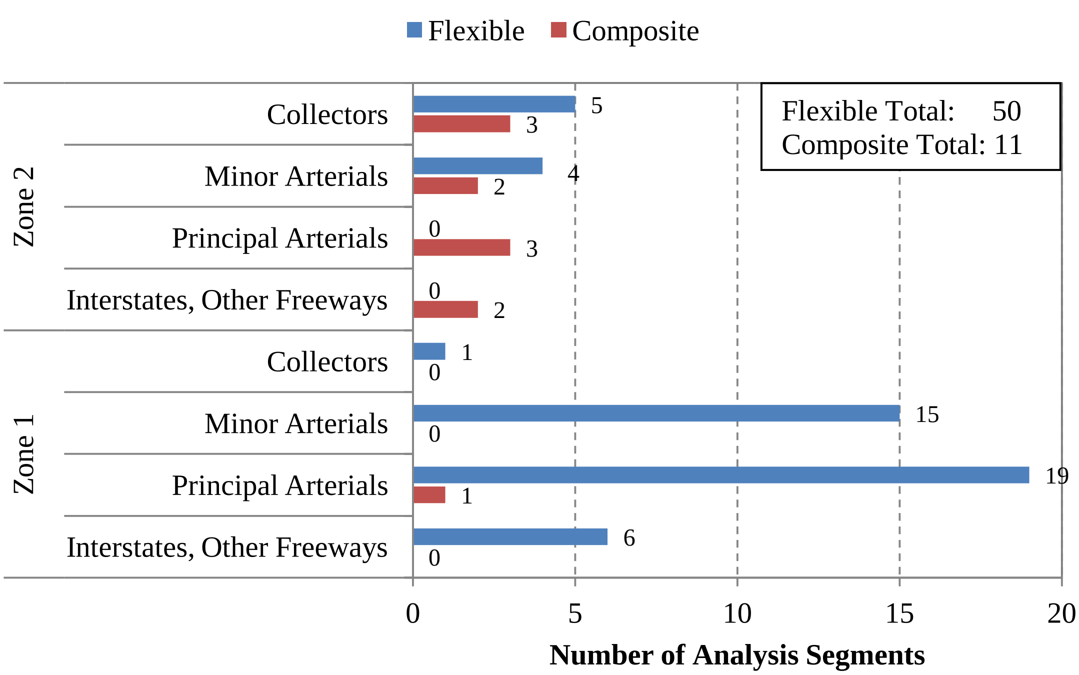


Figure 3.14. Number of ultra-thin HMA OL segments
used in the analysis (post-first treatment).

Figures 3.15 and 3.16 show the number of first and post-first HMA mill and overlay (HMA Mill OL) segments used in the analysis.

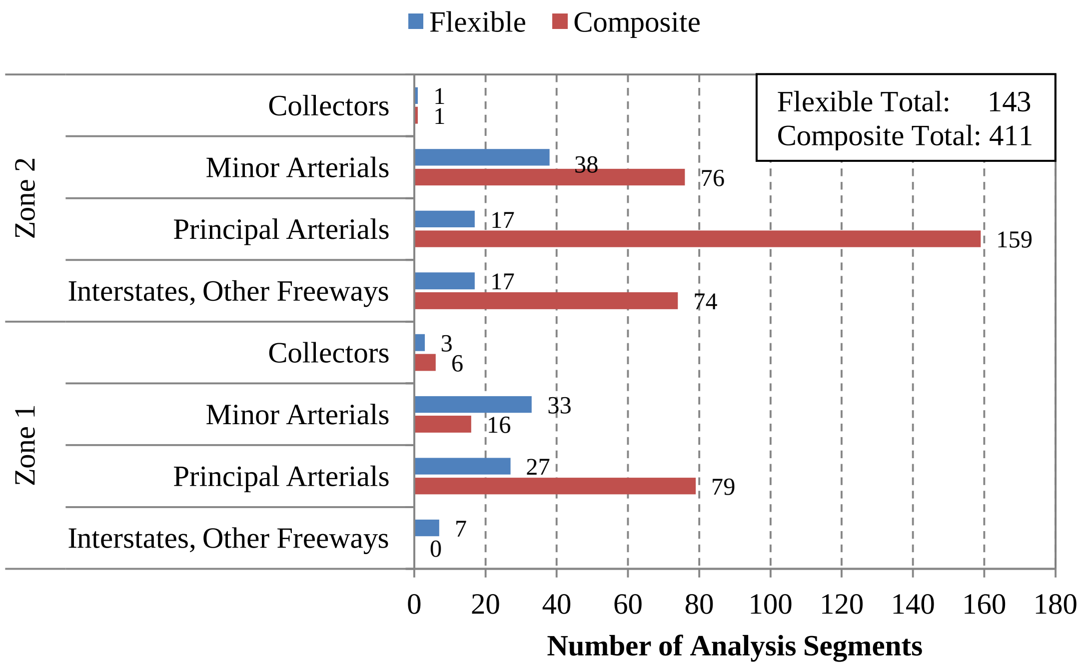


Figure 3.15. Number of HMA Mill OL segments used in the analysis (first treatment).

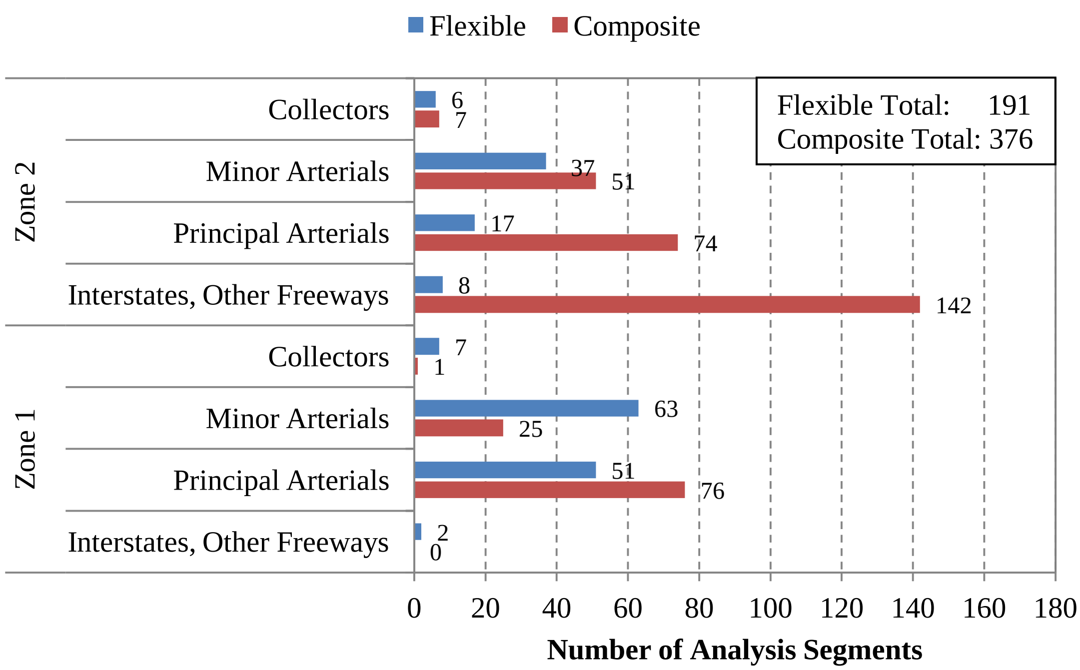


Figure 3.16. Number of HMA Mill OL segments used in the analysis (post-first treatment).

Figures 3.17 and 3.18 show the number of first and post-first HMA overlay (HMA OL) segments used in the analysis.

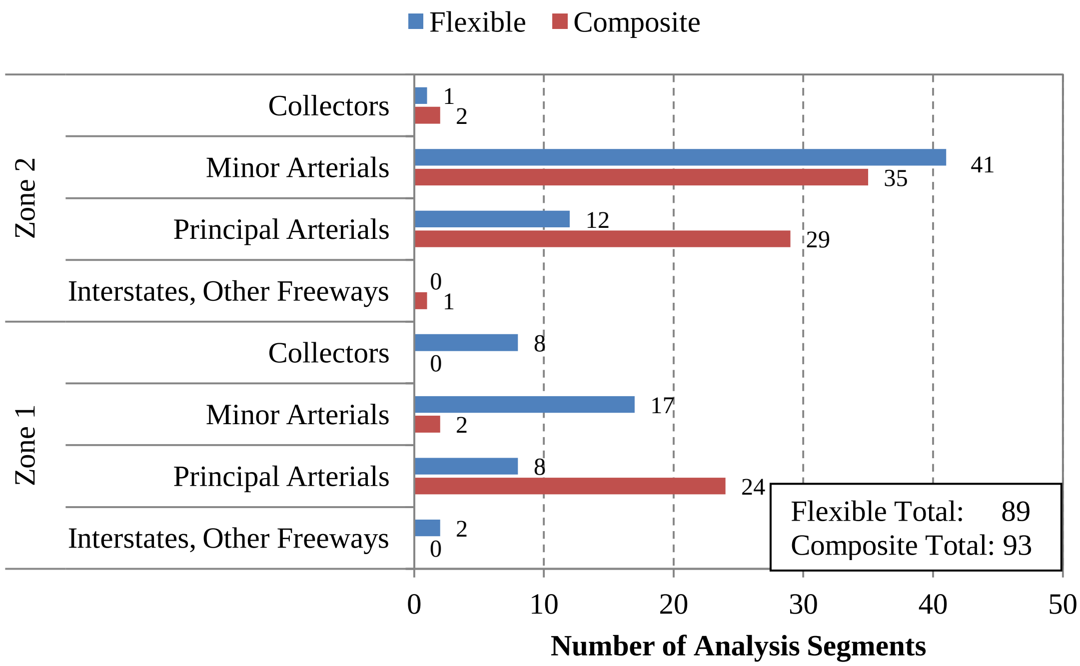


Figure 3.17. Number of HMA OL segments used in the analysis (first treatment).

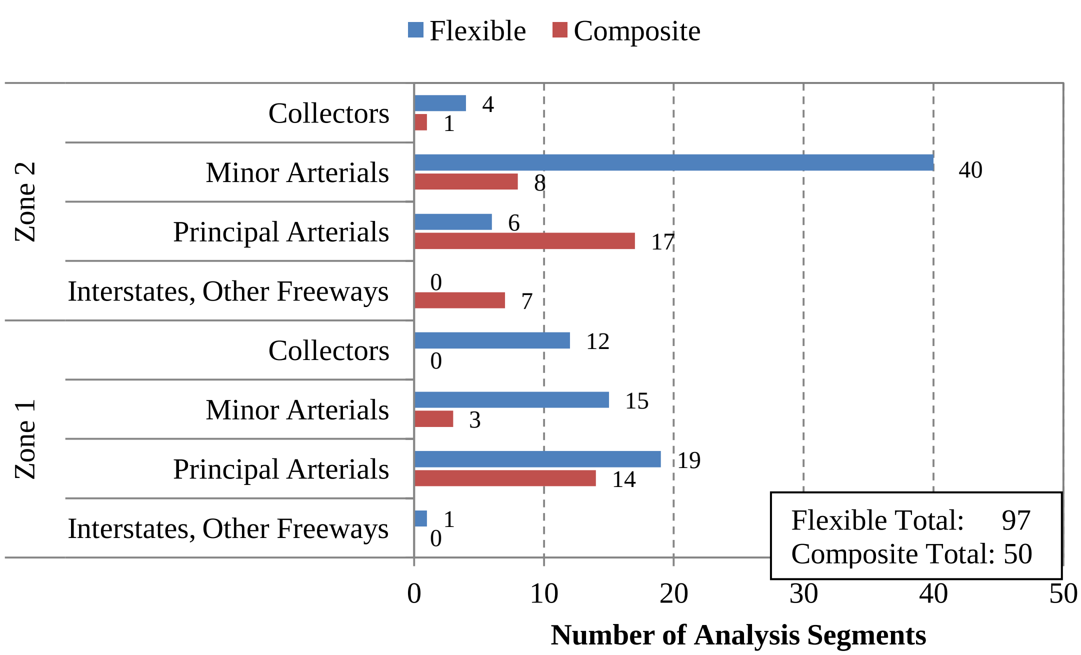


Figure 3.18. Number of HMA OL segments used in the analysis (post-first treatment).

Figures 3.19 and 3.20 show the number of first and post-first PCC joint and crack seal segments used in the analysis.

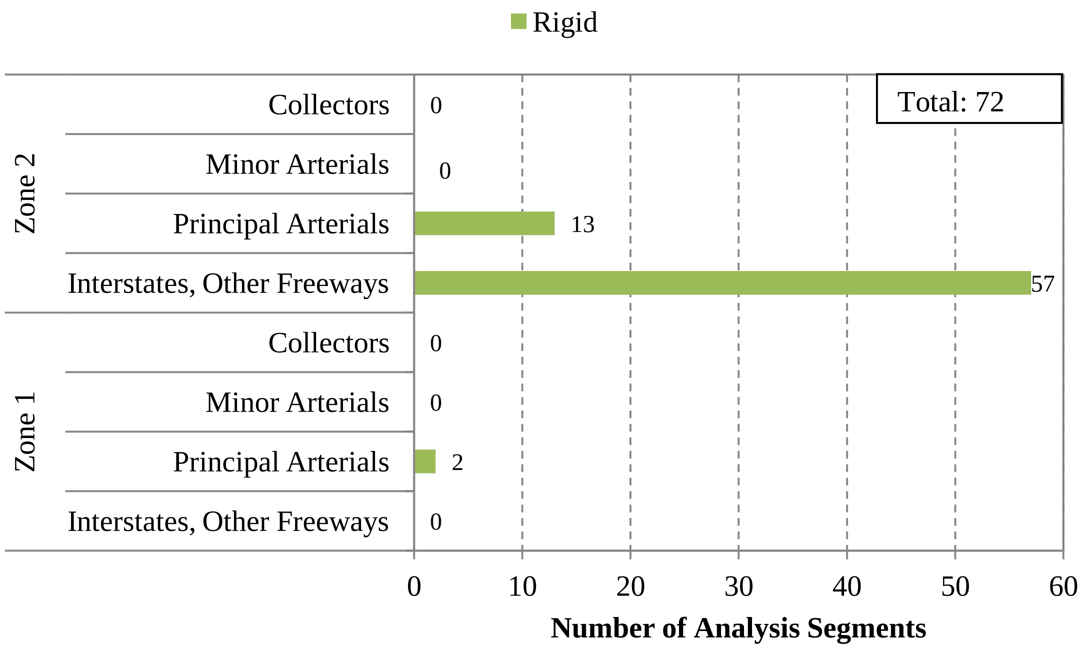


Figure 3.19. Number of PCC joint and crack seal segments used in the analysis (first treatment).

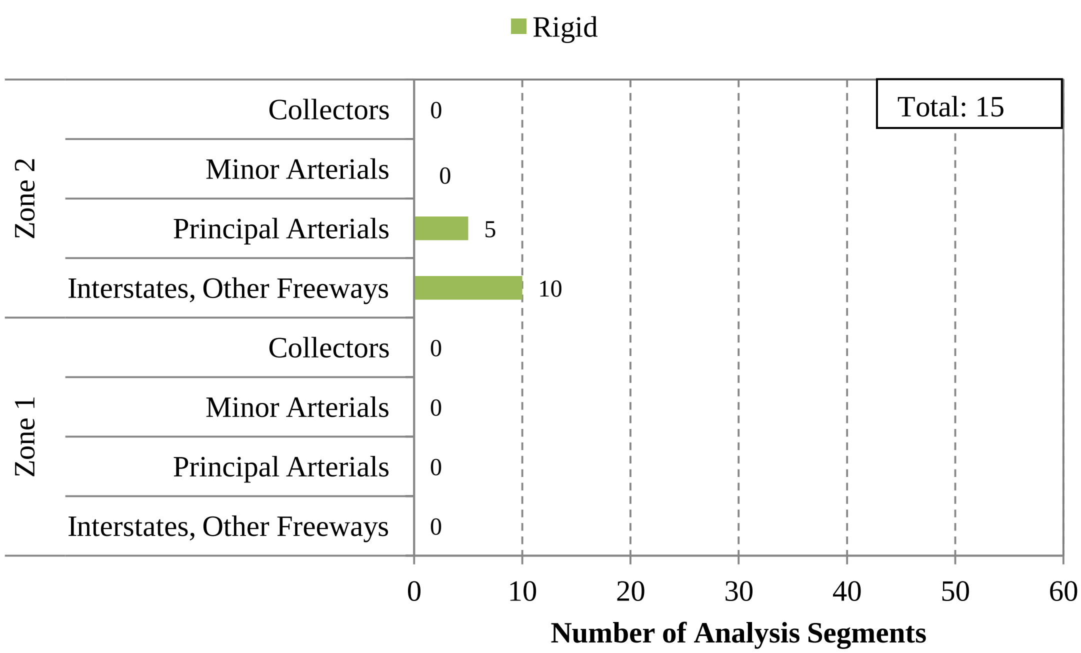


Figure 3.20. Number of PCC joint and crack seal segments used in the analysis (post-first treatment).

Even though there were over 300 concrete pavement rehabilitation (CPR) projects listed in the CPM project list, upon closer examination there were considerable differences in the type of work performed under each project. For example, one project might include only full-depth concrete repairs while another project included concrete joint repairs with diamond grinding. This issue, in addition to the lack of performance data and/or absence of an R&R segment to link the CPM treatment to, resulted in a sufficient number of confounding factors that meant that the performance and benefits of CPR treatments could not be evaluated in this study.

Summary

This chapter describes the data collection and data assembly efforts undertaken as a part of this project. The step-by-step methodology adopted in compiling and assembling the project database is discussed. A summary of the CPM treatments included and excluded from this study is also discussed.

Figure 3.21 summarizes the number of first-treatment-CPM segments included in this study grouped by zone, functional class, and pavement type.

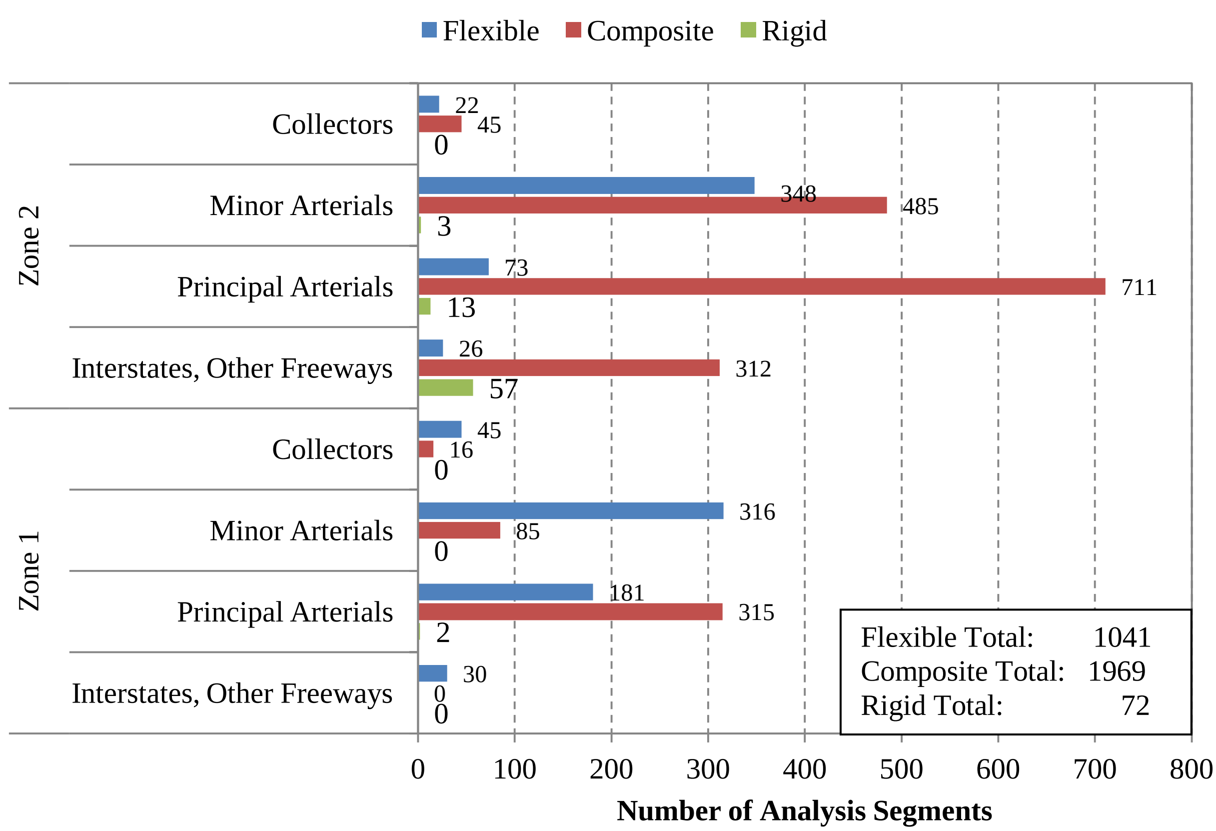


Figure 3.21. Number of CPM segments used in the analysis (first treatment).

Of the 3,085 first-treatment CPM segments used in the analysis, almost 70 percent were in Zone 2. The majority of the CPM treatments were placed on principal and minor arterials. The number of treatments placed on interstate pavements is low in Zone 1 since this region does not have significant interstate pavement mileage.

Figure 3.22 summarizes the number of post-first-treatment-CPM segments included in this study grouped by zone, functional class, and pavement type.

Of the 2,561 post-first-treatment CPM segments used in the analysis, almost 60 percent of the CPM treatments were in Zone 2. The majority of the CPM treatments were placed on principal and minor arterials. Again, there are not many treatments placed on interstate pavements in Zone 1 because this region does not have significant interstate pavement mileage.

There were the most composite pavements in the analysis matrix and the fewest rigid pavements. It appears that most of MDOT's rigid pavements have at some point received an HMA overlay to add to their structural capacity as a part of the R&R program, thereby becoming composite pavements. This would also explain the higher number of analysis segments for composite pavements.

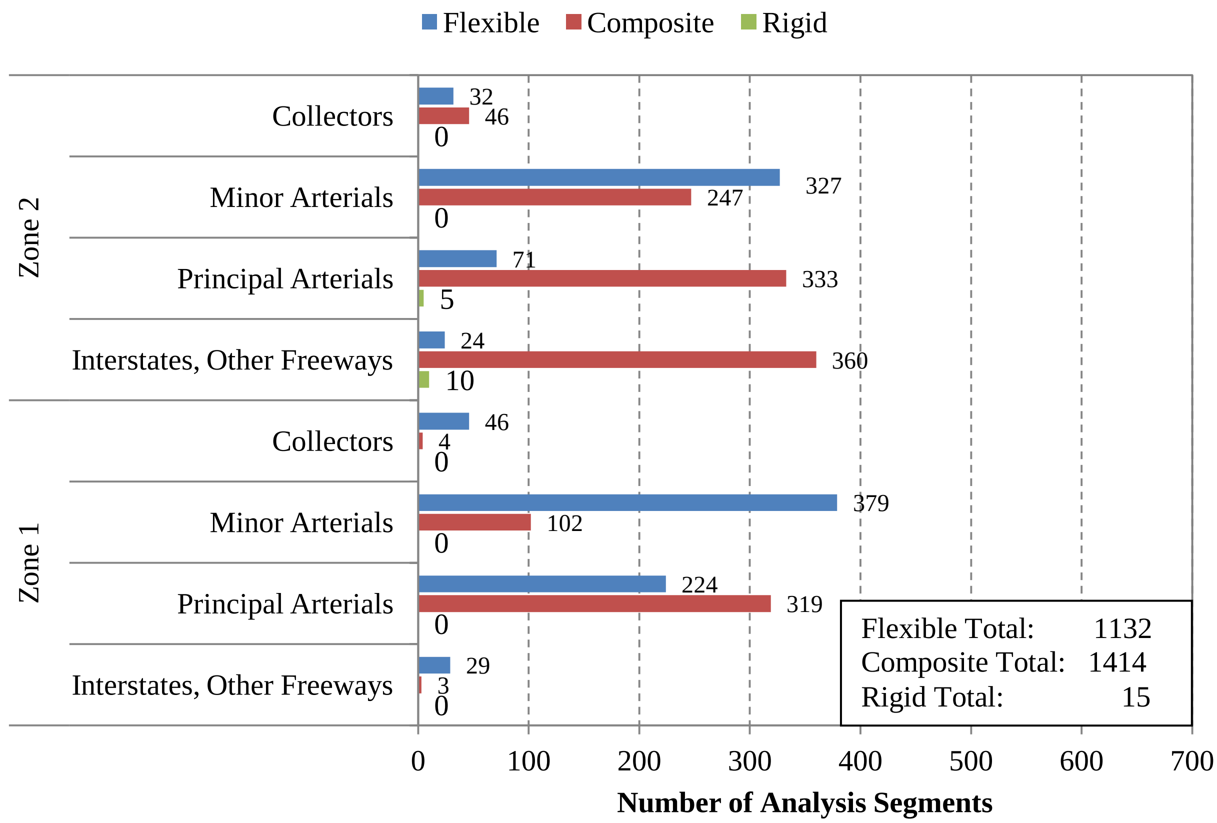


Figure 3.22. Number of CPM segments used in the analysis (post-first treatment).

From treatments considered in the "Pavement Seal" category for flexible and composite pavements, HMA crack seal is the most commonly used treatment by MDOT, followed by double microsurfacing, single and double chip seals, ultra-thin HMA overlays, and paver placed surface seals. As already discussed, crack sealing is analyzed in two ways in this study. First, it is addressed as a stand-alone CPM treatment to study its impact on pavement performance and its cost-effectiveness. However, since crack sealing is commonly used by MDOT as a planned, routine maintenance activity, it was decided not to treat crack sealing as a treatment that reset the treatment cycle based on discussions with MDOT. That means that the discussion of all of the other treatments can be thought of as also capturing the effect of crack sealing applied as a pre-treatment.

Since paver placed surface seals and ultra-thin HMA overlays were not initially approved in the CPM program, the number of treatments in these categories is considerably lower when compared to the rest of the CPM treatments. From treatments classified under the "Functional Enhancement" category, HMA overlays with and without milling were the most commonly used options for flexible and composite pavements. Concrete pavement rehabilitation and joint/crack sealing are the most common treatments used on rigid pavements.

4. PREVENTIVE MAINTENANCE TREATMENT PERFORMANCE AND COST ANALYSIS

Introduction

This chapter presents the analysis of the performance of selected preventive maintenance treatments used by MDOT in its CPM program. Regression curves were developed to model both pre- and post-treatment pavement performance trends. The cost-effectiveness of preventive maintenance was also evaluated. The measures used to describe the treatment effectiveness are pavement service life extension, area bounded by the performance curve, and benefit-cost ratio.

The assessment of benefits associated with a preventive maintenance treatment requires prediction models to describe the anticipated performance of the pavement using historic data. The effect of a treatment is determined by studying the change in the condition indicator (for MDOT the condition indicator is the Distress Index [DI]). This approach is supported by work by Von Quintus and Perera (2011), who investigated the primary factors contributing to premature aging or extended life of asphalt pavements in Michigan and suggested strategies to extend the life of asphalt pavements. Three condition indicators were used to study pavement performance: Distress Index, Rut Depth, and IRI. One of the findings of their study was that the Distress Index was the predominant trigger for maintenance and/or rehabilitation of existing pavements. Based on their findings, in this study the DI was the only condition indicator used to model pavement performance. However, it should be noted that a CPM treatment can be triggered by any of the performance indicators, such as rutting, friction, or IRI, and it is understood that analyzing performance solely based on a composite measure such as the DI has some inherent limitations.

Treatment Benefit

The benefit associated with a preventive maintenance treatment was determined using three measures:

- Pavement service life extension (in years)
- Area bounded by performance curve
- Benefit-cost ratio

As discussed in Chapter 2, the pavement service life extension is the difference between the expected service life computed using the post-treatment performance models and the expected service life computed using the pre-treatment performance models (do-nothing curve). The service life is computed for a threshold DI value, and in this study that threshold was set at 40 to evaluate the performance benefits. A DI threshold value of 40 was chosen for two reasons: (a) the majority of the data for preventive maintenance treatments were between a DI of 0 and 40, so using the models to predict performance for pavement conditions worse than a DI of 40 may not be reliable; and (b) the threshold DI used by MDOT for major rehabilitation activities is 50. Preventive maintenance treatments in general are not expected to perform well for pavements with DI values worse than 50 and the maximum benefit from preventive maintenance is expected to be realized for CPM treatments applied up to DI values of 40. The benefit area associated with a treatment is determined by comparing the post-treatment area with the total area under the pavement performance curve. The benefit is quantified as the difference between the overall post-treatment area and the associated do-nothing area. The concept of pavement service life extension and benefit area is illustrated in figure 4.1.

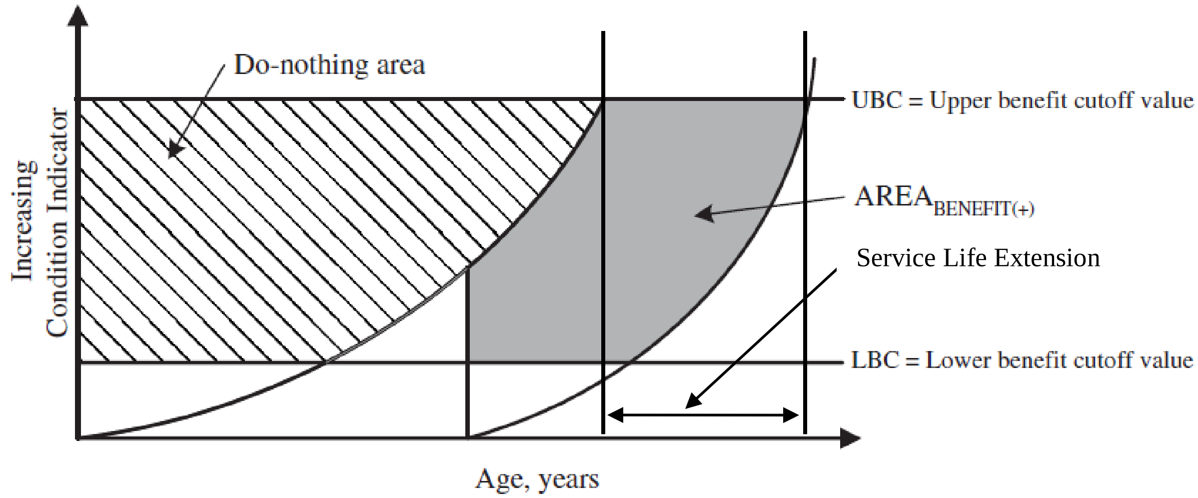


Figure 4.1. Illustration of pavement service life extension and benefit area (Peshkin et al. 2004).

In this study, the computed benefit area was normalized by presenting it as a percentage benefit over the pre-treatment performance area so that the benefits of various treatments relative to the pre-treatment performance could be compared. The benefit-cost ratio was computed as the ratio between the unit cost of the treatment and normalized benefit area. The higher the benefit-cost ratio, the more cost-effective a treatment is. Appendix B provides additional information on how this concept was applied to the data analyzed in this study.

Model Variables and Assumptions

The following independent variables were considered to develop the pavement performance models:

- Climatic Zones: Zone 1 (Superior and North regions) and Zone 2 (Grand, Bay, Southwest, University, and Metro regions).
- Pavement type: flexible, composite, and rigid.
- Pavement age: time since the last major rehabilitation/reconstruction activity, in years.

Functional classification (Interstates/Other Freeways, Other Principal Arterials, Minor Arterials, and Collectors) was included in the original analysis matrix. However, since there were many gaps in the data, this analysis did not result in reliable performance models at the network level and no further analysis on this variable was performed.

An attempt was made to study the impact of pre-treatment pavement condition, climate, and traffic by developing multiple regression models. In a majority of the cases, traffic and pre-treatment condition were found to be insignificant variables and were not further considered in developing the performance models for analysis. However, descriptive statistics (pre-treatment DI, pavement age at treatment placement, and pavement service life extension) are provided to compare the performance of treatments placed on pavement in two pre-treatment condition categories: DI $\leq$ 25 and DI > 25.

It should be noted that independent factors such as pavement structural capacity, subgrade type, and traffic may have a significant impact on performance. However, collecting and analyzing those types of data may be more applicable in a project-level study or a study with a selected sample of analysis segments. Furthermore, while the type, severity, and extent of individual distresses may play a large role in the applicability and performance of preventive maintenance treatments, the impact of individual distresses on pavement performance was not investigated in this study.

MDOT CPM Treatments

MDOT identifies a very broad range of treatments as preventive maintenance. In addition to the standard CPM treatments listed in table 1.1, MDOT also periodically uses new and upcoming preventive maintenance treatments (classified as *Emerging Technology Treatments*). These treatments include:

- Polymer Injection Slab Stabilization.
- Ultra-Thin Bituminous Overlays for High Volume Roads (< 1 inch thick).
- Fibermat (Stress Absorbing Membrane Interlayer [SAMI]).
- TruPave Engineered Paving Mat (Interlayer).
- Longitudinal Joint Stabilizer.

In addition to the *Emerging Technology Treatments* listed above, MDOT tests other treatments to study their performance and cost-effectiveness.

The primary objective of the CPM program is to preserve the structural integrity of existing pavements and extend the service life of the state trunkline network. In addition to the state and federal funding that MDOT receives for its CPM program, a discretionary budget and an emerging technologies budget supplement funding to achieve the most cost-effective preventive maintenance strategy.

Treatment Thresholds

The threshold values for various pavement condition indicators specified in the MDOT CPM manual (MDOT 2010) for flexible, composite, and rigid pavements are shown in tables 4.1 and 4.2. The threshold values are specified for five performance indicators: Remaining Service Life (RSL, years), Distress Index (DI), Ride Quality Index (RQI), International Roughness Index (IRI, inches/mile), and Rutting (Rut, inches). The threshold values specified are the maximum values below which the listed treatments are expected to be effective.

In general, the threshold DI value for the application of preventive maintenance treatments varies between 10 and 40. Substantial treatments like HMA overlays and concrete pavement restoration have a higher threshold DI value since these treatments can address pavements with a higher level of distress when compared to other MDOT CPM treatments.

Pavement Performance Analysis

This section presents the results of the pavement performance analysis efforts. The performance of the pavement before and after the placement of the preventive maintenance treatment was analyzed separately to determine the impact of the treatment.

Table 4.1. Treatment thresholds for flexible and composite pavements (MDOT 2010).

CPM Treatment	Flexible Pavement Thresholds					Composite Pavement Thresholds				
	RSL	**DI**	**RQI**	**IRI**	**Rut**	**RSL**	**DI**	**RQI**	**IRI**	**Rut**
HMA Overlay (non-structural)	3	40	70	163	0.50	3	25	70	163	0.50
HMA Mill and Overlay (non-structural)	3	40	80	212	1.00	3	30	80	212	1.00
Single Chip Seal	6	25	54	107	0.13					
Double Chip Seal	5	30	54	107	0.13	5	15	54	107	0.13
Regular Single Microsurfacing	10	15	54	107	1.00					
Multiple/Heavy Single Microsurfacing	5	30	54	107	1.00					
Double Microsurfacing						5	15	54	107	1.00
Crack Treatment	10	15	54	107	0.13	10	5	54	107	0.13
Overband Crack Filling	7	20	54	107	0.13	7	10	54	107	0.13
Ultra-thin HMA Overlay	7	30	54	107	0.13	7	20	54	107	0.13
Paver Placed Surface Seal	5	30	62	132	0.25	5	15	62	132	0.25

Table 4.2. Treatment thresholds for rigid pavements (MDOT 2010).

CPM Treatment	Rigid Pavement Thresholds			
	RSL	**DI**	**RQI**	**IRI**
Full Depth Concrete Pavement Repair	7	20	54	107
Concrete Joint Resealing	10	15	54	107
Concrete Crack Sealing	10	15	54	107
Diamond Grinding	12	10	54	107
Dowel Bar Retrofit	10	15	54	107
Concrete Pavement Restoration	3	40	80	212

During the preliminary pavement performance model development efforts, the average DI over the analysis segment's limits was plotted against the pavement age. There was a large amount of scatter in the data and reliable performance models could not be developed. This was true with both pre- and post-treatment data sets.

The next modeling technique used was to plot the average pre-treatment DI at a given pavement age. This technique, in conjunction with the elimination of obvious outliers (high DI values at pavement age zero – which are most likely the DI values prior to rehabilitation or treatment placement) and elimination of data points with a very small representation (fewer than five data points) for a given pavement age. These filtering rules were consistently applied and this resulted in performance models that exhibited reasonable trends.

A sample comparison between the preliminary and the refined models is shown in figure 4.2.

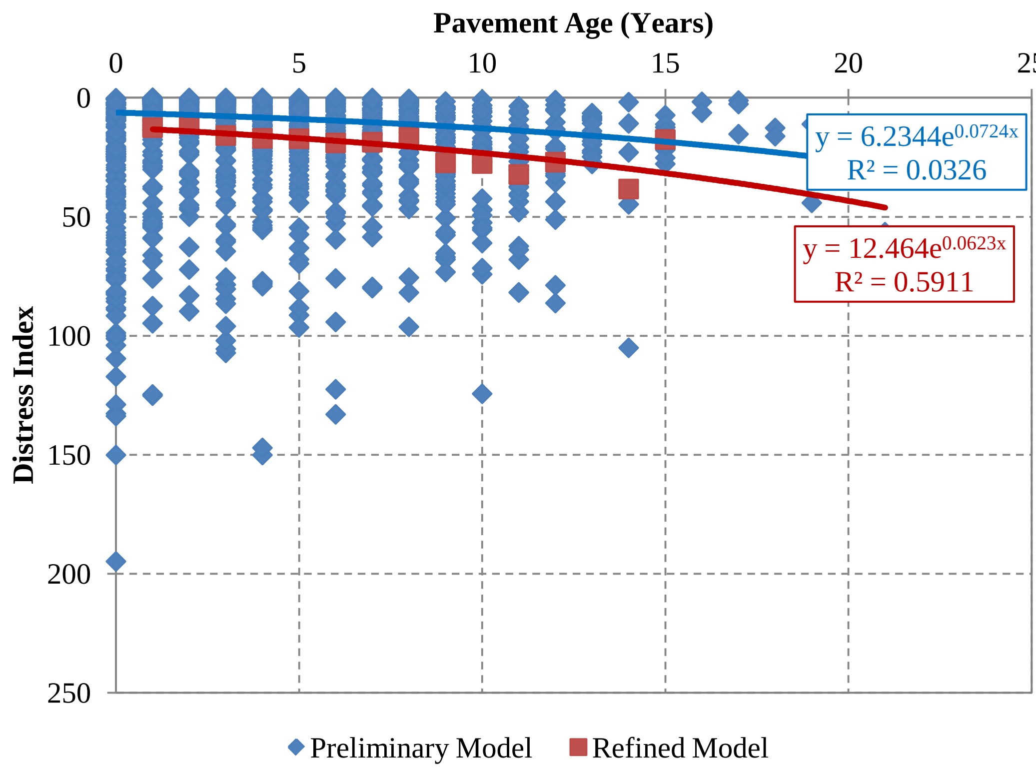


Figure 4.2. Sample comparison between preliminary and refined performance models.

Pre-Treatment Performance (Do-Nothing Performance)

A summary of the pre-treatment regression models is shown in table 4.3. All the models exhibited good correlations with very reasonable R-squared values.

Table 4.3. Pre-treatment performance models.

Pavement Type	Zone	Performance Model	R^2
Flexible	All	$DI = 8.7362e^{0.0819\ Age}$	0.90
	Zone 1	$DI = 6.1979e^{0.0969\ Age}$	0.85
	Zone 2	$DI = 11.414e^{0.0802\ Age}$	0.92
Composite	All	$DI = 9.8396e^{0.0699\ Age}$	0.72
	Zone 1	$DI = 9.8453e^{0.0747\ Age}$	0.76
	Zone 2	$DI = 9.0307e^{0.0839\ Age}$	0.78
Rigid	All	$DI = 3.9579e^{0.0769\ Age}$	0.65
	Zone 1		
	Zone 2		

DI: Distress Index; Age: Pavement Age

The models developed for flexible and composite pavements exhibited good correlations and resulted in high R-squared values. Reliable performance models could not be developed by zone for rigid pavements; however, reasonable trends were observed when all the zones were considered together. These pre-treatment models were used as the basis to compare the pavement performance after application of the preventive maintenance treatment to establish the associated benefits.

Post-Treatment Performance

The performance models and the benefits associated with each preventive maintenance treatment considered in this study are discussed in this section. All the performance models developed for the individual treatments discussed in this section are for the first application of the preventive maintenance treatment after a major rehabilitation or reconstruction activity.

As discussed in Chapter 3, to get a clearer picture of the treatment performance, the analysis of the first CPM activity was separated from all subsequent CPM treatments (and grouped and designated as “post-first CPM”). The post-first CPM treatments are not applied consistently; for example, a chip seal may be placed on a segment with an existing chip seal or on a segment that received a thin HMA overlay. Since the existing surface on which the post-first CPM treatments are placed vary significantly, the anticipated performance is also expected to vary considerably. Hence, only the overall performance of post-first CPM treatments was evaluated rather than evaluating the performance on a treatment-by-treatment basis. The overall performance of the MDOT CPM program is discussed in Chapter 5.

Single Chip Seals

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.3 and 4.4, respectively. For both flexible and composite pavements, the majority of the single chip seals are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years. It is noted that a significantly higher number of analysis segments are available for flexible pavements compared to composite pavements, which is consistent with MDOT’s CPM manual guidelines which recommends the use of single chip seals on flexible pavements only.

Performance Models

Table 4.4 summarizes the models developed to describe the performance of single chip seals. Since very few analysis segments were available for single chip seals placed on composite pavements, reliable performance models could not be developed.

Table 4.4. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
Single Chip Seal	Flexible	All	$DI= 7.0046e^{0.0761\ Age}$	0.46
		Zone 1	$DI = 5.0805e^{0.0942\ Age}$	0.65
		Zone 2	$DI = 5.8142e^{0.0867\ Age}$	0.50
	Composite	All		
		Zone 1		
		Zone 2		

Figures 4.5 through 4.7 illustrate the pre- and post- treatment performance models developed to study the impact of single chip seals.

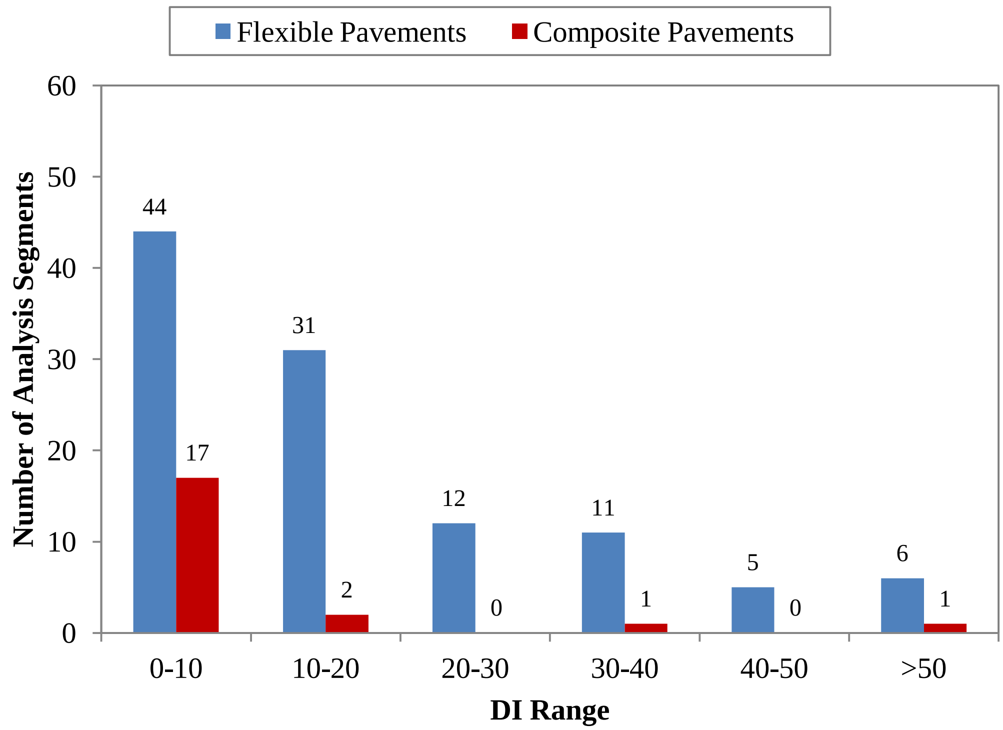


Figure 4.3. Pre-treatment pavement condition distribution for single chip seals.

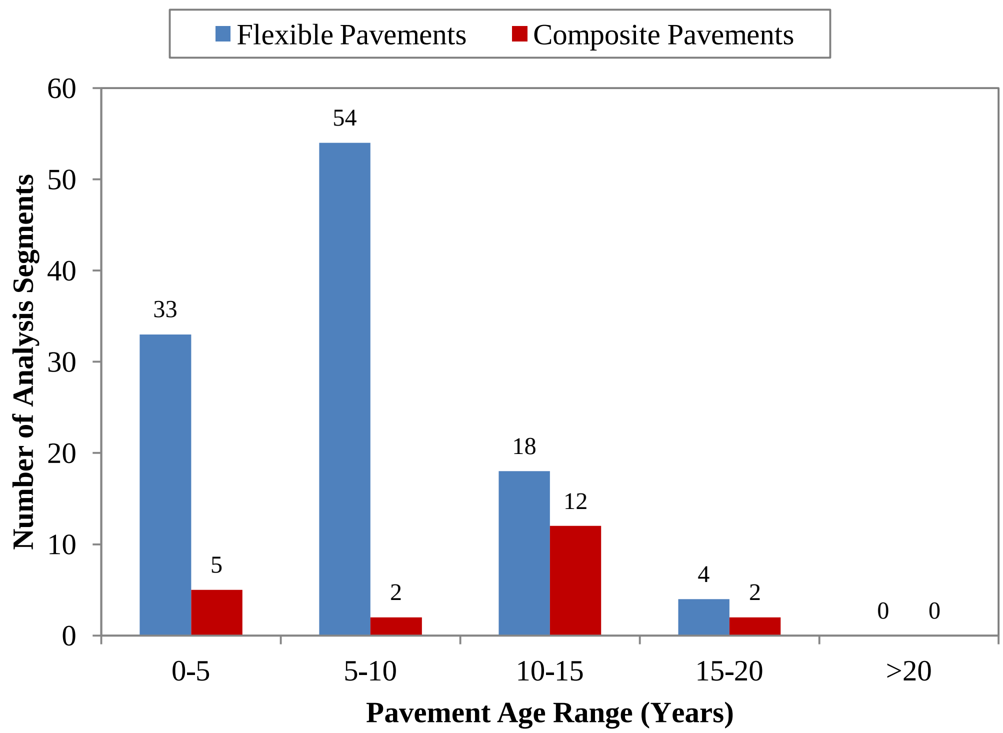


Figure 4.4. Pre-treatment pavement age distribution for single chip seals.

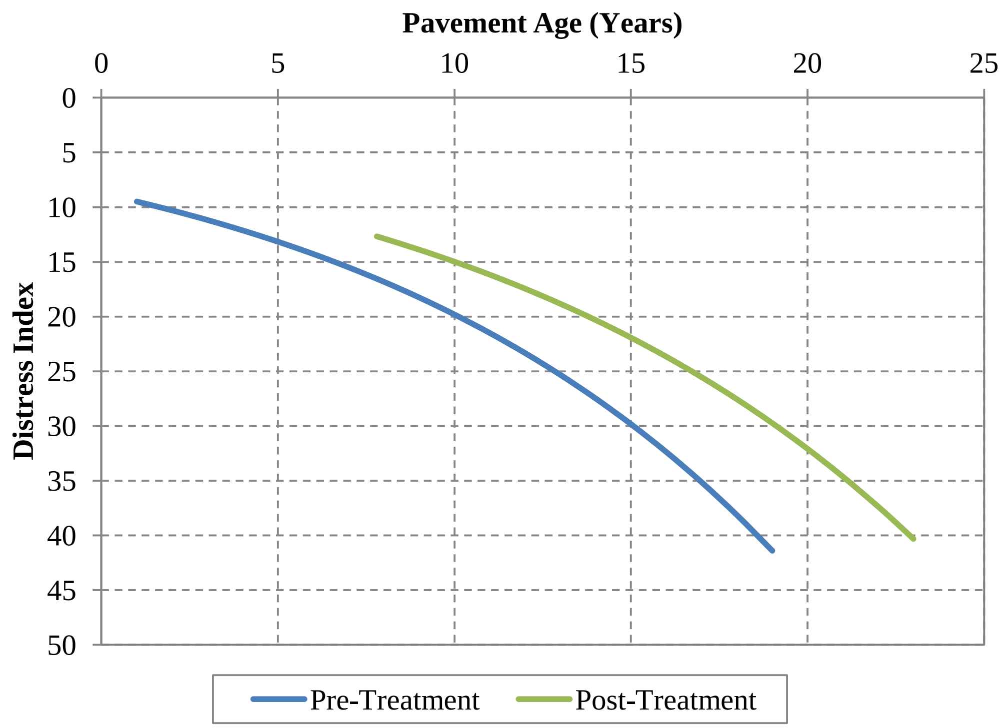


Figure 4.5. Pre- and post-treatment pavement performance – single chip seal on flexible pavement (all zones).

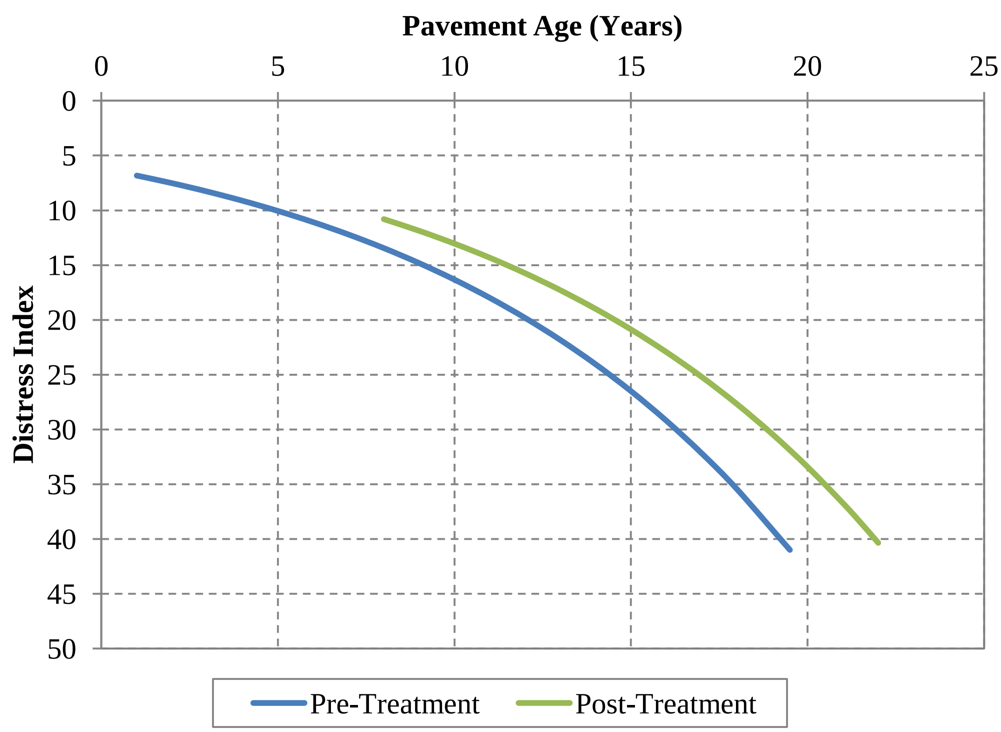


Figure 4.6. Pre- and post-treatment pavement performance – single chip seal on flexible pavement (Zone 1).

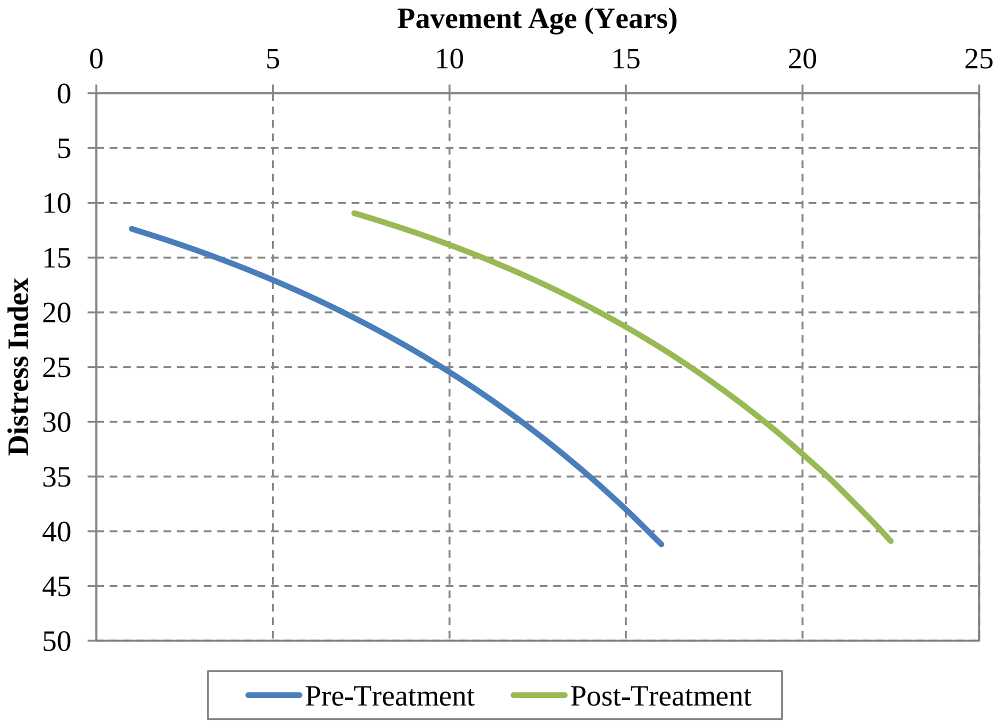


Figure 4.7. Pre- and post-treatment pavement performance – single chip seal on flexible pavement (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.5.

Table 4.5. Service life extension and treatment benefit from single chip seals.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
Single Chip Seal	Flexible	All	4.3	29
		Zone 1	2.7	15
		Zone 2	6.6	63
	Composite	All		
		Zone 1		
		Zone 2		

The pavement service life extension obtained from single chip seals placed on flexible pavements is 4.3 years when all the zones are considered together, with the service life extensions for Zones 1 and 2 being 2.7 and 6.6 years, respectively. The area benefits vary from 15 percent for Zone 1 to 63 percent for Zone 2, with the overall benefit being 29 percent when both the zones are considered together.

Descriptive Statistics

Table 4.6 shows statistics (average [Avg.] and standard deviation [SD]) on the pre-treatment pavement condition for single chip seals. The average pre-treatment DI values for single chip seals varied between 16 and 27 for flexible pavements, and between 7 and 12 for composite pavements. In general, the average pre-treatment DI values were higher for flexible pavements before the placement of single chip seals.

Table 4.6. Pre-treatment DI statistics for single chip seals

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Single Chip Seal	Flexible	All	18.4	17.5	15.8	15.2	26.8	21.6
		DI ≤ 25	10.7	6.6	10.1	6.6	13.3	5.9
		DI > 25	44.3	18.0	41.6	16.6	48.3	20.2
	Composite	All	9.1	13.7	7.4	15.5	12.4	9.1
		DI ≤ 25	5.1	3.8	3.3	2.0	9.2	3.7
		DI > 25	46.3	20.8	61.0	-	31.5	-

Avg: Average; SD: Standard Deviation

Table 4.7 shows statistics on the average age of the pavements on which the single chip seals were placed. The average pavement age at treatment placement was approximately 8 years for flexible pavements and around 9 years for composite pavements.

Table 4.7. Average pavement age statistics for single chip seals.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Single Chip Seal	Flexible	All	7.8	3.9	8.0	3.7	7.3	4.5
		DI ≤ 25	7.7	3.8	7.7	3.7	7.4	4.3
		DI > 25	8.3	4.4	9.1	3.8	7.0	5.2
	Composite	All	9.0	4.9	8.8	5.3	9.6	4.4
		DI ≤ 25	9.1	4.8	9.2	5.2	8.7	4.1
		DI > 25	9.0	8.5	3.0	-	15.0	-

Table 4.8 shows statistics on the average time to the next CPM treatment after the placement of single chip seals. The average time to the next CPM treatment was approximately 5 years for composite pavements and around 5.5 years for flexible pavements.

Table 4.8. Average time to next CPM treatment for single chip seals.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Single Chip Seal	Flexible	All	5.5	1.7	5.5	1.7	5.6	1.8
		DI ≤ 25	5.7	1.6	5.7	1.7	5.6	1.2
		DI > 25	4.8	1.9	4.3	1.1	5.5	2.5
	Composite	All	4.7	2.9	4.7	2.9		
		DI ≤ 25	4.3	1.0	4.3	1.0		
		DI > 25	2.0	-	2.0	-		

When the average DI at treatment application is greater than 25, the time to next CPM treatment decreases by approximately 1 year for flexible pavements and 2 years for composite pavements. This confirms that chip seals exhibit better performance when placed on pavements that are in *fair* to *good* condition.

In order to study the general effect of the timing of the application of single chip seals on the time to the next CPM treatment, the analysis segments were grouped into the five age categories shown in table 4.9.

Table 4.9. Impact of pavement age on average time to next CPM treatment for single chip seals.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
Single Chip Seal	0-5	5.8	1.5	5.3	4.0
	5-10	5.4	1.6		
	10-15	5.3	2.2		
	15-20				
	> 20				

In all the age categories for the single chip seals placed on flexible pavements, the time to next CPM treatment was around 5.5 years. Due to the small number of analysis segments for composite pavements, only one age category is available and the average time to next CPM treatment is around 5 years.

Double Chip Seals

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.8 and 4.9, respectively. For both flexible and composite pavements, the majority of the double chip seals are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years. As in the case of single chip seals, a significantly higher number of analysis segments are available for flexible pavements than for composite pavements, suggesting that both single and double chip seals are preferred for flexible pavements.

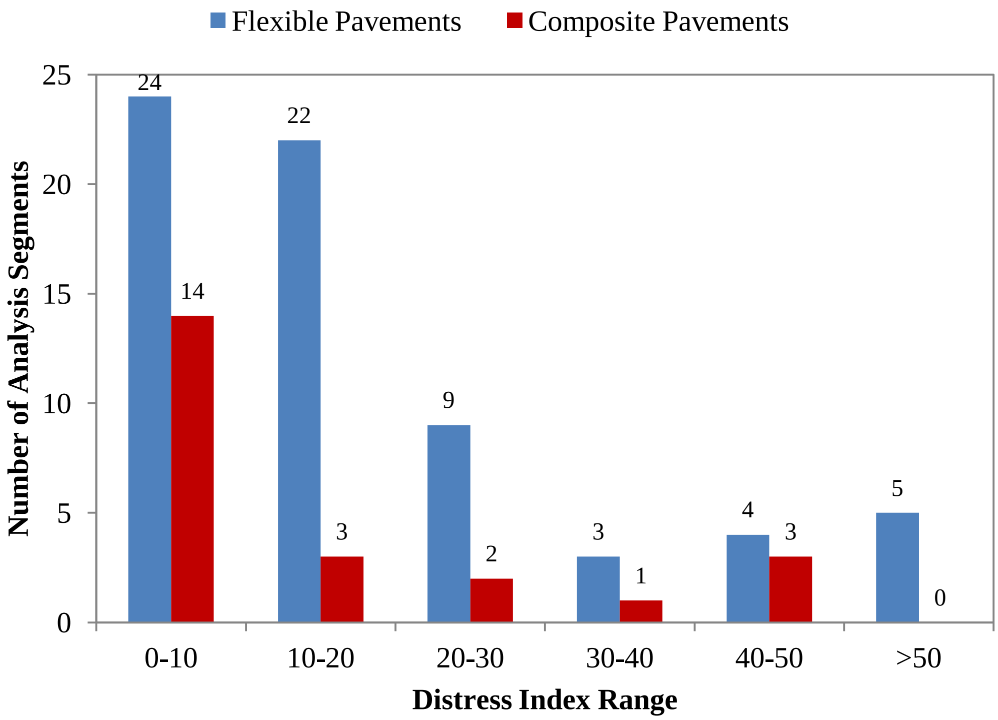


Figure 4.8. Pre-treatment pavement condition distribution for double chip seals.

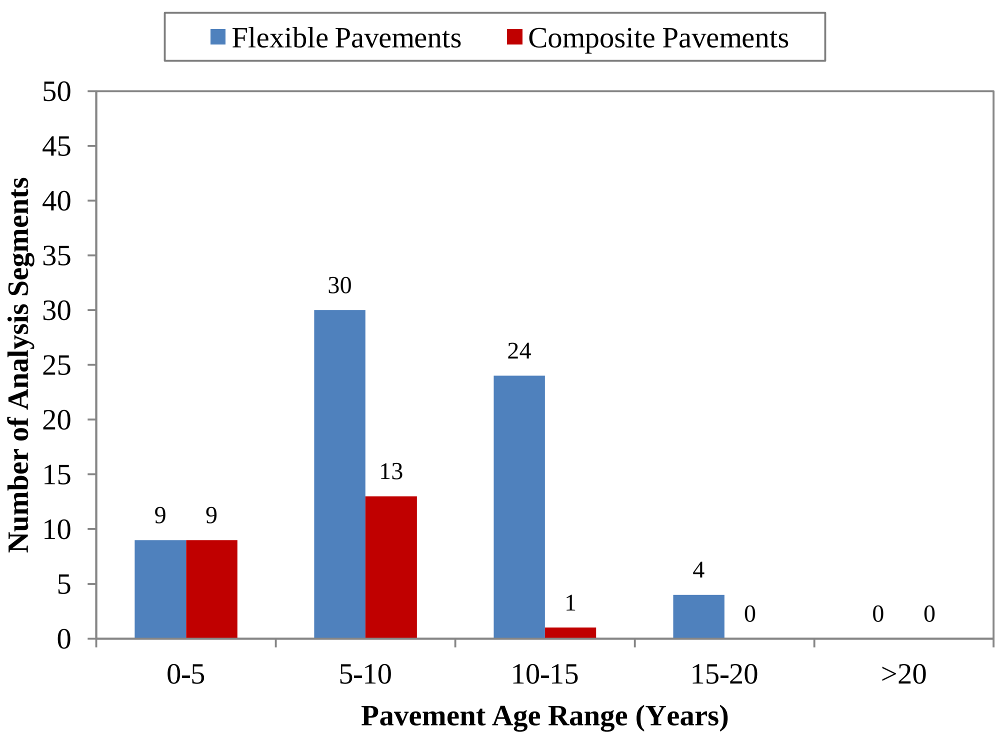


Figure 4.9. Pre-treatment pavement age distribution for double chip seals.

Performance Models

Table 4.10 summarizes the models developed to describe the performance of double chip seals. Reliable zone-specific models could not be developed for double chip seals placed on flexible pavements and hence are not presented in table 4.10. No analysis segments were available for double chip seals placed on composite pavements for Zone 1; only the models developed for Zone 2 are shown in table 4.10.

Table 4.10. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
Double Chip Seal	Flexible	All	$DI = 8.8675e^{0.0592\ Age}$	0.62
		Zone 1		
		Zone 2		
	Composite	All		
		Zone 1		
		Zone 2	$DI = 3.7866e^{0.1196\ Age}$	0.65

Figures 4.10 and 4.11 illustrate the pre- and post- treatment performance models developed to study the impact of double chip seals.

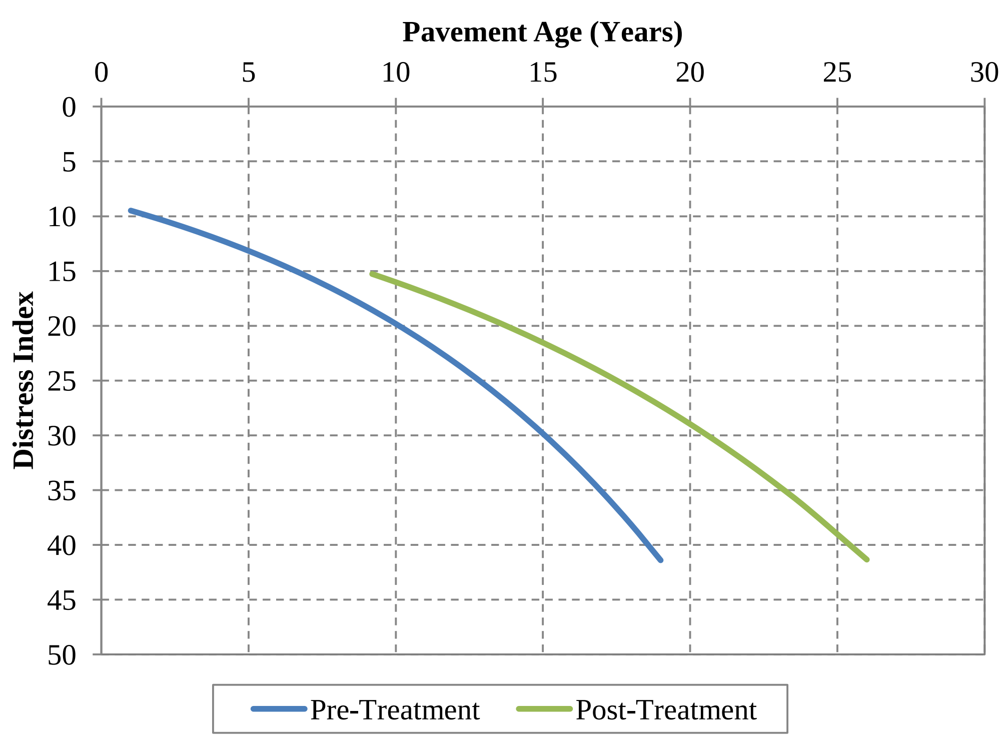


Figure 4.10. Pre- and post-treatment pavement performance – double chip seal on flexible pavements (all zones).

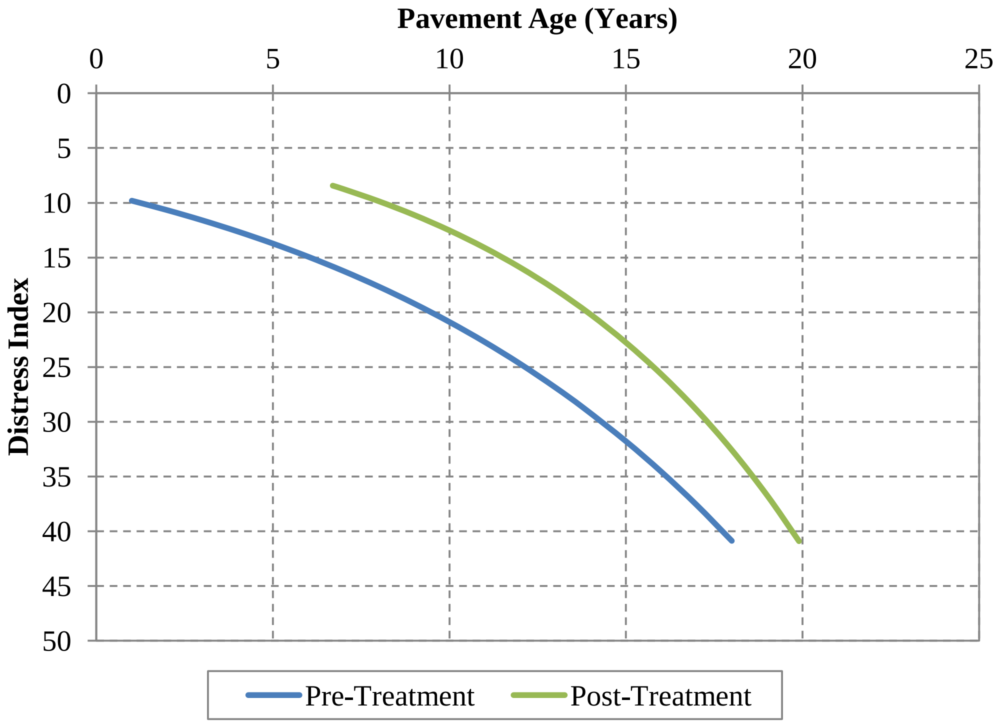


Figure 4.11. Pre- and post-treatment pavement performance – double chip seal on composite pavements (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.11.

Table 4.11. Treatment benefit from double chip seals.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
Double Chip Seal	Flexible	All	6.9	40
		Zone 1		
		Zone 2		
	Composite	All		
		Zone 1		
		Zone 2	2.0	32

The pavement service life extension obtained from double chip seals is around 7 years when placed on flexible pavements and around 2 years when placed on composite pavements. The area benefit obtained from double chip seals is between 30 to 40 percent.

Descriptive Statistics

Table 4.12 shows statistics on the pre-treatment pavement condition for double chip seals.

Table 4.12. Pre-treatment DI statistics for double chip seals.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Chip Seal	Flexible	All	19.5	17.4	12.8	11.8	21.8	18.5
		DI ≤ 25	11.1	6.3	10.4	6.7	11.4	6.1
		DI > 25	44.4	15.8	50.9	-	44.0	16.2
	Composite	All	14.2	15.0			14.2	15.0
		DI ≤ 25	7.2	5.1			7.2	5.1
		DI > 25	39.4	10.6			39.4	10.6

The average pre-treatment DI for double chip seals varied between 13 and 22 for flexible pavements, and was approximately 14 for composite pavements. In general, the average pre-treatment DI values were higher for flexible pavements before the placement of double chip seals.

Table 4.13 shows statistics on the average age of the pavements on which double chip seals were placed. The average pavement age at the time of treatment placement was between 9 and 10 years for flexible pavements and around 7 years for composite pavements.

Table 4.13. Average pavement age statistics for double chip seals.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Chip Seal	Flexible	All	9.2	3.6	10.1	3.2	9.2	3.7
		DI ≤ 25	9.0	3.8	10.5	2.8	9.0	4.0
		DI > 25	9.6	3.0	4.0	-	9.6	2.7
	Composite	All	6.7	3.3			6.7	3.3
		DI ≤ 25	6.3	3.0			6.3	3.0
		DI > 25	7.8	4.5			7.8	4.5

Table 4.14 shows statistics on the average time to the next CPM treatment after the placement of double chip seals. The average time to the next CPM treatment was approximately 5 years for flexible pavements and around 6 years for composite pavements.

Table 4.14. Average time to next CPM treatment for double chip seals.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Chip Seal	Flexible	All	4.9	1.7	7.3	2.9	4.6	1.2
		DI ≤ 25	5.1	1.8	7.3	2.9	4.7	1.3
		DI > 25	4.0	1.4			4.0	1.4
	Composite	All	5.7	1.6			5.7	1.6
		DI ≤ 25	6.2	1.1			6.2	1.1
		DI > 25	3.0	-			3.0	-

When the average DI at treatment application is greater than 25, the time to next CPM treatment decreases by approximately 1 year for flexible pavements and over 3 years for composite pavements. This confirms that the double chip seals are expected to perform better when placed on pavements in *fair*- to *good*-condition.

The impact of pavement age on the average time to the next CPM treatment is summarized in table 4.15. The highest average time to the next CPM treatment was observed when the pavement age was between 10 and 15 years for flexible pavements. For composite pavements, the average time to next CPM treatment was higher for treatments placed on pavements between 5 and 10 years old than for pavements which were less than 5 years old.

Table 4.15. Impact of pavement age on average time
to next CPM treatment for double chip seals.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
Double Chip Seal	0-5	4.3	1.2	4.0	1.4
	5-10	4.8	2.1	6.5	1.0
	10-15	5.7	1.0		
	15-20				
	> 20				

Double Microsurfacing

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.12 and 4.13, respectively. For both flexible and composite pavements, the majority of the microsurfacing treatments are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years. In contrast to the practice with chip seals, a significantly higher number of analysis segments are available for composite pavements than for flexible pavements, which may be indicative of the fact that microsurfacing is preferred over chip seal for composite pavements.

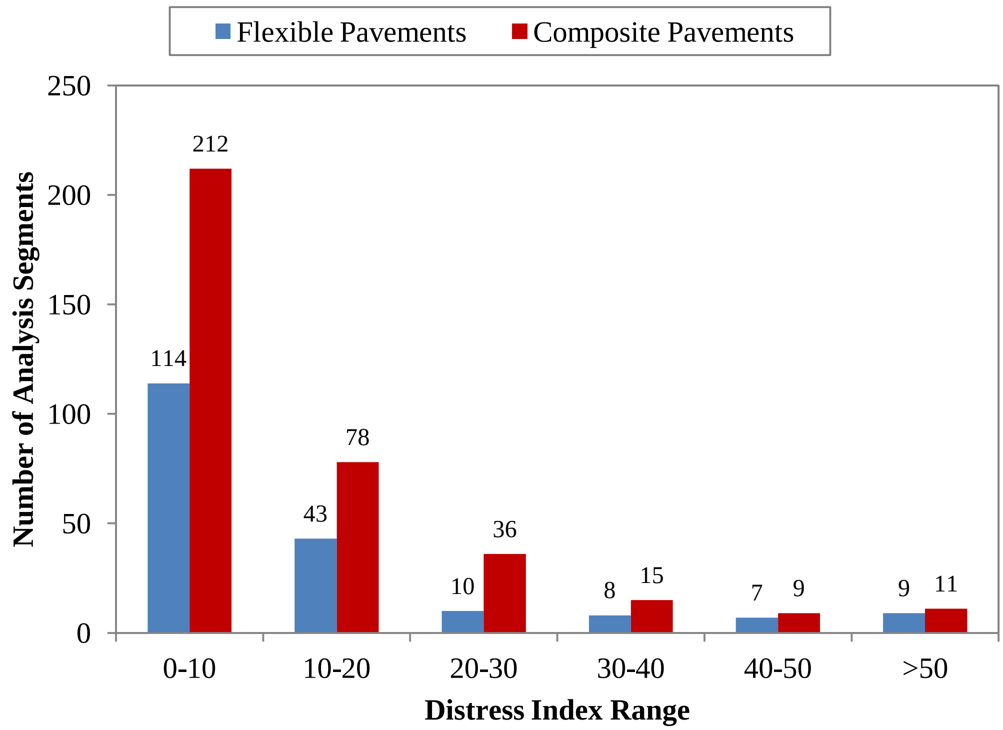


Figure 4.12. Pre-treatment pavement condition distribution for double microsurfacing treatments.

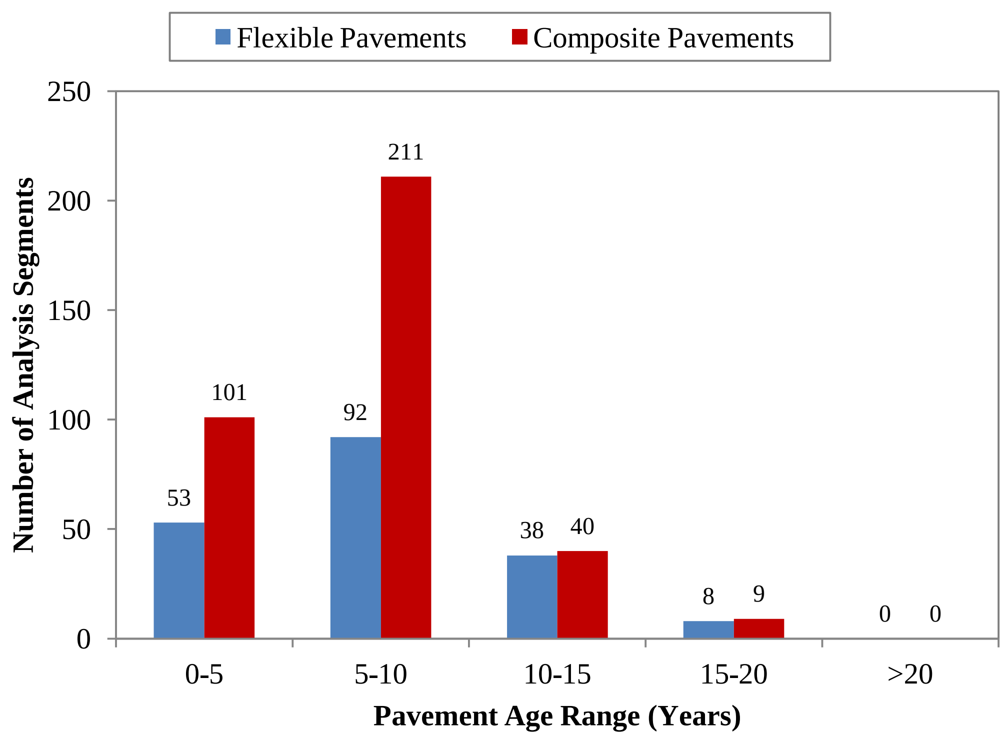


Figure 4.13. Pre-treatment pavement age distribution for double microsurfacing treatments.

Performance Models

Table 4.16 summarizes the models developed to describe the performance of double microsurfacing.

Table 4.16. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
Double Microsurfacing	Flexible	All	$DI = 6.1347e^{0.0848x}$	0.47
		Zone 1	$DI = 2.1665e^{0.108x}$	0.59
		Zone 2	$DI = 4.8883e^{0.1208x}$	0.44
	Composite	All	$DI = 12.024e^{0.0402x}$	0.74
		Zone 2	$DI = 12.394e^{0.0399x}$	0.57

Figures 4.14 through 4.18 illustrate the pre- and post- treatment performance models developed to study the impact of double microsurfacing.

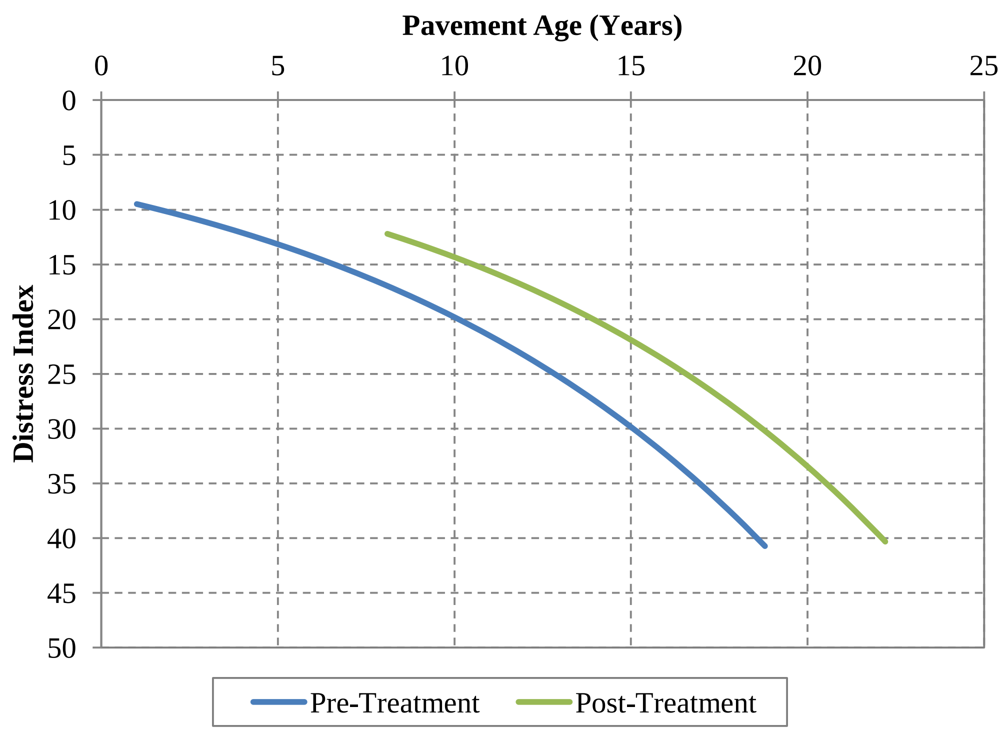


Figure 4.14. Pre- and post-treatment pavement performance – double microsurfacing on flexible pavement (all zones).

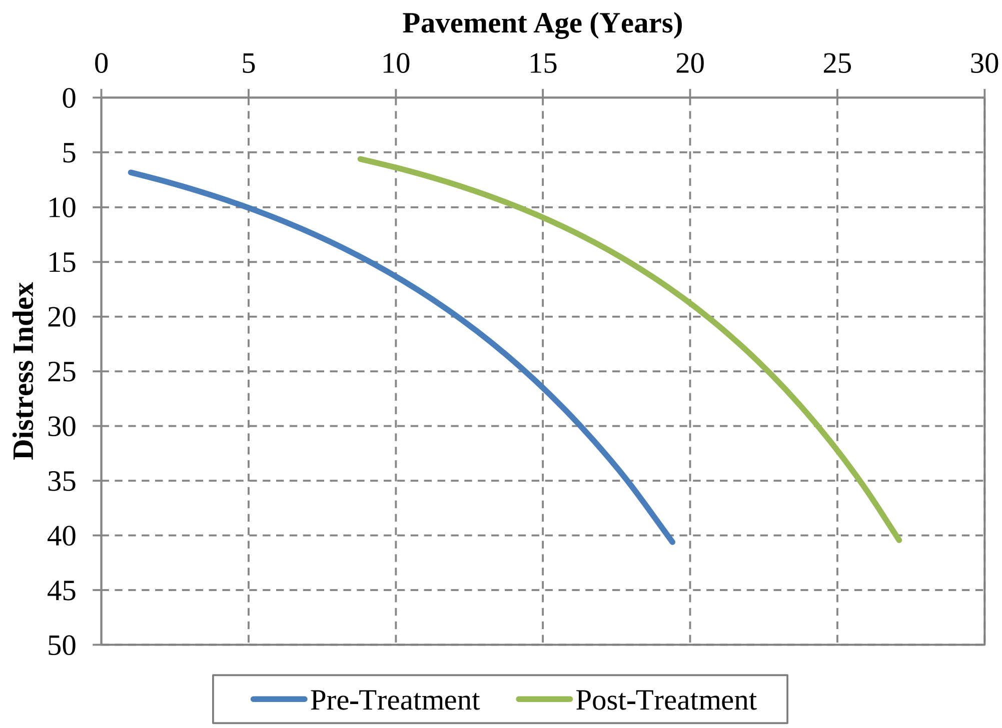


Figure 4.15. Pre- and post-treatment pavement performance – double microsurfacing on flexible pavement (Zone 1).

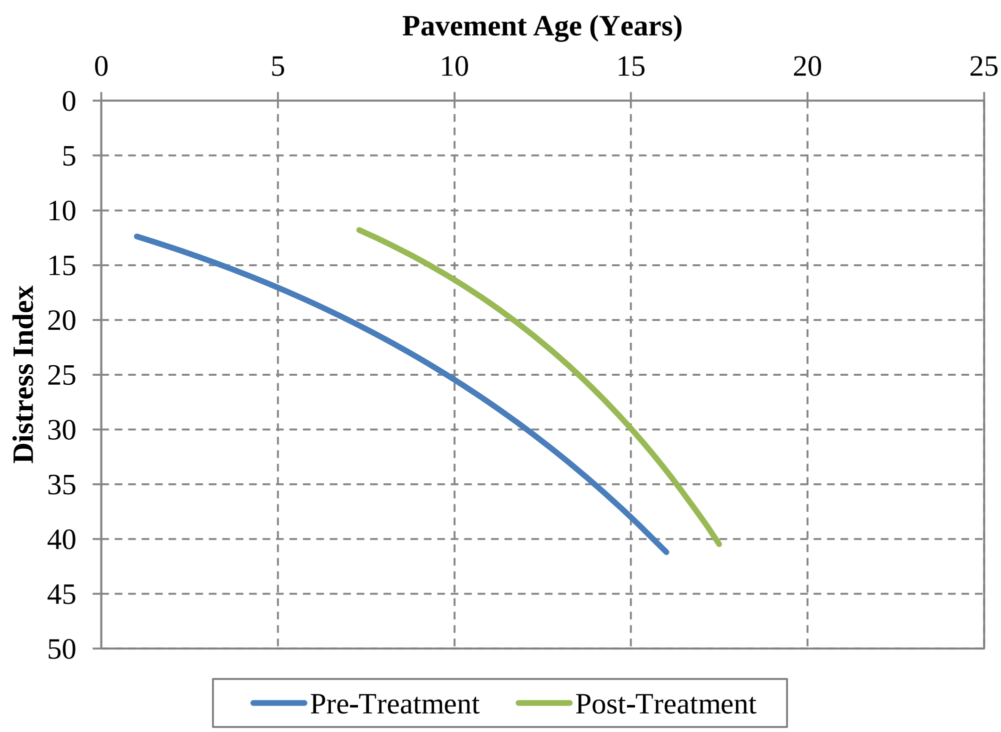


Figure 4.16. Pre- and post-treatment pavement performance – double microsurfacing on flexible pavement (Zone 2).

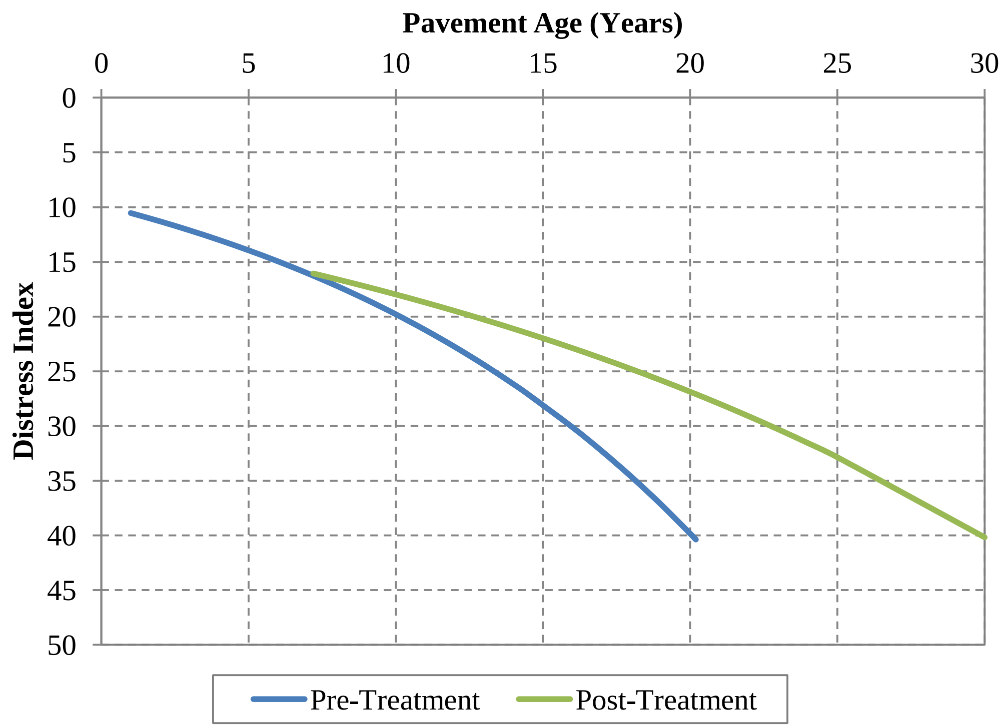


Figure 4.17. Pre- and post-treatment pavement performance – double microsurfacing on composite pavement (all zones).

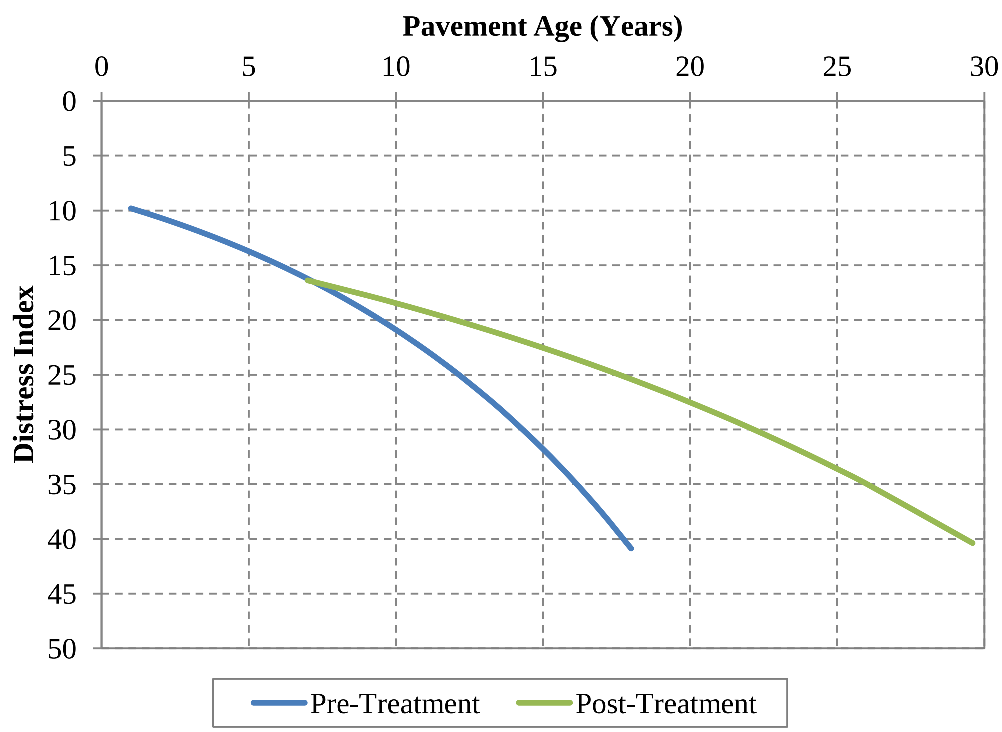


Figure 4.18. Pre- and post-treatment pavement performance – double microsurfacing on composite pavement (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.17.

Table 4.17. Treatment benefit from double microsurfacing.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
Double Microsurfacing	Flexible	All	3.5	22
		Zone 1	7.8	61
		Zone 2	1.8	23
	Composite	All	9.8	56
		Zone 1		
		Zone 2	11.6	49

The pavement service life extension obtained from double microsurfacing placed on flexible pavements varies between 1.8 years for Zone 2 and 7.8 years for Zone 1. When all the zones are considered together, the pavement service life extension obtained from double microsurfacing placed on flexible pavements is around 3.5 years. The pavement service life extension obtained from double microsurfacing placed on composite pavements varies between 10 and 12 years. The pavement service life extensions for double microsurfacing are much lower than the average values reported in the literature for flexible pavements and are much higher than typically reported values for composite pavements. Further investigation of the microsurfacing projects might help to identify the reasons for these differences. The area benefit obtained from double microsurfacing varies between 22 and 60 percent for flexible pavements and is around 50 percent for composite pavements.

Descriptive Statistics

Table 4.18 shows statistics on the pre-treatment pavement condition for double microsurfacing.

Table 4.18. Pre-treatment DI statistics for double microsurfacing.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Microsurfacing	Flexible	All	14.0	21.0	10.2	18.3	18.3	22.9
		DI ≤ 25	7.5	6.5	6.5	5.9	8.8	7.1
		DI > 25	55.7	31.3	67.9	41.8	52.1	27.8
	Composite	All	13.0	14.4	11.6	10.4	13.2	14.9
		DI ≤ 25	8.3	5.8	9.2	6.1	8.2	5.8
		DI > 25	40.6	18.3	41.7	3.8	40.5	18.8

The average pre-treatment DI value for double microsurfacing varied between 10 and 18 for flexible pavements and was 13 for composite pavements. The average pre-treatment values for the DI > 25 category for flexible pavements are greater than 50. At these DI levels, preventive maintenance treatments are not expected to be cost effective because the general condition of the pavement has deteriorated to a point where it is in need of a treatment that can improve the structural capacity of the pavement.

Table 4.19 shows statistics on the average age of the pavements on which the double microsurfacing treatments were placed. The average pavement age at the time of treatment placement was approximately 8 years for flexible pavements and around 7 years for composite pavements.

Table 4.19. Average pavement age statistics for double microsurfacing.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Microsurfacing	Flexible	All	8.1	3.9	8.8	4.4	7.3	3.0
		DI ≤ 25	8.2	3.9	8.8	4.3	7.4	3.0
		DI > 25	7.3	3.9	9.0	6.5	6.8	2.7
	Composite	All	7.2	3.2	9.2	3.7	7.0	3.0
		DI ≤ 25	7.2	3.0	9.1	3.6	6.9	2.9
		DI > 25	7.6	3.8	10.3	5.5	7.4	3.7

Table 4.20 shows statistics on the average time to the next CPM treatment after the placement of a double microsurfacing treatment. The average time to the next CPM treatment is around 5.5 years for both flexible and composite pavements.

Table 4.20. Average time to next CPM treatment for double microsurfacing.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Double Microsurfacing	Flexible	All	5.4	2.1	5.5	2.0	5.3	2.6
		DI ≤ 25	5.5	2.1	5.5	2.0	5.6	2.6
		DI > 25	4.9	2.0	6.0	1.6	3.3	1.2
	Composite	All	5.5	3.0	2.8	2.3	5.8	2.9
		DI ≤ 25	5.4	2.9	2.6	2.4	5.7	2.9
		DI > 25	6.7	3.0	4.0	-	7.0	3.0

DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM treatment for double microsurfacing. A possible explanation is that the microsurfacing treatments may be placed at higher pre-treatment DI values than chip seals.

The impact of pavement age on the time to next CPM treatment is summarized in table 4.21.

Table 4.21. Impact of pavement age on average time to next CPM treatment for double microsurfacing.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
Double Microsurfacing	0-5	5.3	2.3	5.6	2.6
	5-10	5.7	2.2	5.6	3.2
	10-15	5.3	2.0	5.1	1.5
	15-20	4.0	-	2.5	2.1
	> 20				

The highest average time to the next CPM treatment was observed for pavement ages between 5 and 10 years for both flexible and composite pavements.

Paver Placed Surface Seal (PPSS)

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.19 and 4.20 respectively. For both flexible and composite pavements, the majority of the PPSS treatments are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years.

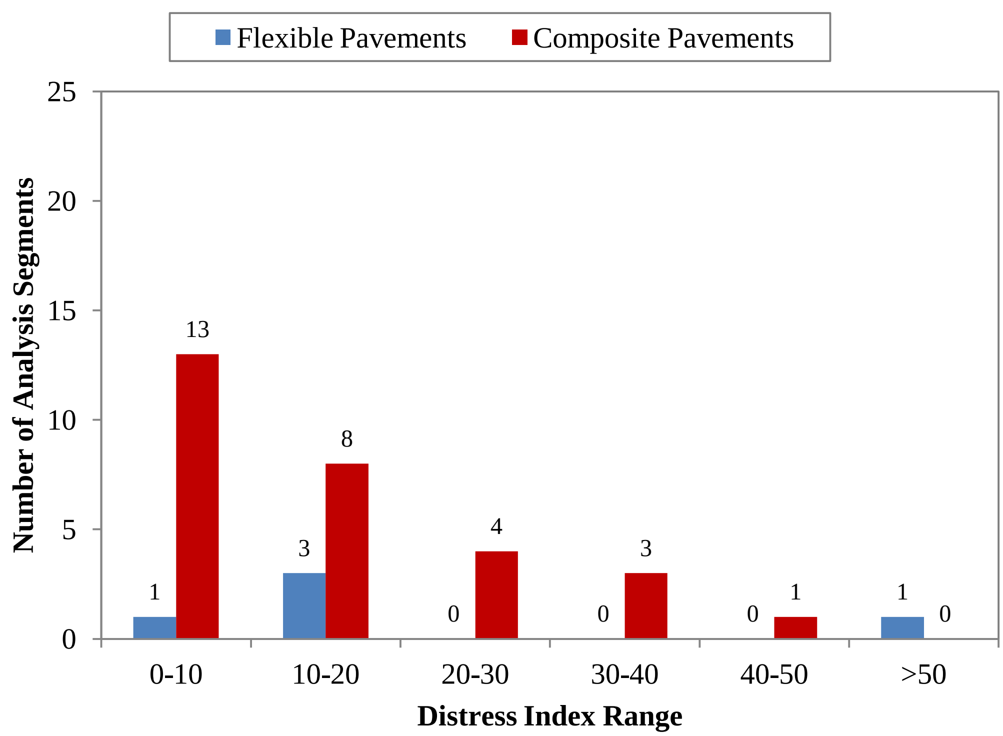


Figure 4.19. Pre-treatment pavement condition distribution for PPSS treatments.

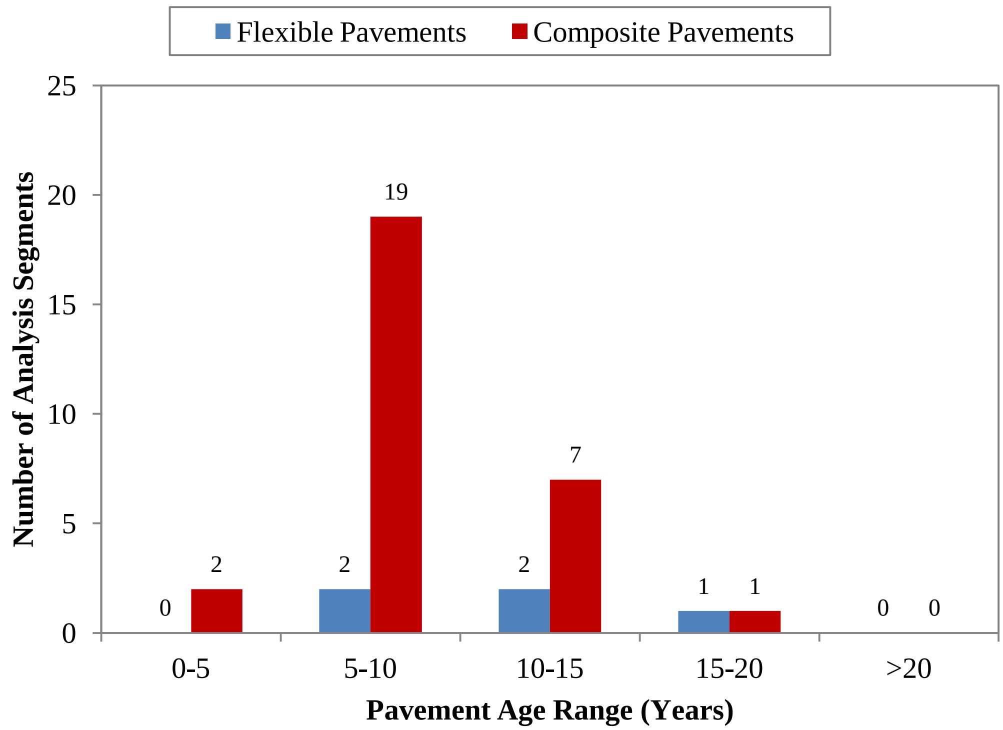


Figure 4.20. Pre-treatment pavement age distribution for PPSS treatments.

Performance Models

Since relatively few analysis segments were available for PPSS treatments, reliable performance models could not be developed. The following section summarizes the descriptive statistics on the performance of paver placed surface seals which can be used to make some general assessments regarding their performance.

Descriptive Statistics

Tables 4.22 shows statistics on the pre-treatment pavement condition for PPSS treatments. The average pre-treatment DI value was around 25 for flexible pavements, and around 15 for composite pavements.

Table 4.22. Pre-treatment DI statistics for PPSS.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Paver Placed Surface Seal	Flexible	All	25.5	31.9			25.5	31.9
		DI ≤ 25						
		DI > 25						
	Composite	All	14.5	10.8	41.1	-	13.5	9.7
		DI ≤ 25	10.5	6.7			10.5	6.7
		DI > 25	33.2	4.8	41.1	-	31.2	2.3

Table 4.23 shows statistics on the average age of the pavements on which the PPSS treatments were placed. The average pavement age at the time of treatment placement is almost 11 years for flexible pavements and around 9 years for composite pavements.

Table 4.23. Average pavement age statistics for PPSS.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Paver Placed Surface Seal	Flexible	All	10.8	4.6			10.8	4.6
		DI ≤ 25						
		DI > 25						
	Composite	All	9.0	3.2	4.0	-	9.2	3.1
		DI ≤ 25	9.5	3.1			9.5	3.1
		DI > 25	6.4	2.6	4.0	-	7.0	2.6

Table 4.24 shows statistics on the average time to the next CPM treatment after the placement of the PPSS treatments. The average time to the next CPM treatment is around 3 years for composite pavements. The average time to the next CPM treatment could not be assessed for flexible pavements because all the PPSS analysis segments included in this study are still in service. The average age of the in-service treatments is around 6 years (until the year of the last available DI data, which is 2010).

Table 4.24. Average time to next CPM treatment for PPSS.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Paver Placed Surface Seal	Flexible	All						
		DI ≤ 25						
		DI > 25						
	Composite	All	3.1*	2.1*			3.1*	2.1*
		DI ≤ 25	3.1*	2.1*			3.1*	2.1*
		DI > 25						

* Note: Over 50 percent of the PPSS treatments placed on composite pavements are still in service. The actual time to the next CPM treatment is likely greater than the values reported here.

HMA Crack Treatment

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.21 and 4.22, respectively. For both flexible and composite pavements, the majority of the HMA crack treatments are applied on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years. A significantly higher number of analysis segments are available for composite pavements than for flexible pavements

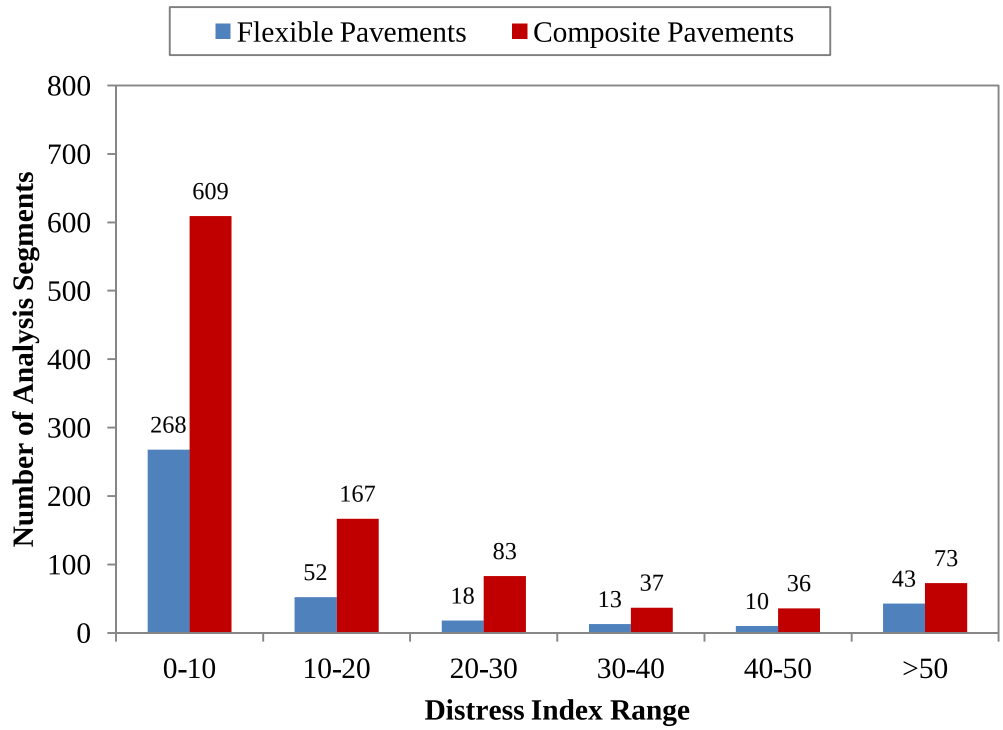


Figure 4.21. Pre-treatment pavement condition distribution for HMA crack treatments.

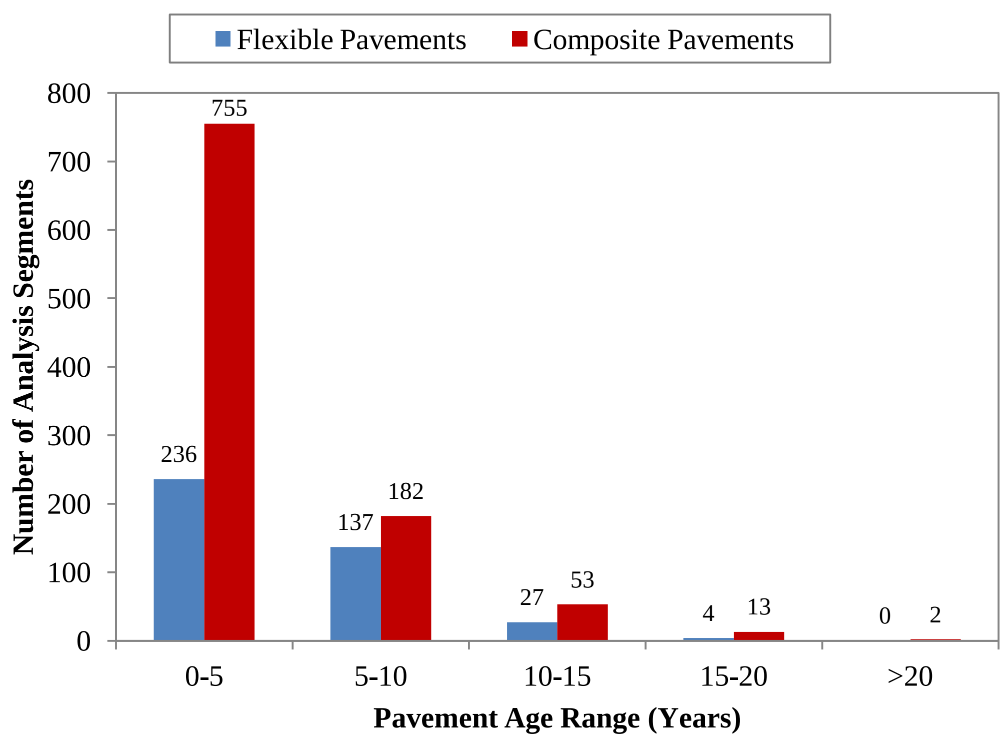


Figure 4.22. Pre-treatment pavement age distribution for HMA crack treatments.

Performance Models

Table 4.25 summarizes the models developed to describe the performance of HMA crack treatments.

Table 4.25. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
HMA Crack Treatment	Flexible	All	$DI = 9.1843e^{0.0688\ Age}$	0.73
		Zone 1	$DI = 6.7532e^{0.0808\ Age}$	0.66
		Zone 2	$DI = 11.53e^{0.0767\ Age}$	0.67
	Composite	All	$DI = 9.0043e^{0.0711\ Age}$	0.76
		Zone 1	$DI = 6.8143e^{0.085\ Age}$	0.65
		Zone 2	$DI = 9.8733e^{0.0723\ Age}$	0.77

Figures 4.23 through 4.28 illustrate the pre- and post- treatment performance models developed to study the impact of HMA crack treatments.

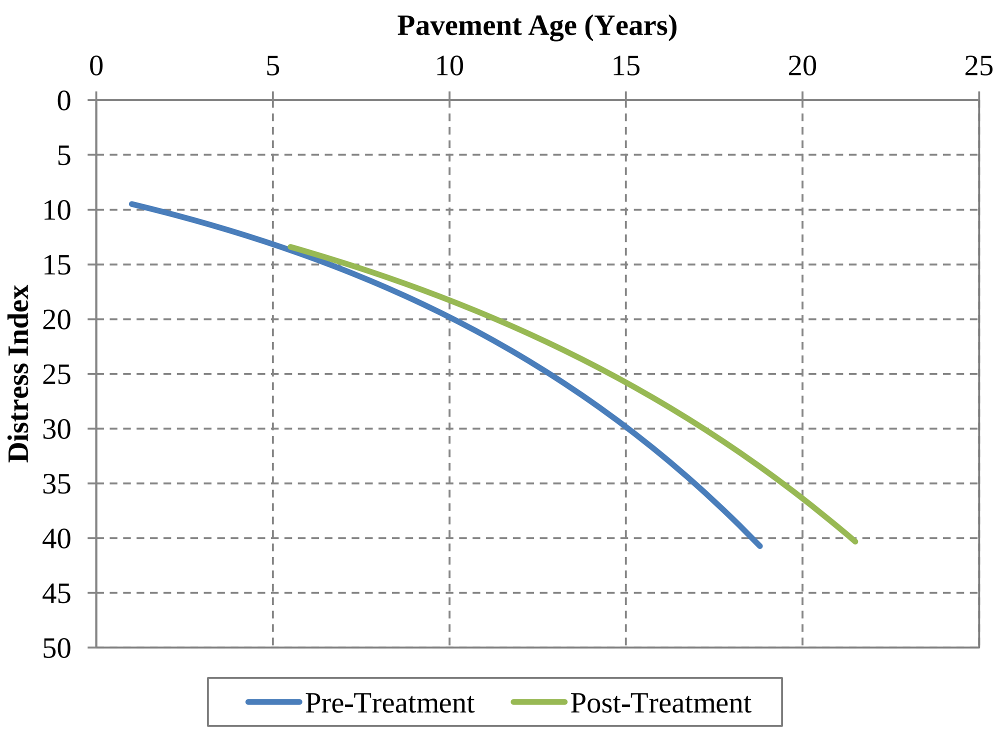


Figure 4.23. Pre- and post-treatment pavement performance – HMA crack treatment on flexible pavement (all zones).

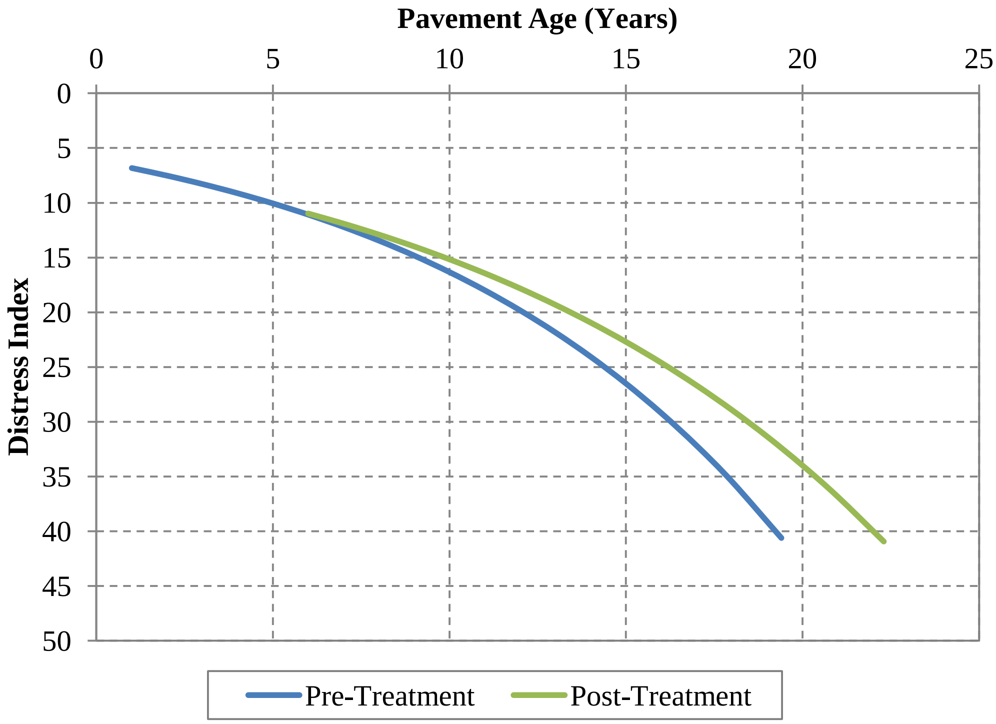


Figure 4.24. Pre- and post-treatment pavement performance – HMA crack treatment on flexible pavement (Zone 1).

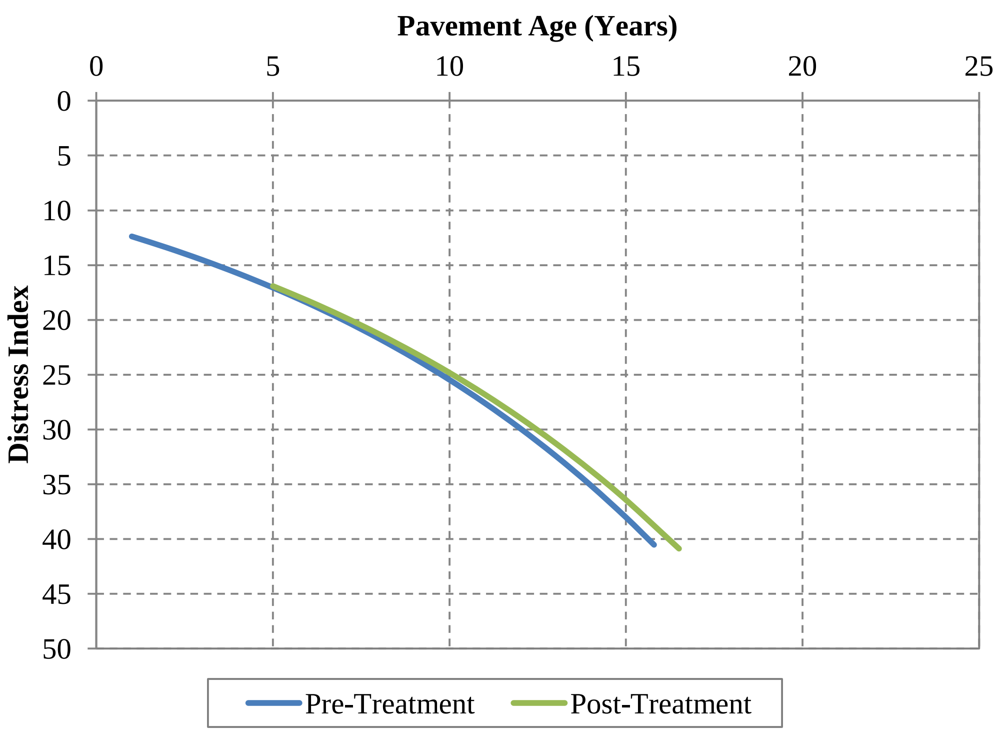


Figure 4.25. Pre- and post-treatment pavement performance – HMA crack treatment on flexible pavement (Zone 2).

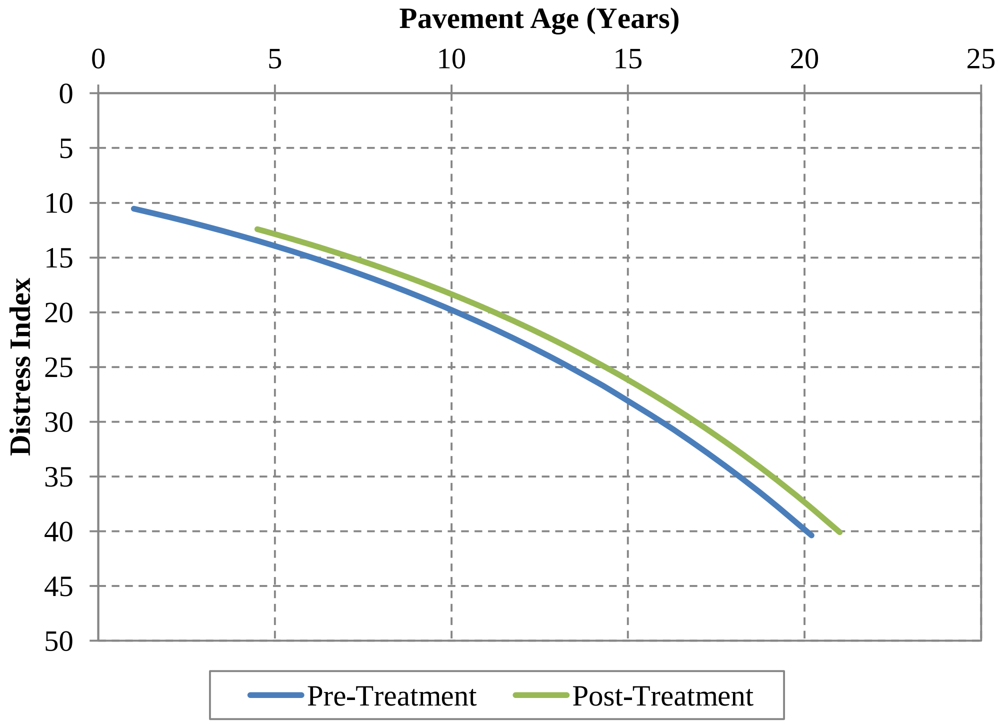


Figure 4.26. Pre- and post-treatment pavement performance –
HMA crack treatment on composite pavement (all zones).

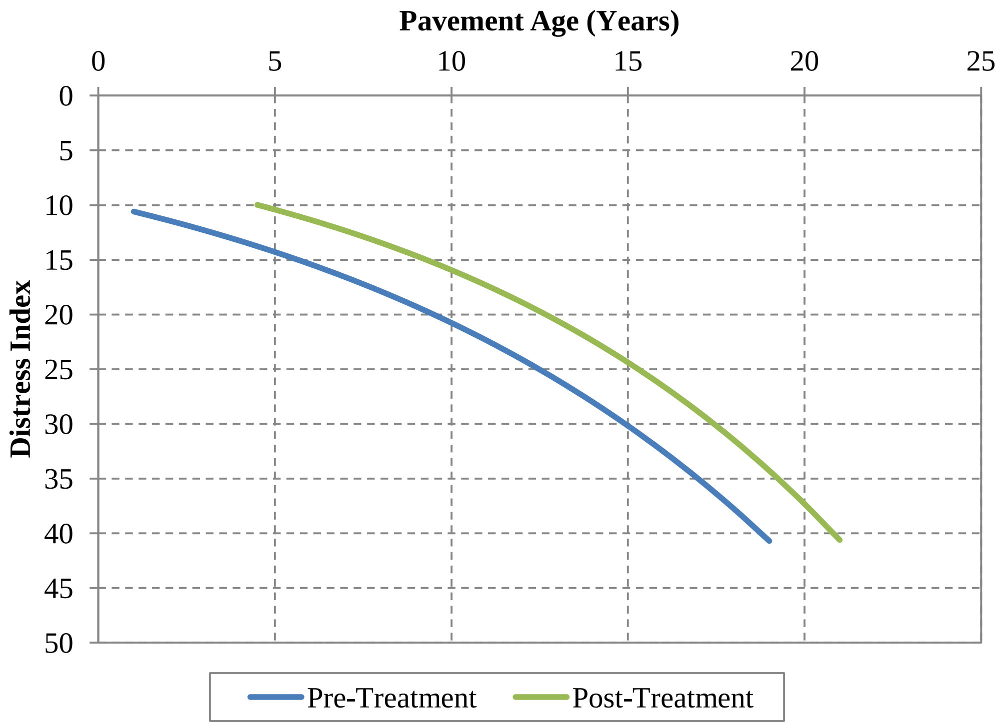


Figure 4.27. Pre- and post-treatment pavement performance –
HMA crack treatment on composite pavement (Zone 1).

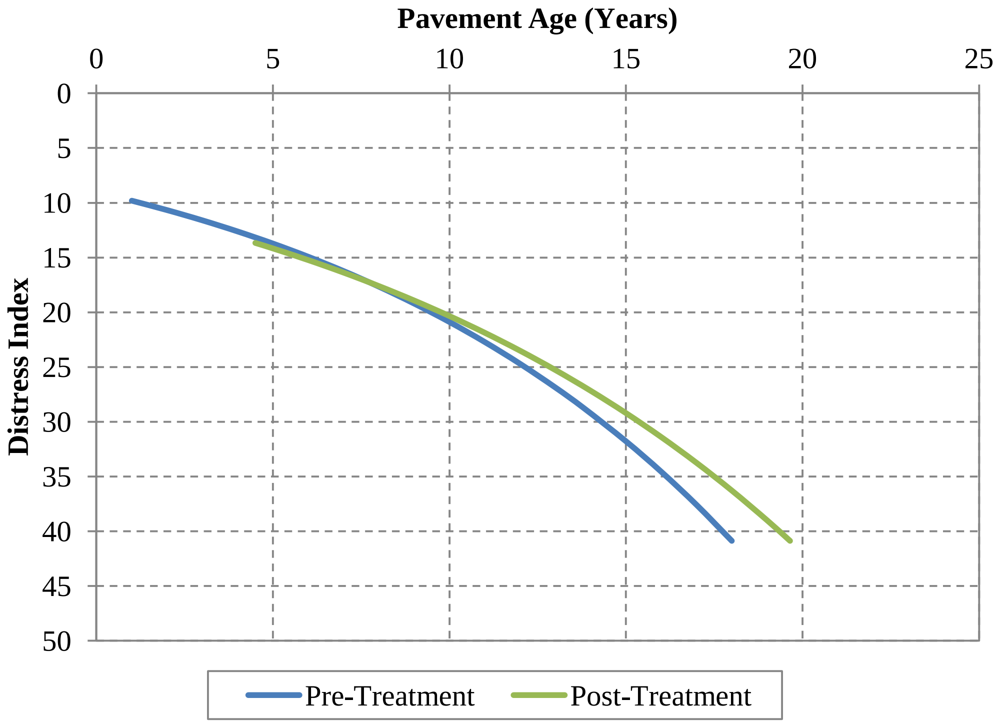


Figure 4.28. Pre- and post-treatment pavement performance – HMA crack treatment on composite pavement (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.26.

Table 4.26. Treatment benefit from HMA crack treatments.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
HMA Crack Treatment	Flexible	All	2.8	12
		Zone 1	2.8	12
		Zone 2	0.6	4
	Composite	All	0.9	5
		Zone 1	2.1	21
		Zone 2	1.6	5

The pavement service life extension obtained from HMA crack treatments placed on flexible pavements varies between 0.6 years for Zone 2 and 2.8 years for Zone 1. For composite pavements, the pavement service life extensions vary between 1.6 years for Zone 2 and about 2 years for Zone 1. The area benefit obtained from HMA crack treatments vary between 4 and 12 percent for flexible pavements and between 5 and 21 percent for composite pavements.

Descriptive Statistics

Table 4.27 shows statistics on the pre-treatment pavement condition for HMA crack treatments. The average pre-treatment DI value varied between 14 and 18 for flexible pavements, and between 13 and 21 for composite pavements.

Table 4.27. Pre-treatment DI statistics for HMA crack treatment.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Crack Treatment	Flexible	All	15.6	24.8	14.1	23.4	17.9	26.7
		DI ≤ 25	5.4	5.2	5.0	5.0	6.0	5.6
		DI > 25	60.5	26.8	60.1	25.5	61.0	28.7
	Composite	All	15.1	20.2	21.1	27.0	13.3	17.3
		DI ≤ 25	7.3	6.2	7.7	6.2	7.3	6.2
		DI > 25	51.4	23.1	57.2	28.3	48.2	19.1

Table 4.28 shows statistics on the average age of the pavements on which the HMA crack treatments were applied. The average pavement age at the time of treatment application is 5.5 years for flexible pavements and 4.5 years for composite pavements.

Table 4.28. Average pavement age statistics for HMA crack treatment.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Crack Treatment	Flexible	All	5.5	3.3	5.9	3.4	5.0	3.0
		DI ≤ 25	5.6	3.0	5.8	3.0	5.2	3.0
		DI > 25	5.3	4.4	6.2	5.1	4.1	3.1
	Composite	All	4.5	3.3	4.6	3.7	4.5	3.2
		DI ≤ 25	4.7	3.2	5.2	3.7	4.6	3.1
		DI > 25	3.9	3.5	3.0	3.2	4.3	3.5

Table 4.29 shows statistics on the average time to the next CPM treatment after the application of HMA crack treatments. The average time to the next CPM treatment is around 5 years for both flexible and composite pavements. DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM treatment.

Table 4.29. Average time to next CPM treatment for HMA crack treatment.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Crack Treatment	Flexible	All	4.8	2.4	5.0	2.5	4.2	2.1
		DI ≤ 25	4.8	2.4	5.1	2.5	4.0	2.1
		DI > 25	4.6	1.9	4.1	1.8	5.1	2.0
	Composite	All	5.2	2.4	5.8	2.2	8.0	2.5
		DI ≤ 25	5.1	2.4	5.8	2.2	4.8	2.4
		DI > 25	5.9	2.6	5.6	2.4	6.1	2.7

The impact of pavement age on the time to next CPM treatment is summarized in table 4.30. For flexible pavements, the maximum time to the next CPM treatment was observed when the crack seal treatment was applied within 5 years of a major rehabilitation/reconstruction activity. Pavement age did not have any appreciable impact on the time to the next CPM treatment for composite pavements.

Table 4.30. Impact of pavement age on average time to next CPM treatment for HMA crack treatment.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
HMA Crack Treatment	0-5	4.9	2.2	5.2	2.4
	5-10	4.6	2.6	5.2	2.4
	10-15	3.8	1.9	5.4	3.5
	15-20			5.8	0.5
	> 20				

Ultra-Thin HMA Overlay

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 4.29 and 4.30, respectively. For both flexible and composite pavements, the majority of the ultra-thin HMA overlay treatments are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years.

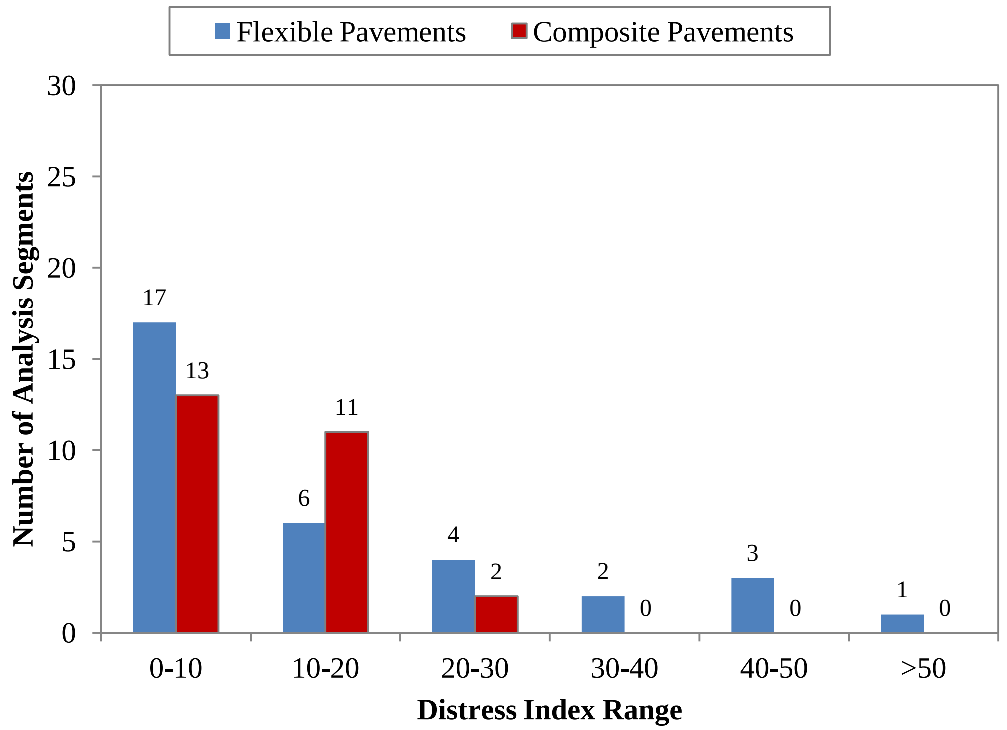


Figure 4.29. Pre-treatment pavement condition distribution for ultra-thin HMA OL.

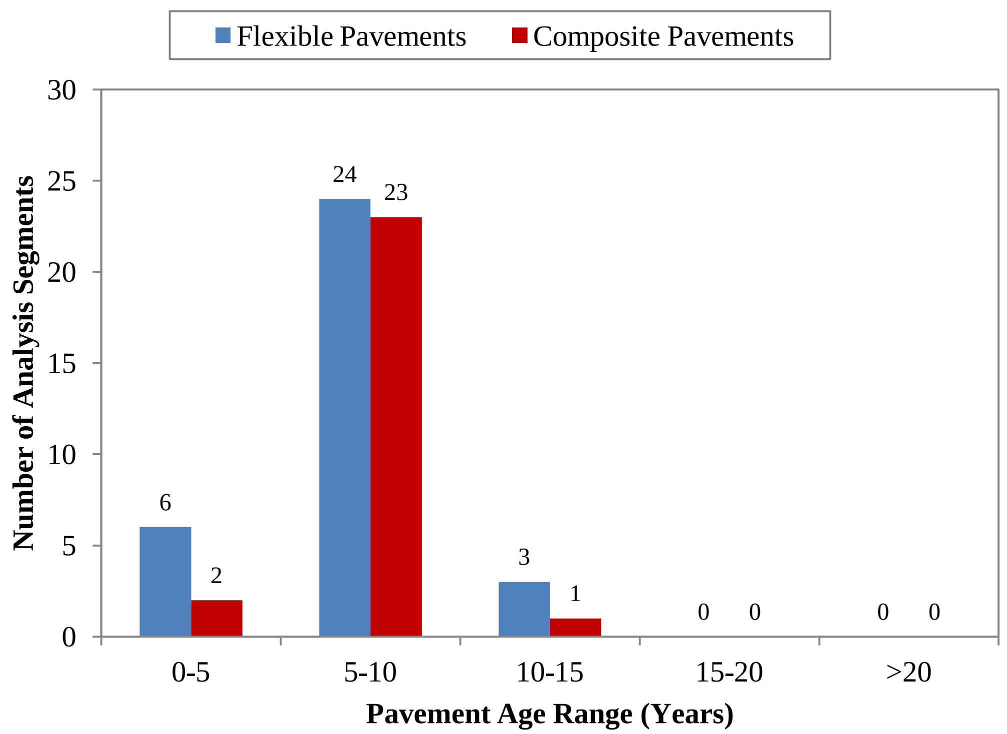


Figure 4.30. Pre-treatment pavement age distribution for ultra-thin HMA OL.

Performance Models

Since relatively few analysis segments were available for ultra-thin HMA OL treatments, reliable performance models could not be developed. The following section summarizes the descriptive statistics, which can be used to make some general assessments regarding the performance of ultra-thin HMA OL treatments.

Descriptive Statistics

Table 4.31 shows statistics on the pre-treatment pavement condition for ultra-thin HMA OL treatments. The average pre-treatment DI value was around 17 for flexible pavements and 10 for composite pavements.

Table 4.31. Pre-treatment DI statistics for Ultra-Thin HMA OL.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Ultra-Thin HMA Overlay	Flexible	All	17.2	19.0	12.7	14.2	24.1	23.6
		DI ≤ 25	8.7	7.1	6.4	5.4	12.9	8.0
		DI > 25	43.6	20.5	37.9	8.1	49.4	28.7
	Composite	All	9.7	5.7	21.8	-	9.2	5.2
		DI ≤ 25	9.7	5.7	21.8	-	9.2	5.2
		DI > 25						

Table 4.32 shows statistics on the average age of the pavements on which the ultra-thin HMA OL treatments were placed. The average pavement age at the time of treatment placement is around 7 years for flexible pavements and 8 years for composite pavements.

Table 4.32. Average pavement age statistics for Ultra-Thin HMA OL.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Ultra-Thin HMA Overlay	Flexible	All	7.2	2.5	7.4	2.2	7.0	3.0
		DI ≤ 25	7.6	2.6	7.6	2.4	7.7	3.0
		DI > 25	6.0	1.8	6.5	0.6	5.5	2.5
	Composite	All	7.8	1.9	2.0	-	8.0	1.6
		DI ≤ 25	7.8	1.9	2.0	-	8.0	1.6
		DI > 25						

Table 4.33 shows statistics on the average time to the next CPM treatment after the placement of the ultra-thin HMA OL treatment. The average time to the next CPM treatment is around 2 years for composite pavements and around 2.5 years for flexible pavements. These are very short intervals for this type of treatment, but about 60 percent of these sections were still in service

when the data were collected in 2010. As such, the actual time to the next CPM treatment is likely greater than the values reported in table 4.33.

Table 4.33. Average time to next CPM treatment for Ultra-Thin HMA OL.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Ultra-Thin HMA Overlay	Flexible	All	2.6*	1.6*	2.7*	1.8*	2.3*	0.6*
		DI ≤ 25	2.6*	1.8*	2.7*	2.1*	2.3*	0.3*
		DI > 25	2.7*	0.6*	2.7*	0.6*		
	Composite	All	2.0*	-			2.0*	-
		DI ≤ 25	2.0*	-			2.0*	-
		DI > 25						

* Note: Over 60 percent of the ultra-thin HMA OL treatments are still in service. The actual time to the next CPM treatment is likely greater than the values reported here.

HMA Mill and Overlay (Non-Structural)

The number of analysis segments for non-structural HMA mill and overlay, grouped by the DI range and pavement age at the time of treatment placement, is shown in figures 4.31 and 4.32, respectively. For both flexible and composite pavements, the majority of the HMA mill and overlay treatments are placed on pavements with a pre-treatment DI less than 20 and a pavement age less than 10 years. A significantly higher number of analysis segments are available for composite pavements than for flexible pavements.

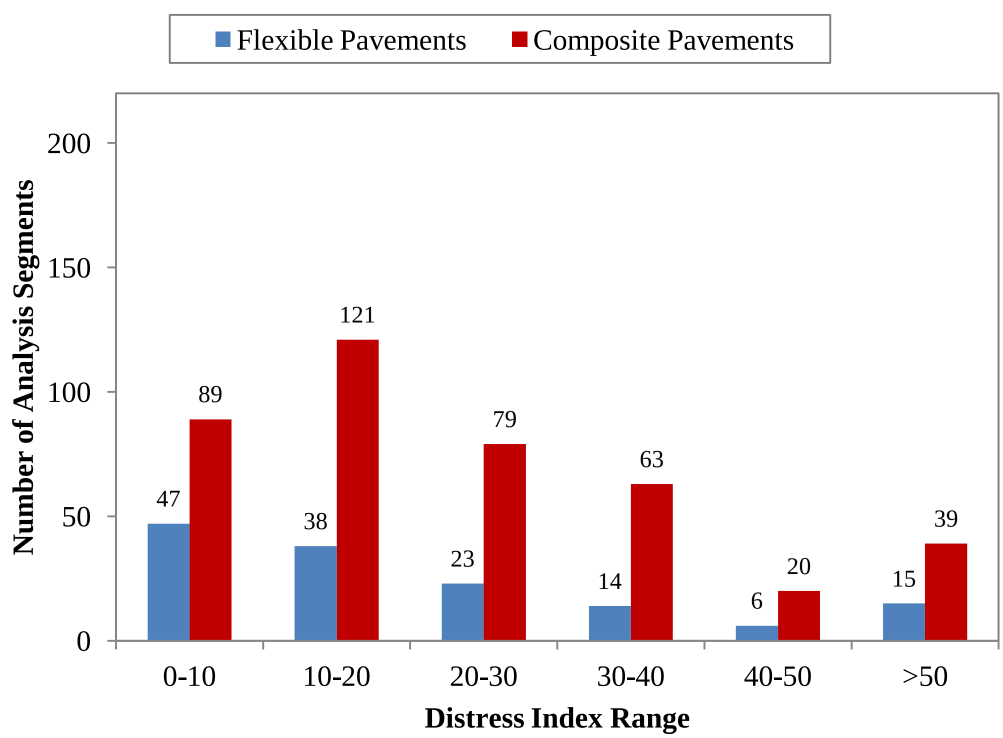


Figure 4.31. Pre-treatment pavement condition distribution for HMA mill and overlay treatments.

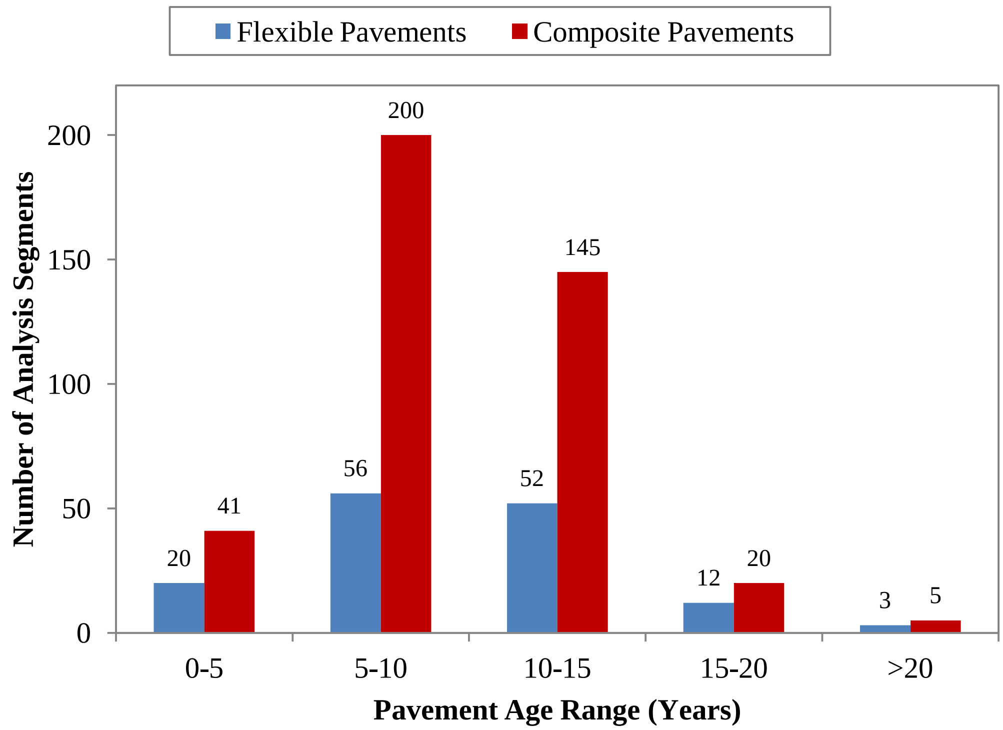


Figure 4.32. Pre-treatment pavement age distribution for HMA mill and overlay treatments.

Performance Models

Table 4.34 summarizes the models developed to describe the performance of HMA mill and overlay treatments.

Table 4.34. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
HMA Mill and Overlay	Flexible	All	$DI = 6.0726e^{0.0711\ Age}$	0.60
		Zone 1		
		Zone 2	$DI = 3.964e^{0.0985\ Age}$	0.63
	Composite	All	$DI = 6.3335e^{0.0778\ Age}$	0.60
		Zone 1	$DI = 4.4538e^{0.0805\ Age}$	0.49
		Zone 2	$DI = 6.7745e^{0.077Age}$	0.68

Figures 4.33 through 4.37 illustrate the pre- and post- treatment performance models developed to study the impact of HMA mill and overlay treatments.

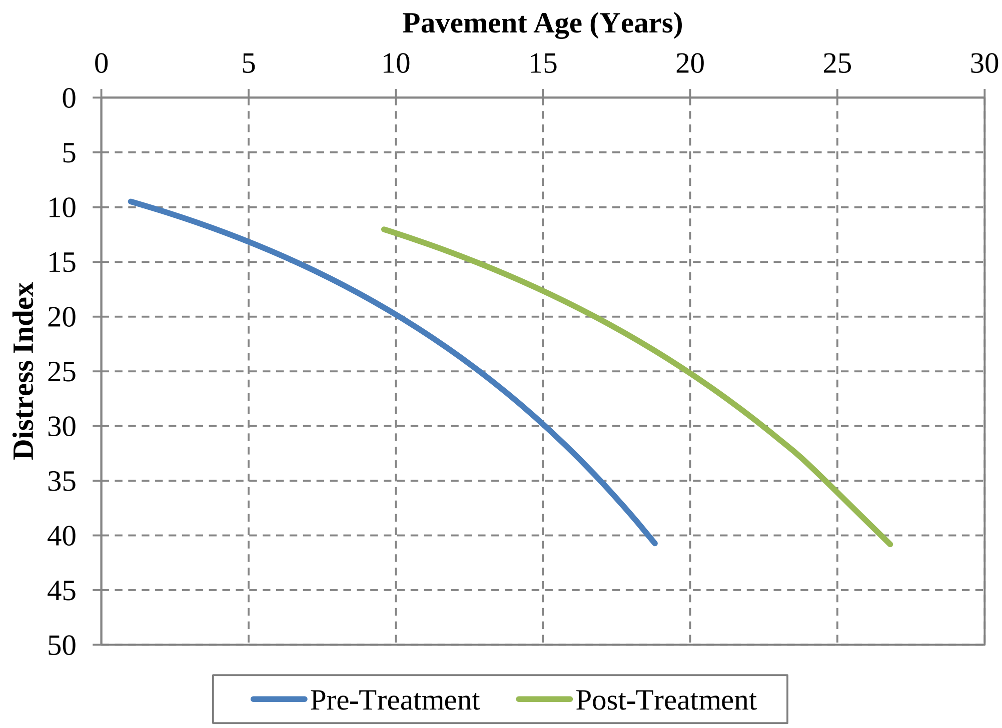


Figure 4.33. Pre- and post-treatment pavement performance – HMA mill and overlay on flexible pavement (all zones).

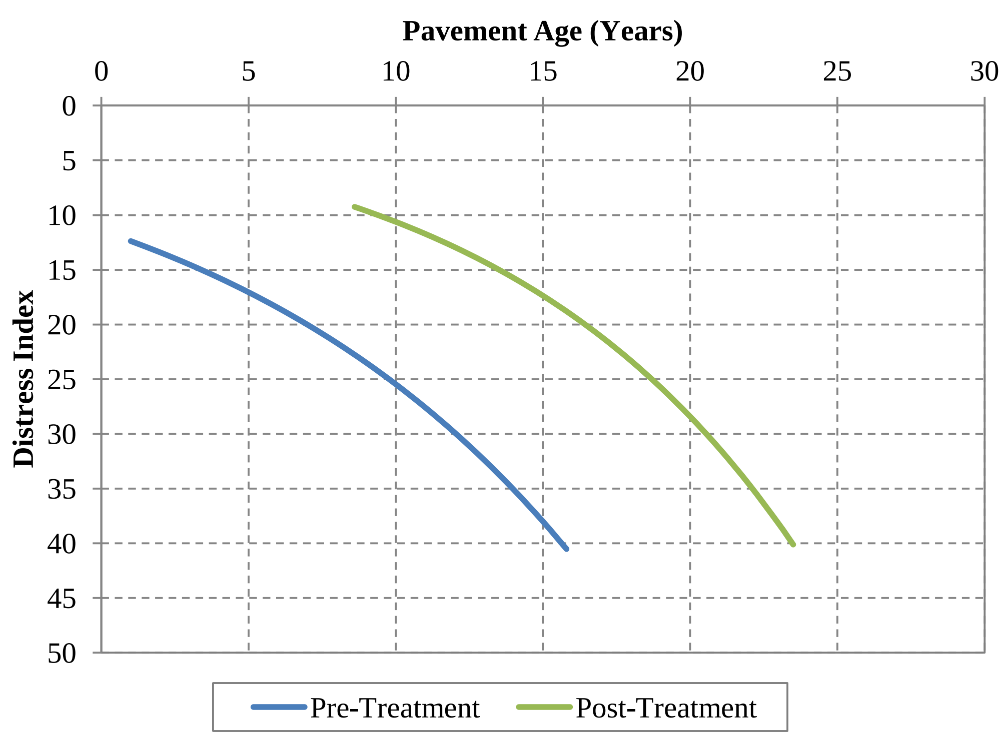


Figure 4.34. Pre- and post-treatment pavement performance – HMA mill and overlay on flexible pavement (Zone 2).

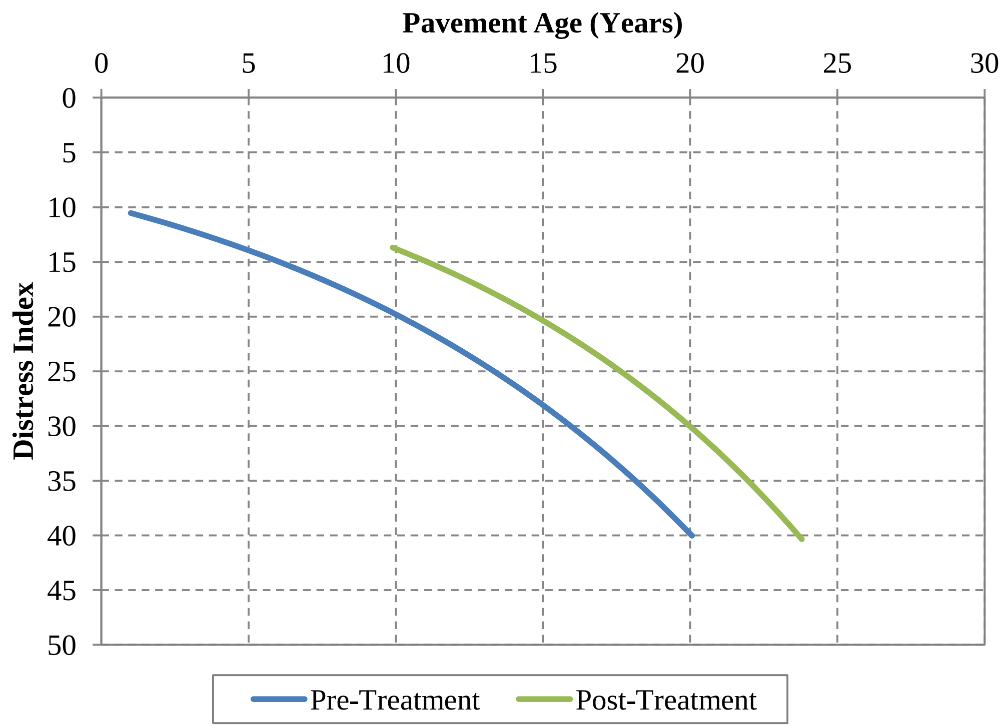


Figure 4.35. Pre- and post-treatment pavement performance – HMA mill and overlay on composite pavement (all zones).

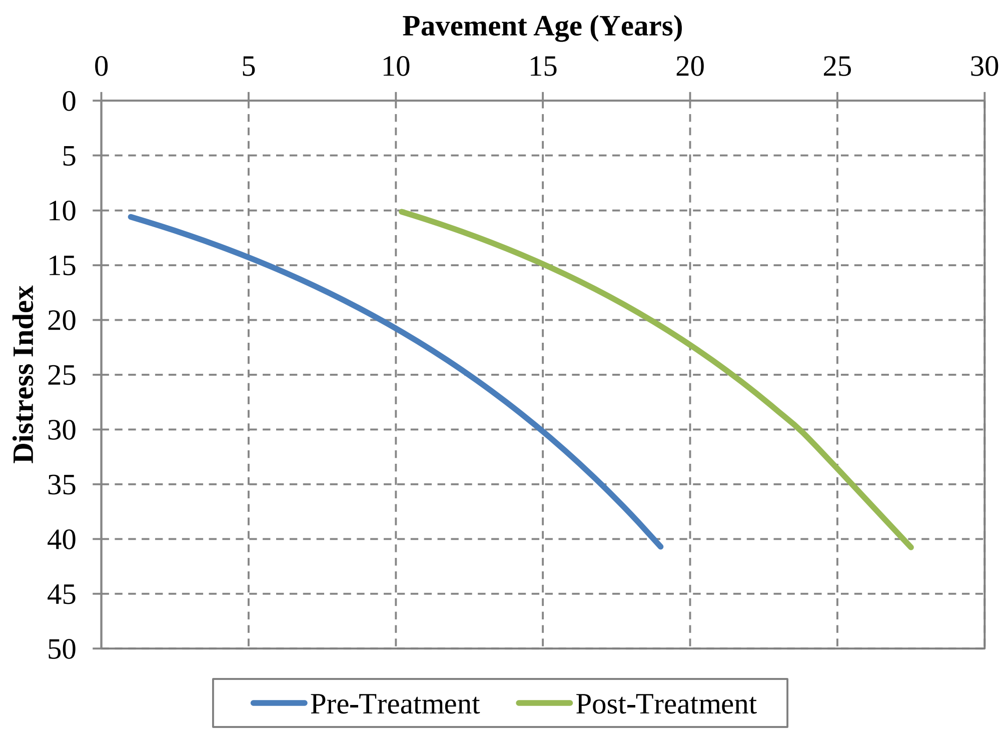


Figure 4.36. Pre- and post-treatment pavement performance – HMA mill and overlay on composite pavement (Zone 1).

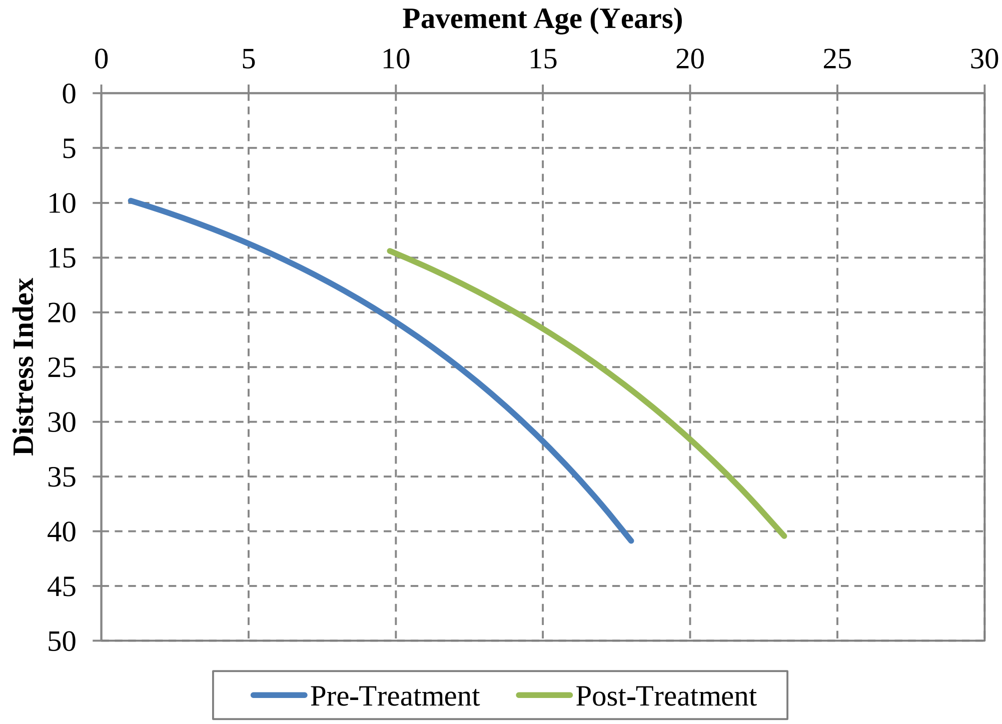


Figure 4.37. Pre- and post-treatment pavement performance –
HMA mill and overlay on composite pavement (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.35.

Table 4.35. Treatment benefit from HMA mill and overlay.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
HMA Mill and Overlay	Flexible	All	7.9	49
		Zone 1		
		Zone 2	7.8	79
	Composite	All	3.6	26
		Zone 1	8.5	68
		Zone 2	5.3	33

The pavement service life extensions obtained from HMA mill and overlay treatments placed on flexible pavements is around 8 years. For composite pavements, the pavement service life extensions obtained from HMA mill and overlay are approximately 5 years for Zone 2 and around 8.5 years for Zone 1. The area benefit varies between 49 and 79 percent for flexible pavements and between 26 and 68 percent for composite pavements.

Descriptive Statistics

Table 4.36 shows statistics on the pre-treatment pavement condition for HMA mill and overlay treatments. The average pre-treatment DI value varied between 20 and 28 for flexible pavements and between 23 and 25 for composite pavements.

Table 4.36. Pre-treatment DI statistics for HMA mill and overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Mill and Overlay	Flexible	All	23.9	26.3	19.8	20.7	27.9	30.3
		DI ≤ 25	10.6	6.9	10.4	6.1	10.8	7.9
		DI > 25	50.3	30.3	46.7	24.3	52.5	33.6
	Composite	All	24.2	17.8	23.1	17.5	24.6	17.9
		DI ≤ 25	13.1	6.3	12.8	6.7	13.2	6.2
		DI > 25	41.9	15.9	42.4	15.2	41.8	16.2

Table 4.37 shows statistics on the average age of the pavements on which the HMA mill and overlay treatment was applied. The average pavement age at the time of treatment application is around 10 years for both flexible and composite pavements.

Table 4.37. Average pavement age statistics for HMA mill and overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Mill and Overlay	Flexible	All	9.6	4.7	10.7	4.9	8.6	4.2
		DI ≤ 25	9.4	4.6	10.5	4.6	8.0	4.1
		DI > 25	10.1	4.9	11.3	5.6	9.4	4.3
	Composite	All	9.9	3.8	10.8	4.8	9.6	3.4
		DI ≤ 25	9.9	3.8	10.2	4.6	9.8	3.5
		DI > 25	9.8	3.9	12.0	4.9	9.2	3.3

Table 4.38 shows statistics on the average time to the next CPM treatment after the placement of the HMA mill and overlay treatment. The average time to the next CPM treatment is around 7.4 years for flexible pavements and 5.2 years for composite pavements. DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM treatment for HMA mill and overlay treatments.

Table 4.38. Average time to next CPM treatment for HMA mill and overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Mill and Overlay	Flexible	All	7.4	3.2	5.6	2.6	8.2	3.2
		DI ≤ 25	6.6	3.2	5.8	2.8	7.4	3.5
		DI > 25	8.3	3.0	5.0	1.7	8.8	2.9
	Composite	All	5.2	2.8	5.0	3.3	5.5	2.7
		DI ≤ 25	5.3	2.8	4.8	3.1	5.4	2.7
		DI > 25	5.4	2.9	5.3	3.7	5.5	2.8

The impact of pavement age on the time to next CPM treatment is summarized in table 4.39. It was observed that the pavement age did not have any appreciable impact on the time to the next CPM treatment for composite pavements. HMA mill and overlays placed between 5 and 10 years on flexible pavements resulted in the maximum time to the next CPM treatment.

Table 4.39. Impact of pavement age on average time to next CPM treatment for HMA mill and overlay.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
HMA Mill and Overlay	0-5	7.5	3.9	5.3	2.9
	5-10	8.3	3.2	4.5	2.9
	10-15	6.6	2.4	6.2	2.6
	15-20	2.7	1.2	4.7	2.3
	> 20				

HMA Overlay (Without Milling; Non-Structural)

The number of analysis segments for a non-structural HMA overlay without milling, grouped by the DI range and pavement age at the time of treatment placement, is shown in figures 4.38 and 4.39, respectively. For flexible pavements, the majority of the HMA overlays are placed on pavements with a pre-treatment DI of less than 30 and a pavement age of less than 10 years. The majority of the HMA overlays placed on composite pavements have pre-treatment DI values greater than 30 and pavement ages of less than 10 years.

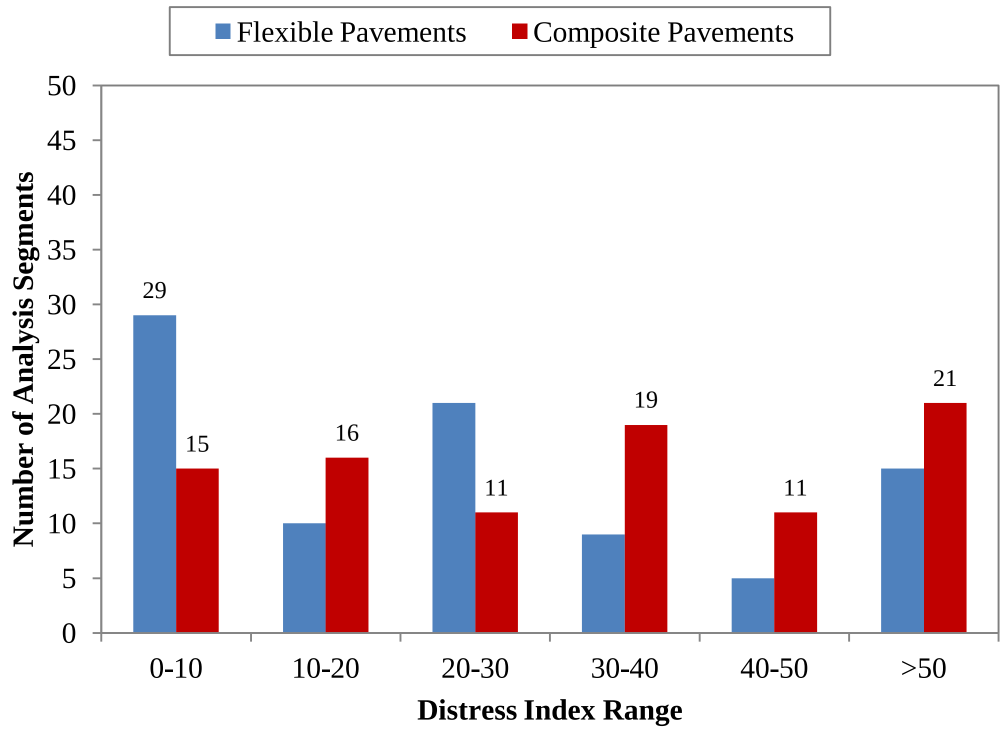


Figure 4.38. Pre-treatment pavement condition distribution for HMA overlay.

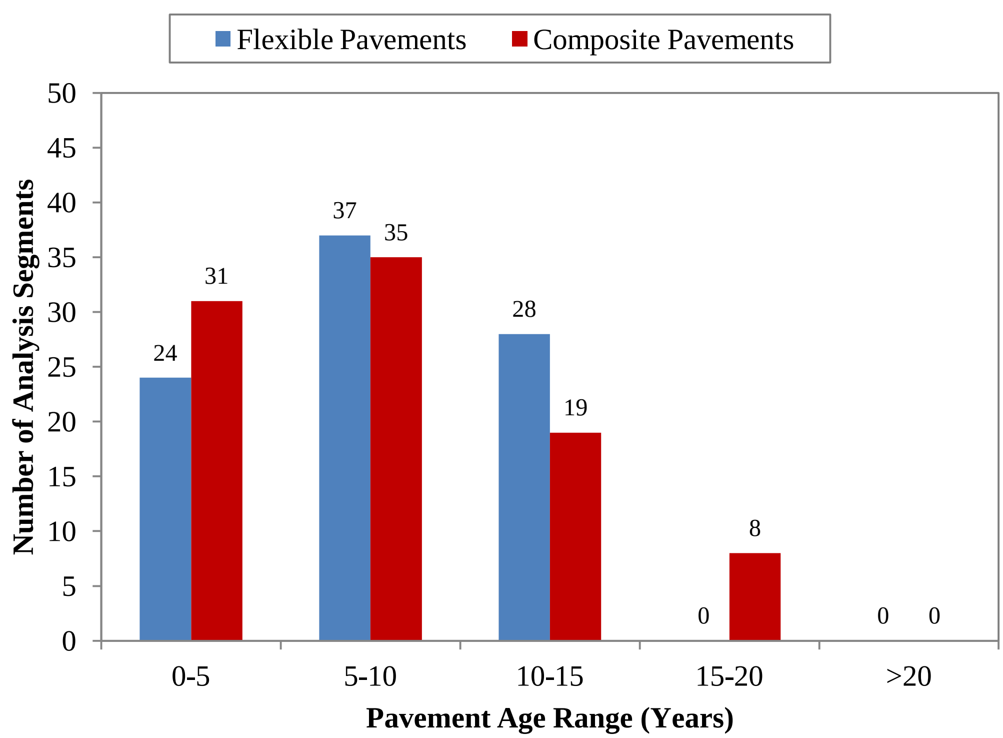


Figure 4.39. Pre-treatment pavement age distribution for HMA overlay.

Performance Models

Table 4.40 summarizes the models developed to describe the performance of HMA overlays.

Table 4.40. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
HMA Overlay	Flexible	All	$DI = 3.6825e^{0.108\ Age}$	0.59
		Zone 1		
		Zone 2	$DI = 5.1129e^{0.1045\ Age}$	0.64
	Composite	All	$DI = 10.146e^{0.0589\ Age}$	0.83
		Zone 1		
		Zone 2	$DI = 6.1648e^{0.094\ Age}$	0.85

Figures 4.40 through 4.43 illustrate the pre- and post-treatment performance models developed to study the impact of HMA overlays.

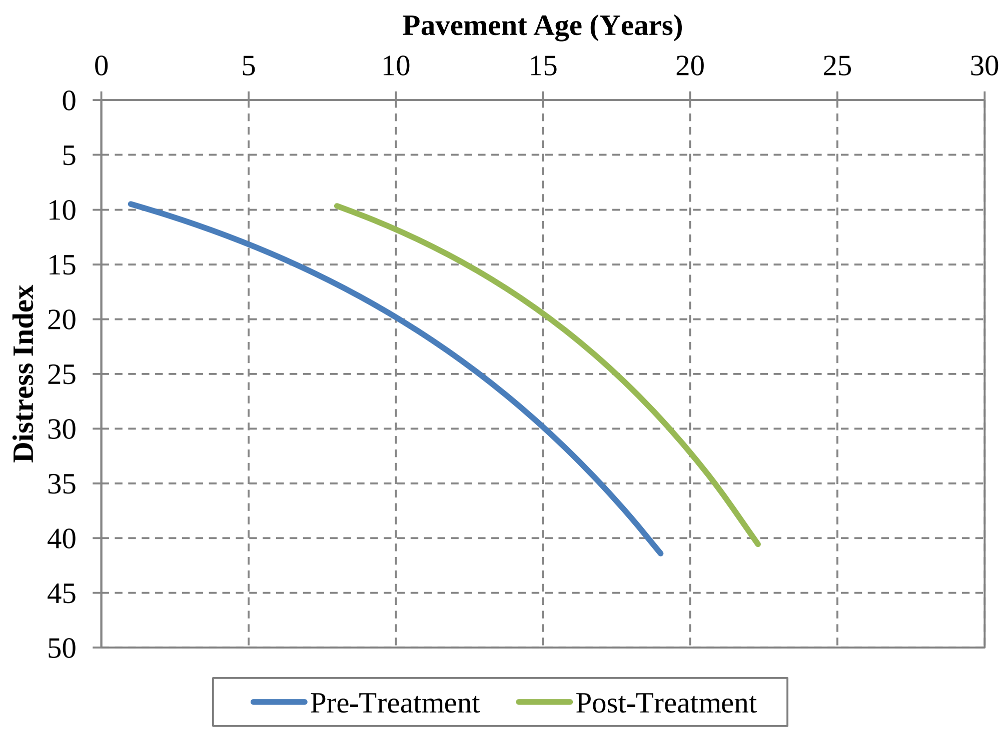


Figure 4.40. Pre- and post-treatment pavement performance – HMA overlay on flexible pavement (all zones).

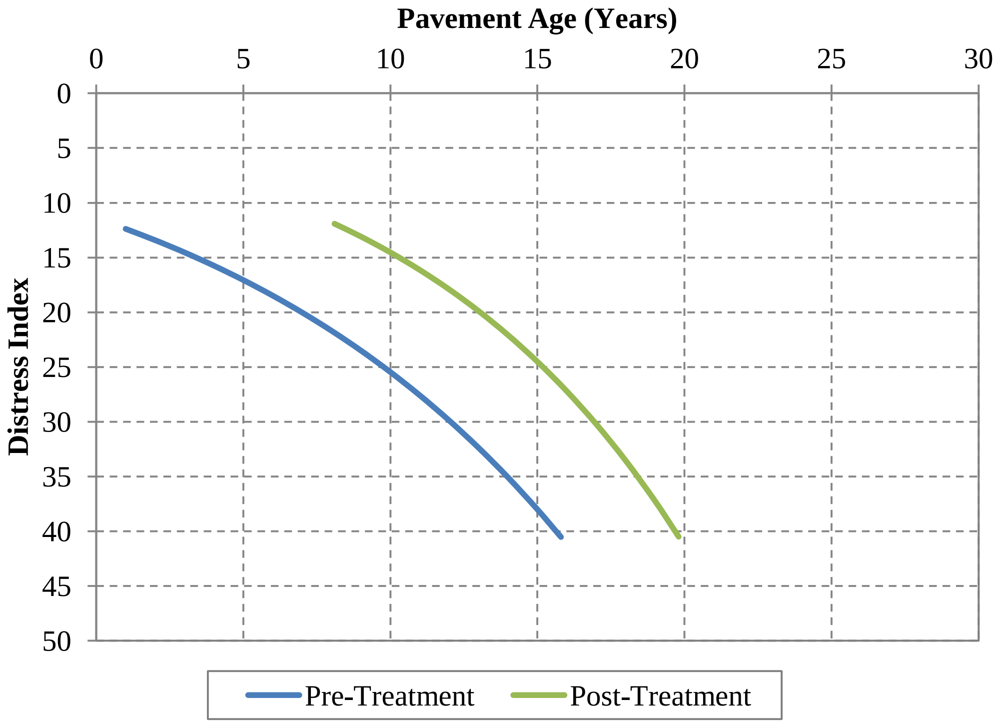


Figure 4.41. Pre- and post-treatment pavement performance – HMA overlay on flexible pavement (Zone 2).

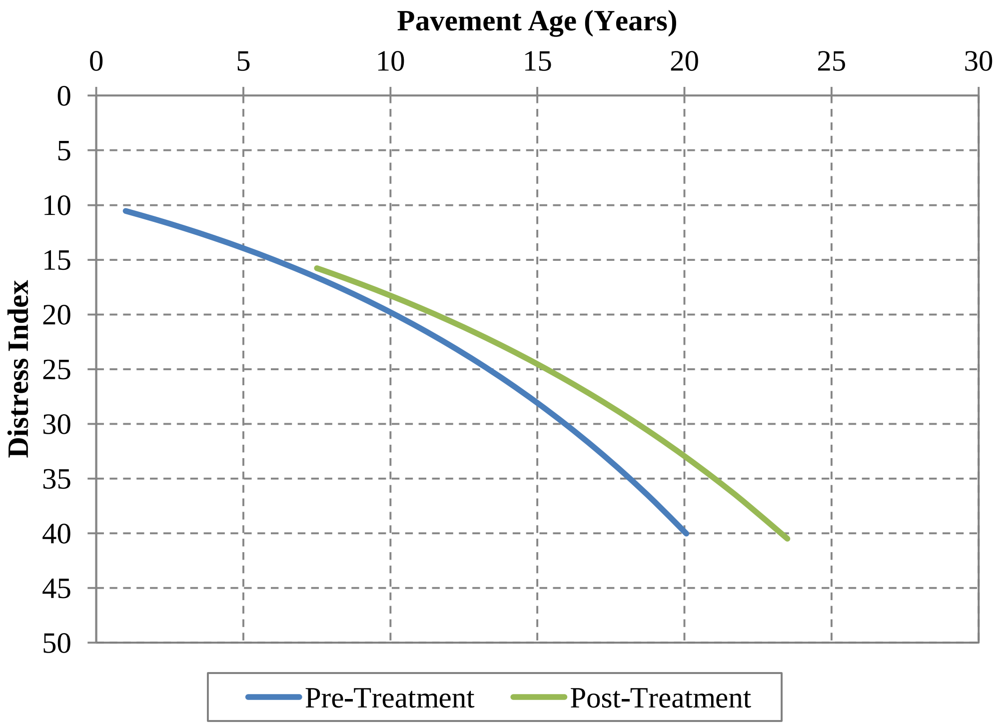


Figure 4.42. Pre- and post-treatment pavement performance – HMA overlay on composite pavement (all zones).

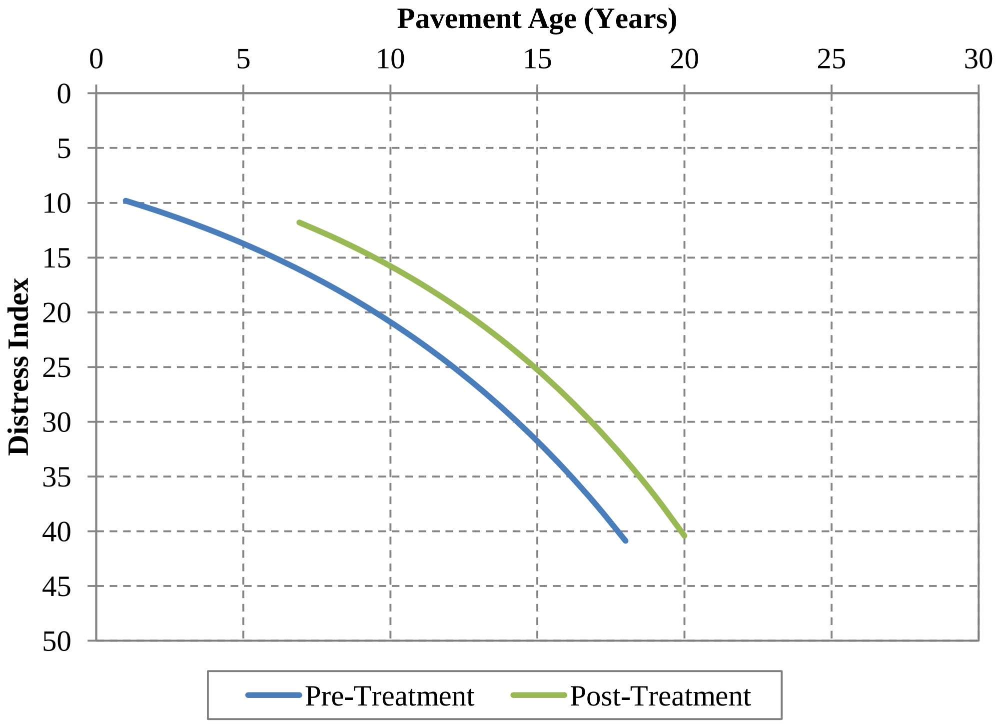


Figure 4.43. Pre- and post-treatment pavement performance – HMA overlay on composite pavement (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 4.41.

Table 4.41. Treatment benefit from HMA overlay.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
HMA Overlay	Flexible	All	3.6	35
		Zone 1		
		Zone 2	4.0	49
	Composite	All	3.2	12
		Zone 1		
		Zone 2	2.2	20

The pavement service life extensions obtained from HMA overlays placed on flexible pavements was 3.6 in all zones and 4.0 years in Zone 2. For composite pavements, the pavement service life extensions obtained from HMA overlays is 2.2 years for Zone 2 and 3.2 years for all zones. The service life extensions obtained from HMA overlays are less than the typical values reported in the literature. One potential reason for this may be the generally higher DI levels associated with the pavements receiving HMA overlays. In order to get a better understanding of the lower service life extensions obtained from HMA overlays, a project-level analysis is required. . The area benefit obtained from HMA overlays placed on flexible pavements was 35 percent for All zones and 49 percent for Zone 2. For composite pavements, the area benefit was 12 percent for All zones and 20 percent for Zone 2.

Descriptive Statistics

Table 4.42 shows statistics on the pre-treatment pavement condition for HMA overlays. The average pre-treatment DI values varied between 18 and 35 for flexible pavements, and between 20 and 39 for composite pavements. The pre-treatment DI values for HMA overlays are generally higher when compared to the rest of the treatments.

Table 4.42. Pre-treatment DI statistics for HMA overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Overlay	Flexible	All	28.6	27.4	18.2	23.4	35.3	27.8
		DI ≤ 25	10.3	7.9	7.9	7.9	12.9	7.2
		DI > 25	52.0	25.5	48.2	27.8	53.2	25.1
	Composite	All	33.8	22.5	20.0	12.7	39.1	23.2
		DI ≤ 25	11.5	6.5	11.5	7.1	11.5	6.2
		DI > 25	47.9	16.7	33.8	4.7	50.9	16.9

Table 4.43 shows statistics on the average age of the pavements on which the HMA overlays were applied. The average pavement age at the time of treatment application is around 8 years for flexible pavements and 7.5 years for composite pavements.

Table 4.43. Average pavement age statistics for HMA overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Overlay	Flexible	All	8.0	4.1	7.9	4.4	8.1	4.0
		DI ≤ 25	8.1	4.4	7.7	4.2	8.5	4.1
		DI > 25	7.9	4.2	8.7	4.1	7.7	4.0
	Composite	All	7.5	5.4	9.0	6.9	6.9	4.7
		DI ≤ 25	9.2	4.6	11.3	4.5	7.5	4.0
		DI > 25	6.4	5.7	5.3	8.6	6.7	5.0

Table 4.44 shows statistics on the average time to the next CPM treatment after the placement of the HMA overlays. The average time to the next CPM treatment is around 7 years for flexible pavements and 7.5 years for composite pavements. DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM treatment for HMA overlays.

Table 4.44. Average time to next CPM treatment for HMA overlay.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
HMA Overlay	Flexible	All	6.7	2.0	6.9	1.8	6.5	2.1
		DI ≤ 25	6.7	1.7	7.1	1.4	6.3	1.9
		DI > 25	6.7	2.4	6.0	4.2	6.7	2.3
	Composite	All	7.6	4.1	4.5	2.1	7.8	4.1
		DI ≤ 25	6.8	5.9	3.0	-	8.0	6.6
		DI > 25	7.7	3.9	6.0	-	7.8	4.0

The impact of pavement age on the time to next CPM treatment is summarized in table 4.45. For composite pavements, the maximum time to the next CPM treatment was observed when the HMA overlays were placed on pavements that were less than 5 years old. For flexible pavements, the maximum time to the next CPM treatment was observed when the HMA overlays were placed on pavements that were between 10 and 15 years old.

Table 4.45. Impact of pavement age on average time to next CPM treatment for HMA overlays.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
HMA Overlay	0-5	5.8	1.4	8.5	4.9
	5-10	6.5	2.2	7.3	3.3
	10-15	7.5	2.0	5.8	2.7
	15-20				
	> 20				

PCC Joint and Crack Seal

The number of analysis segments for PCC joint and crack seal, grouped by the DI range and pavement age at the time of treatment placement, is shown in figures 4.44 and 4.45, respectively. The majority of the PCC joint and crack seal treatments are applied on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years.

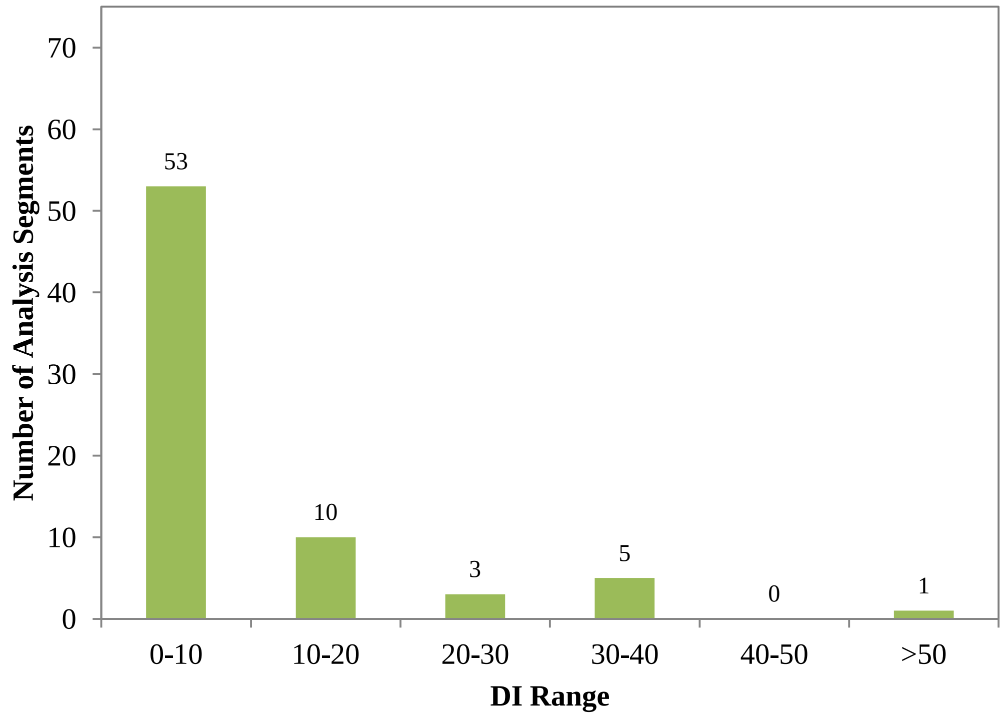


Figure 4.44. Pre-treatment pavement condition distribution for PCC joint and crack seals.

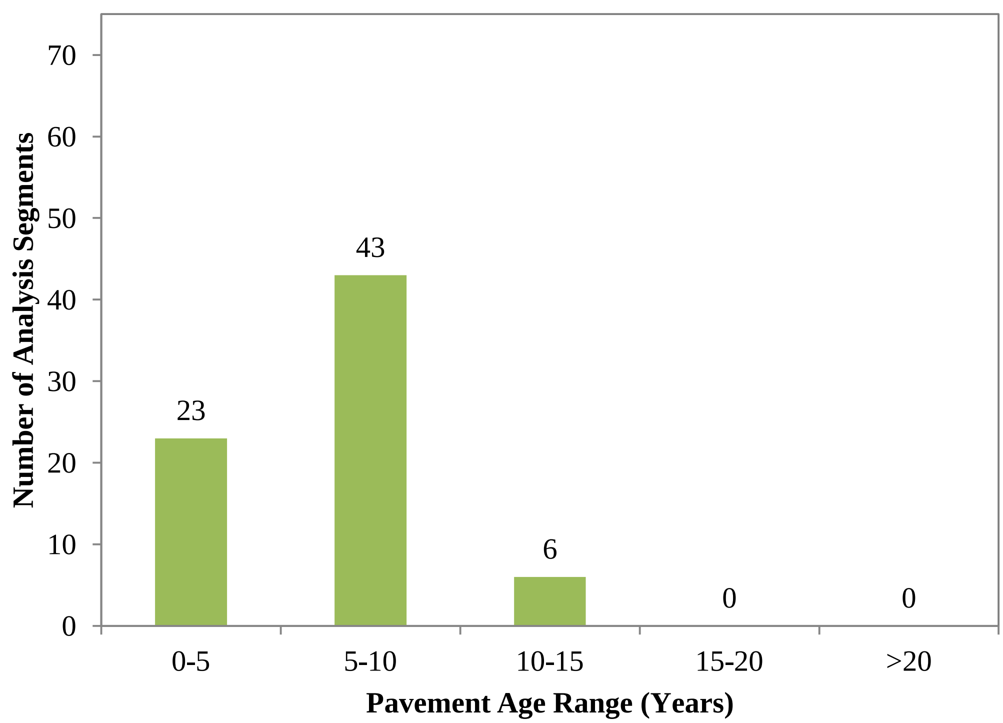


Figure 4.45. Pre-treatment pavement age distribution for PCC joint and crack seals.

Performance Models

The performance models developed for PCC joint and crack seal treatments had extremely low R-squared values (less than 0.1) and no logical trends could be discerned. The following section summarizes the descriptive statistics, which can be used to make some general assessments regarding the performance of PCC joint and crack seal treatments.

Descriptive Statistics

Table 4.46 shows statistics on the pre-treatment pavement condition for PCC joint and crack seal treatments. The average pre-treatment DI value was approximately 8. It was noted that only two analysis segments were available for Zone 1.

Table 4.46. Pre-treatment DI statistics for PCC joint and crack seal treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
PCC Joint and Crack Seal	Rigid	All	8.4	14.1	50.0	58.4	7.2	10.2
		DI ≤ 25	4.0	4.4	8.7		3.9	4.4
		DI > 25	39.0	20.2			32.5	5.1

Table 4.47 shows statistics on the average pavement age on which the PCC joint and crack seal treatments were applied. The average pavement age at the time of treatment application is around 6.5 years.

Table 4.47. Average pavement age statistics for PCC joint and crack seal treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
PCC Joint and Crack Seal	Rigid	All	6.5	3.0	3.5	3.5	6.6	2.9
		DI ≤ 25	6.6	3.6			6.2	3.6
		DI > 25	5.7	1.9			6.3	0.8

Table 4.48 shows statistics on the average time to the next CPM treatment after the application of the PCC joint and crack seal treatment. The average time to the next CPM treatment is around 6.5 years.

Table 4.48. Average time to next CPM treatment for PCC joint and crack seal treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
PCC Joint and Crack Seal	Rigid	All	6.3	3.8	9.0		6.1	3.8
		DI ≤ 25	6.2	3.6				
		DI > 25	6.4	5.0			5.8	5.5

The impact of pavement age on the time to next CPM treatment is summarized in table 4.49. In the two pavement age categories for which data were available, it was observed that the pavement age did not have any appreciable impact on the time to the next CPM treatment.

Table 4.49. Impact of pavement age on average time to Next CPM treatment for PCC joint and crack seals.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)	
		Rigid	
		Average	SD
PCC Joint and Crack Seal	0-5	6.0	3.5
	5-10	6.3	3.9
	10-15		
	15-20		
	> 20		

Benefit-Cost Analysis

This section presents the results of the benefit-cost analysis of the preventive maintenance treatments used by MDOT. The MDOT CPM Manual (MDOT 2010) provides average historical unit costs for the preventive maintenance treatments based on CPM project bid tabs. A summary of the historical unit costs from 2005 through 2008 is provided in table 4.50.

Table 4.50. Historical average preventive maintenance costs.

Treatment	Unit	Yearly Average Cost				4-Year Avg. Cost ($/yd^2)
		2008	2007	2006	2005	
Single Chip Seal	yd^2	$1.21	$1.37	$1.05	$1.62	$1.31
Double Chip Seal	yd^2	$2.35	$2.30	$2.15		$2.27
Double Microsurfacing	yd^2	$2.57	$2.33	$2.24	$2.27	$2.35
PPSS	yd^2	$4.40	$4.72	$5.50	$4.19	$4.70
HMA Crack Seal*	rbmi	$3,699	$3,477	$3,846	$3,829	$0.26
Ultra Thin OL	yd^2	$2.53	$2.37	$2.50	$1.76	$2.29
HMA Mill	yd^2	$0.72	$0.84	$0.69	$0.74	$0.75
HMA OL**	ton	$52.97	$43.33	$42.78	$37.21	$3.59
HMA Mill and Overlay						$4.34
Diamond Grinding	yd^2	$4.88	$3.37	$3.49	$4.84	$4.15
PCC Joint/Crack Seal***	ft	$1.20	$1.09	$1.37	$1.28	$0.44

Rbmi = roadbed miles
* While units are rbmi, costs were expressed in $/yd^2 (for consistency) by using the following conversion: [(Average Cost, $/rbmi) / (5280*24)]*9
** The cost of an HMA overlay was converted from $/ton to $/yd^2 by assuming the density of asphalt to be 145 lbs/yd^3 and a typical overlay thickness of 1.5 inches.
*** The cost for PCC joint and crack seal was converted from $/ft to $/yd^2 by assuming the joint/crack sealing quantity to be approximately 2500 linear feet for one lane-mile of a highway.

The four-year average unit cost was used for the benefit-cost analysis. To convert HMA crack seals from *rbmi* to square yards, it was assumed that the unit cost for HMA crack seal was considering two lanes of a highway. This resulted in an average unit cost of $0.26 per square yard for HMA crack sealing. If the cost of HMA crack sealing per lineal feet is assumed to be around the same as that for PCC joint/crack sealing, the average amount of crack sealing quantity computed per lane-mile of a highway is around 2,500 ft., which was consistent with a selected sample of Michigan-specific pavement management databases that were reviewed. The cost of an HMA overlay was converted from $/ton to $/yd^2 by assuming the density of asphalt to be 145 lbs/yd^2 and a typical overlay thickness of 1.5 inches was used.

Using the unit costs shown in table 4.50 and the percent benefit area (area under the post-treatment performance curve divided by the area under the pre-treatment performance curve) discussed along with the performance models, the benefit-cost ratios were computed to evaluate the cost effectiveness of the various preventive maintenance treatments used by MDOT (see table 4.51). As discussed earlier, there are some gaps in the data due to poor reliability of performance models (very low R-squared values), which means that some of the areas under the performance curve could not be calculated and thus the benefit-cost ratios could not be calculated.

Table 4.51. Calculated benefit-cost ratios for selected treatments.

Treatment	Benefit-Cost Ratios					
	Flexible Pavements			Composite Pavements		
	All	Zone 1	Zone 2	All	Zone 1	Zone 2
Single Chip Seal	0.22	0.11	0.48			
Double Chip Seal	0.18			0.14		
Double Microsurfacing	0.09	0.26	0.10	0.24		0.21
HMA Crack Seal	0.46	0.46	0.15	0.19	0.80	0.19
HMA Mill and Overlay	0.11		0.18	0.06	0.16	0.08
HMA Overlay	0.10		0.14	0.03		0.06

For flexible pavements, HMA crack seals have the highest benefit-cost ratio when data from all the zones are considered together. Comparing single chip seals, double chip seals, and double microsurfacing, the single chip seals have the highest benefit-cost ratios for flexible pavements (overall and Zone 2). For Zone 1, microsurfacing has a higher benefit-cost ratio compared to single chip seals. Overall, the HMA overlays (with and without milling) and double microsurfacing have the lowest benefit-cost ratios for flexible pavements.

For composite pavements, double microsurfacing has the highest benefit-cost ratio, followed by HMA crack seals and double chip seals when all the zones are considered together. Microsurfacing has a higher benefit-cost ratio compared to HMA overlays in Zone 2 and also when both zones are considered together.

It must be emphasized that benefit-cost ratios should not be used as the single measure of the cost effectiveness of a given preventive maintenance treatment. Treatments such as crack sealing exhibit relatively high benefit-cost ratios primarily because of their low treatment costs. However, crack sealing is not effective in mitigating distresses like rutting and alligator cracking. When selecting a particular treatment, benefit-cost ratios, along with the applicability of the treatment to address the existing pavement condition, should be considered to achieve a long-lasting preventive maintenance solution. It should also be noted that while all the analyses were based on the DI, treatments may be triggered by other performance indicators such as friction and IRI. The overall objective should be the application of the most suitable treatment based on the project specific goals.

Summary

This chapter presents the analysis of the performance of various preventive maintenance treatments used by MDOT as a part of its Capital Preventive Maintenance program. Regression models were developed to describe both pre- and post-treatment performance trends to establish the benefits obtained from the preventive maintenance treatments. The pavement service life extension, benefit area, and benefit-cost ratios were also discussed. In addition descriptive statistics on the pre-treatment pavement condition, pavement age at treatment, and the time to the next CPM treatment have also been summarized.

A summary of the pavement service life extensions obtained from the various preventive maintenance treatments used by MDOT is provided in table 4.52. While performance models could not be developed for PPSS and ultra-thin HMA overlay treatments (due to lack of data), the average service life extensions (as estimated by the time to the next CPM treatment) is between 2 to 3 years. However, MDOT's use of these treatments is relatively new and around 60 percent of these treatments were still in service when the data were analyzed in 2010.

Table 4.52. Summary of pavement service life extensions.

Treatment	Pavement Type	Life Extension (Years)		
		All	Zone 1	Zone 2
Single Chip Seal	Flexible	4.3	2.7	6.6
	Composite			
Double Chip Seal	Flexible	6.9		
	Composite		2.0	
Double Microsurfacing	Flexible	3.5	7.8	1.8
	Composite	9.8		11.6
HMA Crack Seal	Flexible	2.8	2.8	0.6
	Composite	0.9	2.1	1.6
HMA Mill & Overlay	Flexible	7.9		7.8
	Composite	3.6	8.5	5.3
HMA Overlay	Flexible	3.6		4.0
	Composite	3.2		2.2

Overall, the HMA mill and overlay and double microsurfacing treatments provided the longest service life extensions (around 8 and 12 years, respectively). HMA crack sealing was the most common treatment being used, and it provides a service life extension of up to 3 years. The rest of the preventive maintenance treatments used by MDOT provided service life extensions ranging from 2 to 7 years. It is interesting to note that non-structural HMA overlays without milling have significantly lower life extensions than do HMA overlays with milling. An explanation for this is that the HMA overlays without milling are placed on pavements with higher DI values than the rest of the treatments. The surface may have deteriorated to such an extent that the distresses in the underlying surface may have reflected through the overlay placed at very early ages. A more detailed project-level analysis would be required to confirm this explanation.

In general, it was noted that the majority of the preventive maintenance treatments are placed on pavements that have DI values less than 25, which is generally representative of pavements in *fair* or better condition. The data suggest that MDOT's CPM program is extending the service life of pavements in a cost-effective manner and it is recommended that MDOT actively continues its CPM program. However, care should be taken to select appropriate candidates for preservation in conjunction with the appropriate treatments to ensure maximum benefit and performance.

5. MDOT CAPITAL PREVENTIVE MAINTENANCE PROGRAM PERFORMANCE

Introduction

This chapter addresses the overall performance of MDOT's Capital Preventive Maintenance (CPM) program based on the data gathered in this study. As described in Chapter 2, two aspects of the overall performance of the CPM program are analyzed: (a) first application CPM treatment since a major rehabilitation/reconstruction activity, and (b) CPM treatments placed after the first CPM treatment application. A simplified life-cycle cost analysis was conducted to study the cost effectiveness of a preventive maintenance strategy versus a rehabilitation strategy.

First CPM Treatment Performance

The number of analysis segments grouped by the DI range and pavement age at the time of treatment placement is shown in figures 5.1 and 5.2, respectively. For both flexible and composite pavements, the majority of the first CPM treatments are placed on pavements with a pre-treatment DI of less than 20 and a pavement age of less than 10 years.

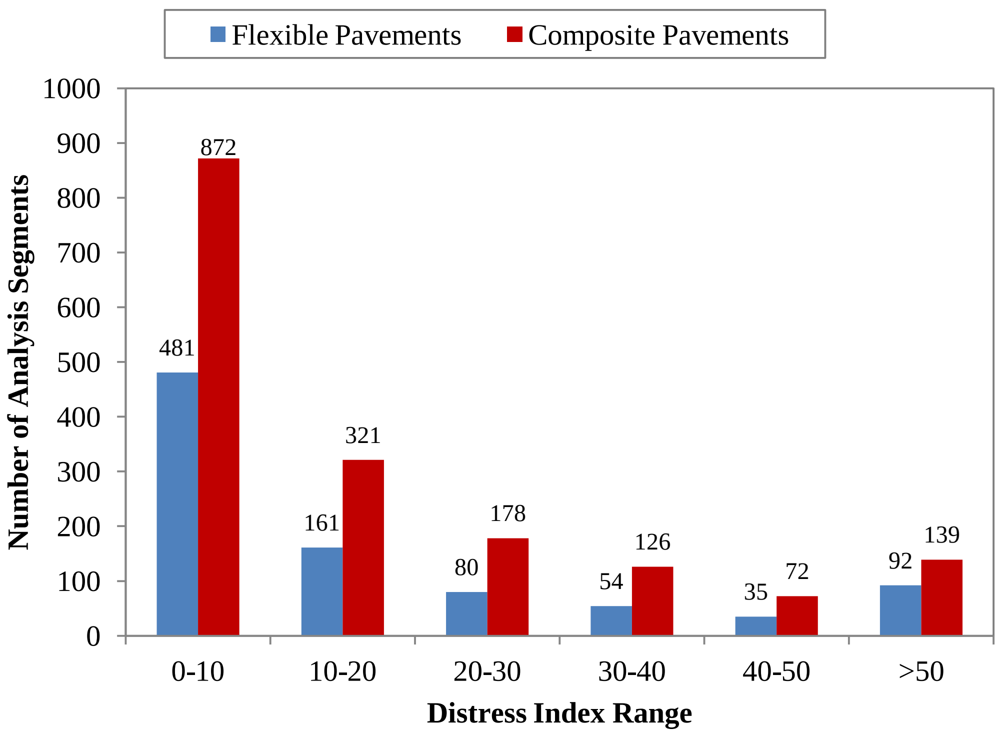


Figure 5.1. Distribution of pre-treatment pavement conditions (DI) for first CPM treatments.

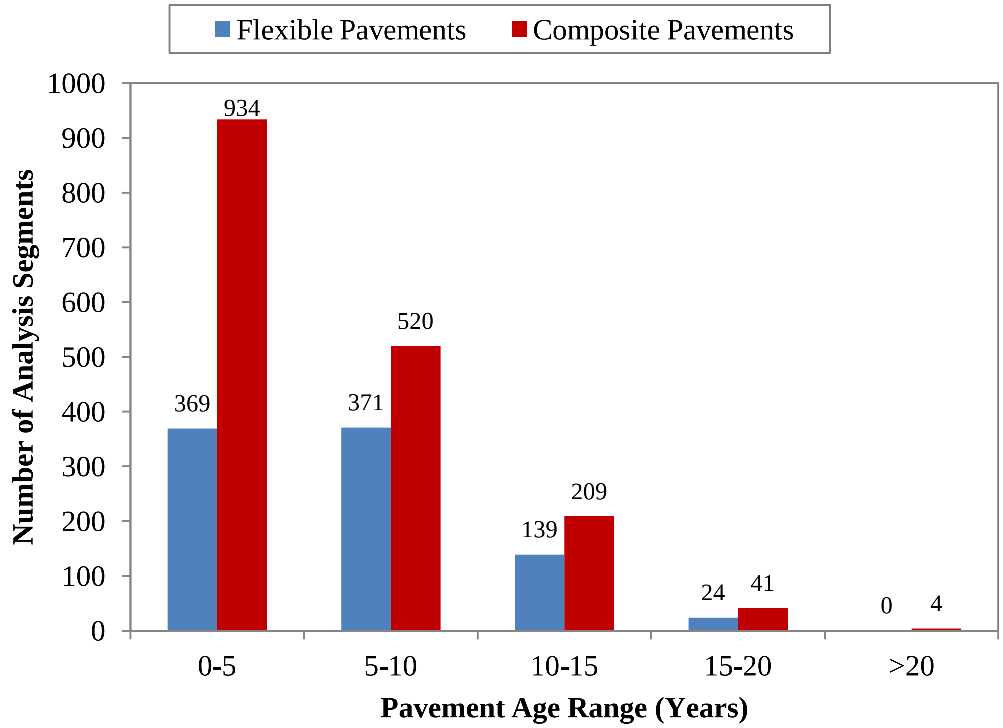


Figure 5.2. Distribution of pre-treatment pavement age for first CPM treatments.

Performance Models

Table 5.1 summarizes the models developed to describe the performance of the first application of the CPM treatments.

Table 5.1. First CPM treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
First CPM Treatments	Flexible	All	$DI = 9.2283e^{0.0553\ Age}$	0.72
		Zone 1	$DI = 6.57e^{0.0674\ Age}$	0.71
		Zone 2	$DI = 12.155e^{0.0461\ Age}$	0.53
	Composite	All	$DI = 11.058e^{0.0444\ Age}$	0.71
		Zone 1		
		Zone 2	$DI = 9.7363e^{0.0583\ Age}$	0.62

Figures 5.3 through 5.7 illustrate the pre- and post-treatment performance models developed to study the impact of the first application of the CPM treatments.

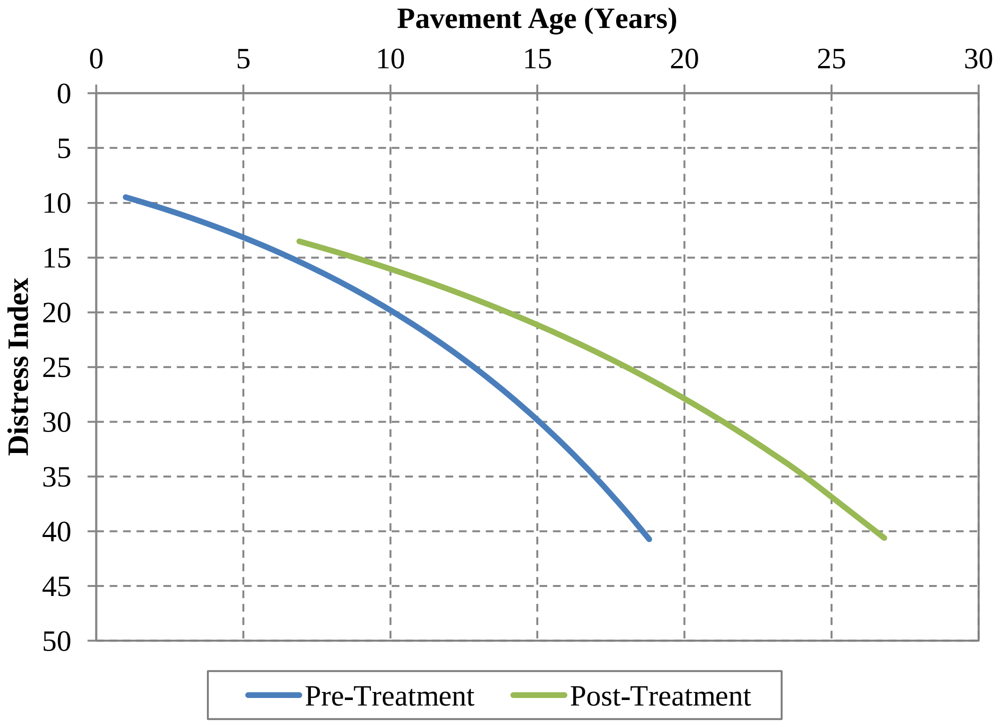


Figure 5.3. Pre- and post-treatment pavement performance – first CPM treatments on flexible pavements (all zones).

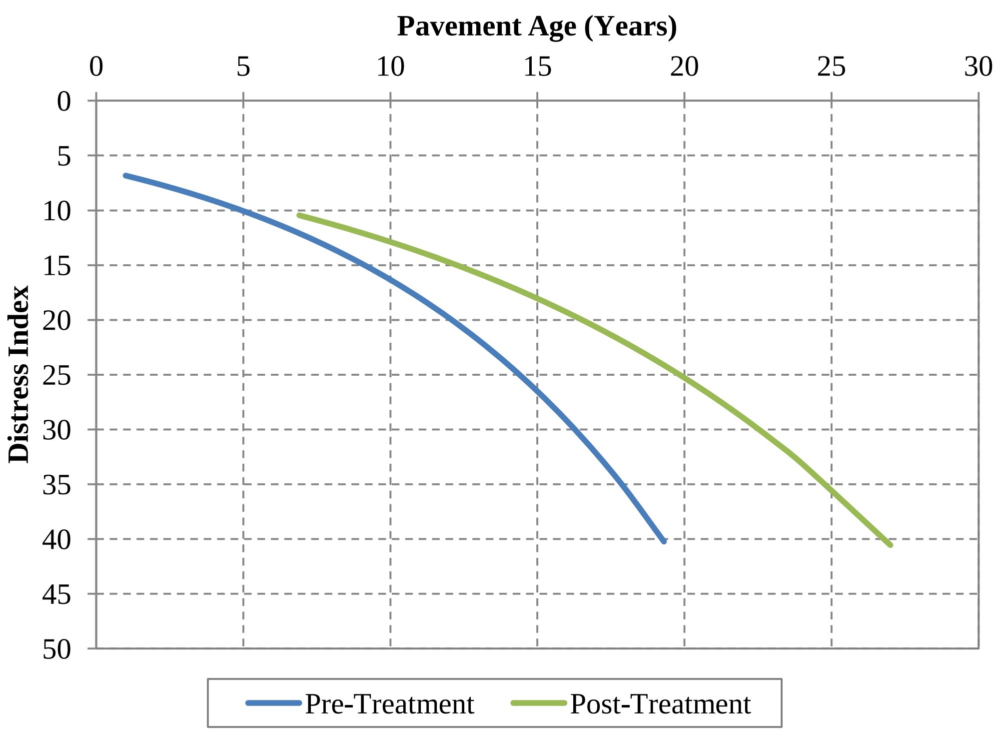


Figure 5.4. Pre- and post-treatment pavement performance – first CPM treatments on flexible pavements (Zone 1).

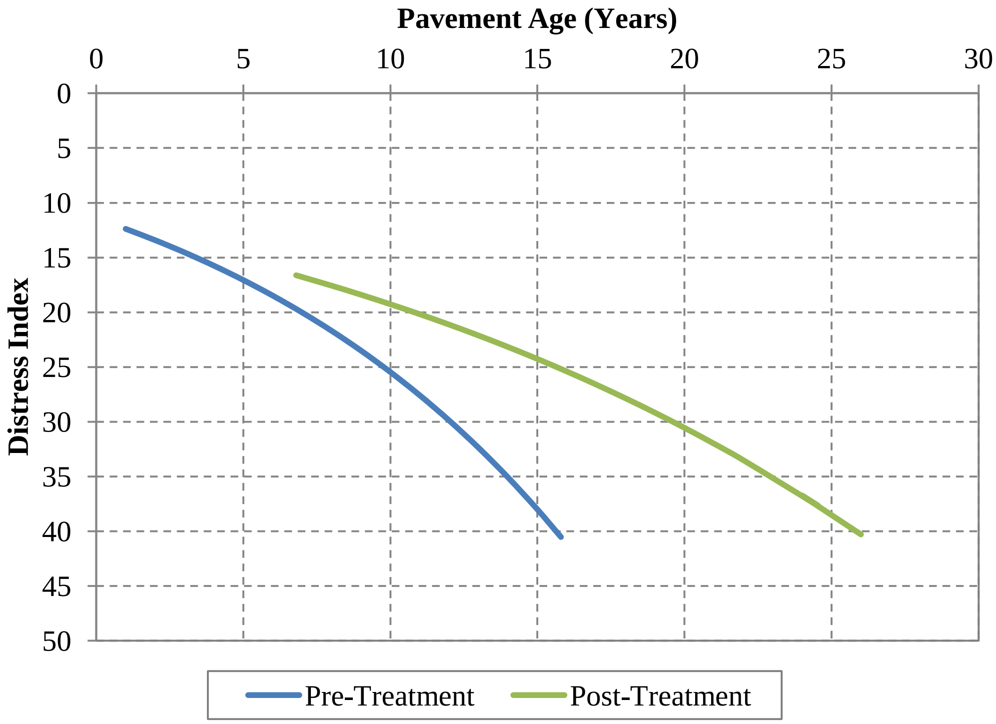


Figure 5.5. Pre- and post-treatment pavement performance – first CPM treatments on flexible pavements (Zone 2).

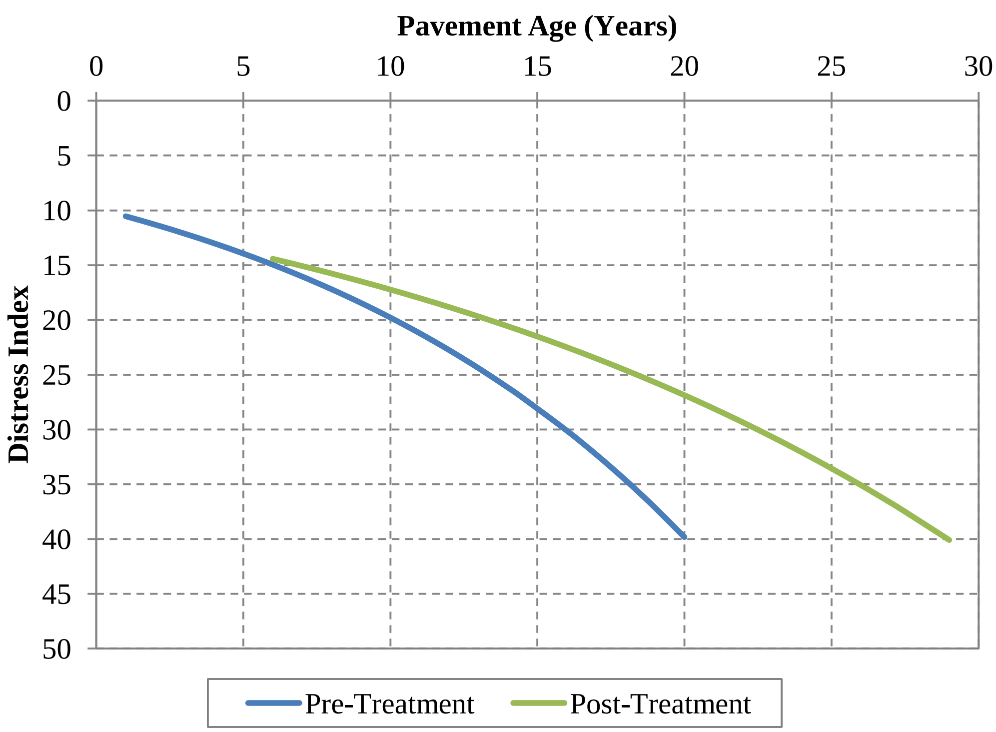


Figure 5.6. Pre- and post-treatment pavement performance – first CPM treatments on composite pavements (all zones).

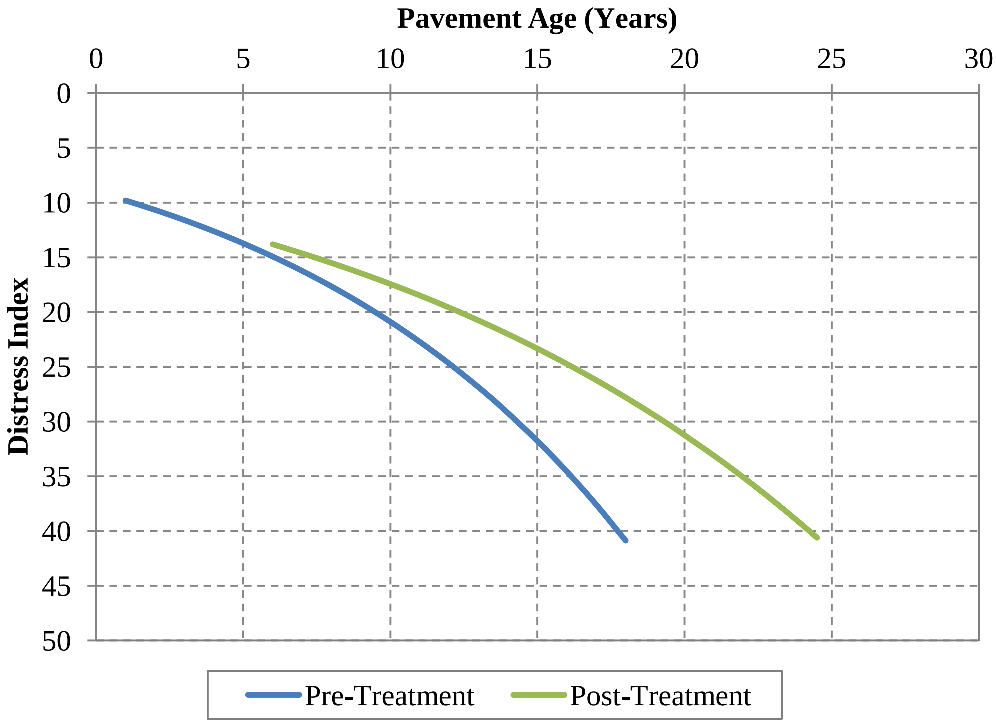


Figure 5.7. Pre- and post-treatment pavement performance – first CPM treatments on composite pavements (Zone 2).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 5.2.

Table 5.2. Treatment benefit from the first CPM treatments.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
First CPM Treatments	Flexible	All	7.9	38
		Zone 1	7.6	31
		Zone 2	10.2	51
	Composite	All	8.9	32
		Zone 1		
		Zone 2	6.5	32

The pavement service life extensions obtained from the first CPM treatments placed on flexible pavements are 7.6 years for Zone 1 and 10.2 years for Zone 2. For composite pavements, the pavement service life extension is 6.5 years for Zone 2 and 8.9 years for All zones. The area benefit varies between 31 and 51 percent for flexible pavements and is around 30 percent for composite pavements.

Descriptive Statistics

Table 5.3 shows statistics on the pre-treatment pavement condition before the application of the first CPM treatments. The average pre-treatment DI value varied between 14 and 23 for flexible pavements and between 17 and 21 for composite pavements.

Table 5.3. Pre-treatment DI statistics for the first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
First CPM Treatments	Flexible	All	18.7	24.8	14.8	21.9	23.3	27.0
		DI ≤ 25	7.4	6.5	6.7	6.0	8.5	7.0
		DI > 25	54.7	27.1	56.0	26.4	53.9	27.5
	Composite	All	17.7	20.1	21.3	24.5	16.8	18.8
		DI ≤ 25	8.3	6.5	8.6	6.8	8.2	6.4
		DI > 25	47.0	20.2	51.7	25.0	45.5	18.1

Table 5.4 shows statistics on the average age of the pavements on which the first CPM treatments were applied. The average pavement age at the time of treatment application is almost 7 years for flexible pavements and around 6 years for composite pavements.

Table 5.4. Average pavement age statistics for the first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
First CPM Treatments	Flexible	All	6.9	3.9	6.9	3.9	6.8	3.9
		DI ≤ 25	6.7	3.7	6.8	3.6	6.7	3.8
		DI > 25	7.2	4.5	7.5	5.1	0.1	4.1
	Composite	All	6.0	4.0	6.0	4.8	6.0	3.8
		DI ≤ 25	5.9	3.8	6.4	4.5	5.7	3.6
		DI > 25	6.3	4.6	5.2	6.6	6.6	4.2

Table 5.5 shows statistics on the average time to the next CPM treatment after the placement of the first CPM treatments. The average time to the next CPM treatment is between 5 and 6 years for both flexible and composite pavements. DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM.

Table 5.5. Average time to next CPM treatment for the first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
First CPM Treatments	Flexible	All	5.5	2.5	5.5	2.4	5.6	2.7
		DI ≤ 25	5.4	2.4	5.6	2.4	5.1	2.5
		DI > 25	6.0	2.7	4.7	1.9	6.6	2.8
	Composite	All	5.7	2.7	6.0	2.4	5.6	2.8
		DI ≤ 25	5.5	2.6	5.9	2.3	5.3	2.6
		DI > 25	6.5	3.1	6.0	2.9	6.7	3.2

The impact of pavement age on the time to next CPM treatment is summarized in table 5.6. While the pavement age did not have any appreciable impact on the time to the next CPM treatment for both flexible and composite pavements, the maximum time to the next CPM treatment was observed when the treatment was placed on pavements that were between 10 and 15 years old.

Table 5.6. Impact of pavement age on average time to next CPM treatment for the first CPM treatments.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
First CPM Treatments	0-5	5.2	2.2	5.4	2.7
	5-10	5.7	2.8	5.9	2.8
	10-15	6.1	2.3	6.5	2.6
	15-20	4.5	0.7	5.1	1.2
	> 20				

Post-First CPM Treatment Performance

The number of analysis segments, organized by the DI range and pavement age at the time of treatment placement, is shown in figures 5.8 and 5.9, respectively. For both flexible and composite pavements, the majority of the post-first CPM treatments are placed on pavements with pre-treatment DI values of less than 20 and a pavement age of between 5 and 15 years.

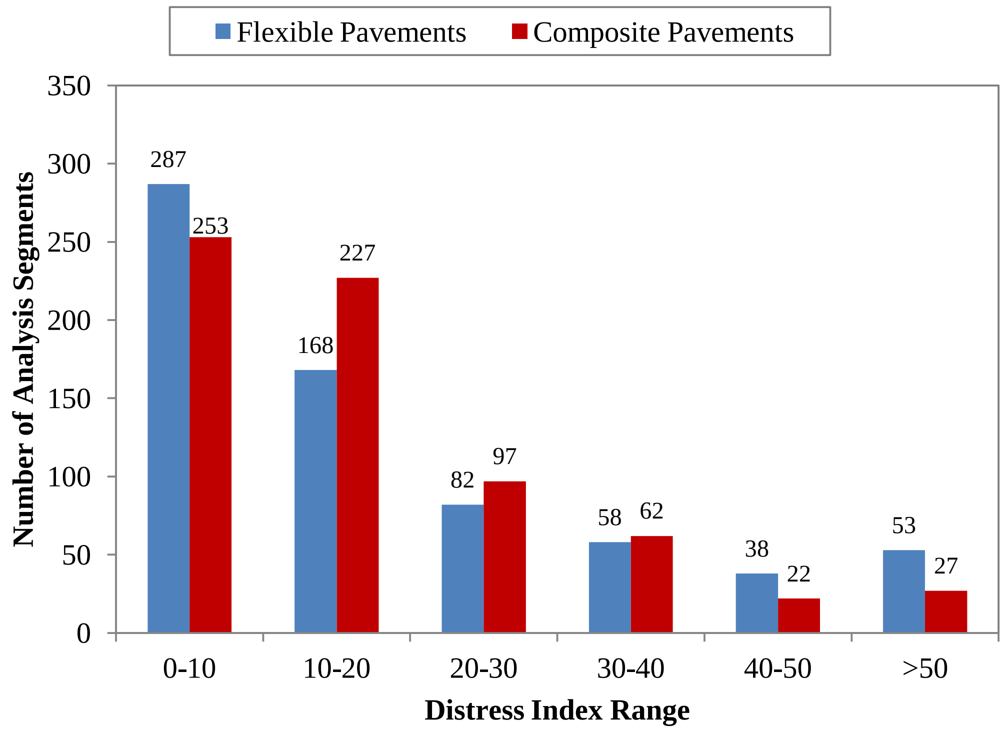


Figure 5.8. Pre-treatment pavement condition distribution for post-first CPM treatments.

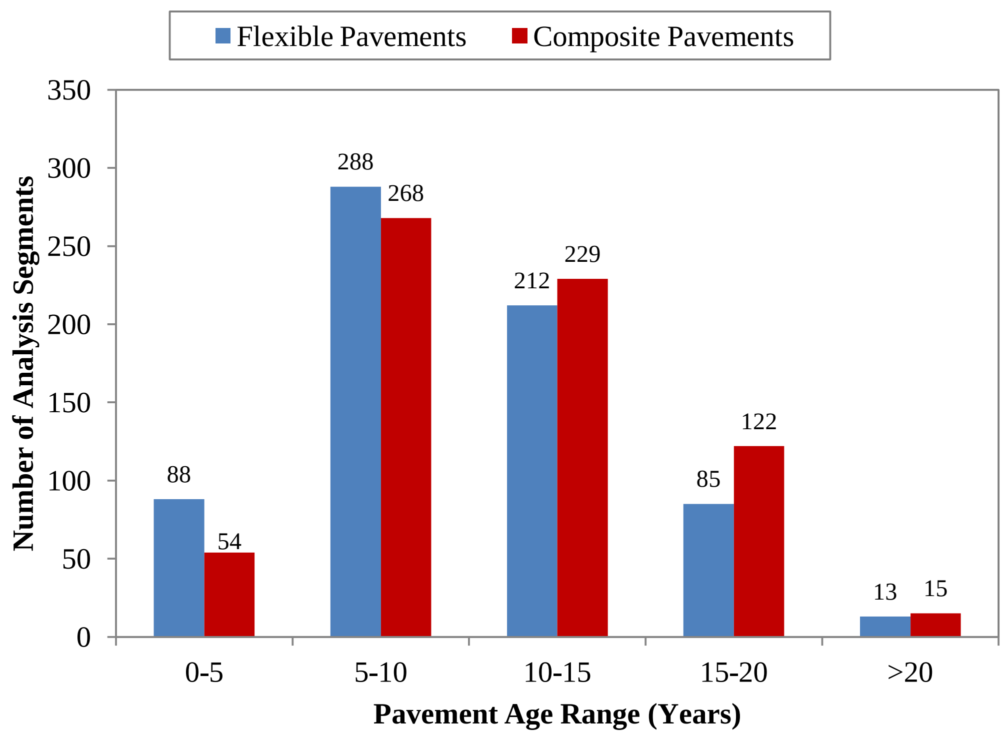


Figure 5.9. Pre-treatment pavement age distribution for post-first CPM treatments.

Performance Models

Table 5.7 summarizes the models developed to describe the performance of the post-first CPM treatments. Reliable zone-specific models could not be developed for either flexible or composite pavements.

Table 5.7. Post-treatment performance models.

Treatment	Pavement Type	Zone	Performance Model	R^2
Post-first CPM Treatments	Flexible	All	$DI = 9.4968e^{0.0417\ Age}$	0.36
		Zone 1		
		Zone 2		
	Composite	All	$DI = 13.573e^{0.0304\ Age}$	0.58
		Zone 1		
		Zone 2		

Figures 5.10 and 5.11 illustrate the pre- and post-treatment performance models developed to study the impact of the post-first CPM treatments.

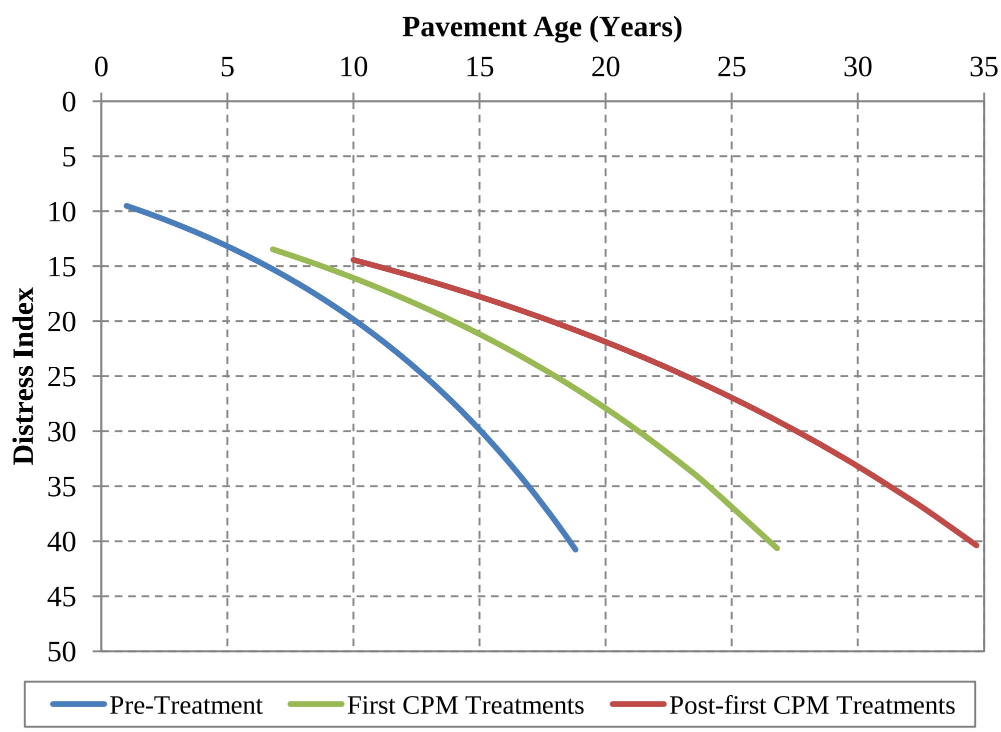


Figure 5.10. Pre- and post-treatment pavement performance on flexible pavement (all zones).

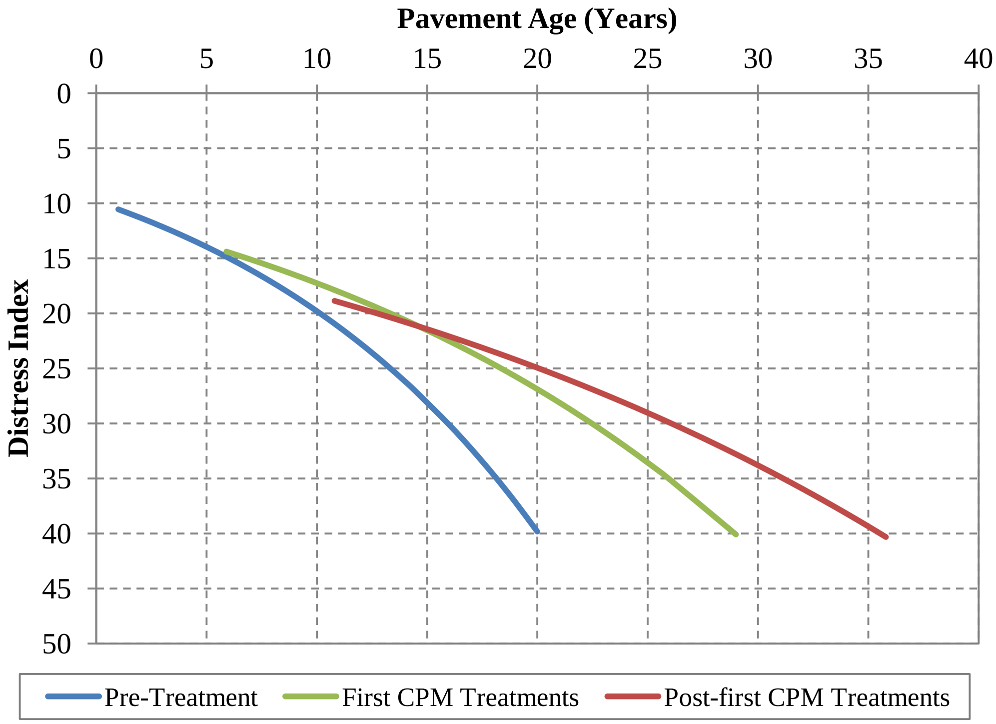


Figure 5.11. Pre- and post-treatment pavement on composite pavement (all zones).

The pavement service life extension and the percent benefit over the pre-treatment performance are summarized in table 5.8.

Table 5.8. Treatment benefit from the post-first CPM treatments.

Treatment	Pavement Type	Zone	Pavement Service Life Extension (years)	Benefit Area (%)
Post-first CPM Treatments	Flexible	All	8.0	38
		Zone 1		
		Zone 2		
	Composite	All	6.6	20
		Zone 1		
		Zone 2		

The pavement service life extensions obtained from the post-first CPM treatments are 8 years for flexible pavements and around 6.6 years for composite pavements. The area benefits are 38 and 20 percent for flexible and composite pavements, respectively.

Descriptive Statistics

Table 5.9 shows statistics on the pre-treatment pavement condition before the application of the post-first CPM treatments. The average pre-treatment DI value varied between 16 and 25 for flexible pavements, and was around 17 for composite pavements.

Table 5.9. Pre-treatment DI statistics for the post-first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Pre-Treatment DI					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Post-first CPM Treatments	Flexible	All	19.8	21.8	16.5	16.9	24.6	26.7
		DI ≤ 25	9.4	6.7	9.5	6.7	9.3	6.6
		DI > 25	46.6	24.4	40.7	19.3	51.8	27.2
	Composite	All	17.6	14.8	17.5	13.3	17.7	15.4
		DI ≤ 25	11.3	5.9	11.9	6.5	11.1	5.7
		DI > 25	40.3	15.2	38.9	10.7	40.9	16.7

Table 5.10 shows statistics on the average age of the pavements on which the post-first CPM treatments were applied. The average pavement age at the time of treatment application is between 10 and 12 years for both flexible and composite pavements.

Table 5.10. Average pavement age statistics for the post-first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Age at Treatment Placement (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Post-first CPM Treatments	Flexible	All	10.4	4.4	10.3	4.2	10.6	4.7
		DI ≤ 25	10.5	4.3	10.3	4.1	10.8	4.7
		DI > 25	10.5	4.7	10.2	4.6	10.2	4.8
	Composite	All	11.5	4.4	10.5	3.6	11.9	4.6
		DI ≤ 25	11.5	4.5	10.4	3.4	12.0	4.8
		DI > 25	11.4	3.9	11.2	4.4	11.6	3.7

Table 5.11 shows statistics on the average time to the next CPM treatment after the placement of the post-first CPM treatments. The average time to the next CPM treatment is around 4 years for flexible pavements and around 3 years for composite pavements. DI values greater than 25 prior to treatment placement did not result in significant changes in the time to next CPM treatment.

Table 5.11. Average time to next CPM treatment for the post-first CPM treatments.

Treatment	Pavement Type	Pre-Treatment Condition Category	Time to Next CPM Treatment (Years)					
			All		Zone 1		Zone 2	
			Avg.	SD	Avg.	SD	Avg.	SD
Post-first CPM Treatments	Flexible	All	3.7	2.0	3.7	2.2	3.6	1.6
		DI ≤ 25	3.5	1.8	3.5	2.0	3.5	1.6
		DI > 25	3.9	2.2	4.1	2.7	.3.8	1.7
	Composite	All	3.3	1.8	2.7	1.6	3.5	1.8
		DI ≤ 25	3.1	1.7	2.6	1.3	3.4	1.8
		DI > 25	3.7	2.0	3.4	2.1	3.9	1.9

The impact of pavement age on the time to next CPM treatment is summarized in table 5.12. It is observed that the CPM treatments applied on pavements which were older than 20 years had the lowest time to the next CPM treatment. A possible explanation for this result is that as pavements age, and certainly as they approach 20 years, they have started to lose their structural capacity, their rate of deterioration is increasing, and CPM treatments are unable to maintain functional performance. Otherwise, in the four age ranges or categories between 0 and 20 years there is not a definitive trend, particularly for composite pavements.

Table 5.12. Impact of pavement age on average time to next CPM treatment for the post-first CPM treatments.

Treatment	Pavement Age Category (Years)	Time to Next CPM Treatment (Years)			
		Flexible		Composite	
		Average	SD	Average	SD
Post-first CPM Treatments	0-5	4.5	2.9	3.2	1.7
	5-10	3.6	1.6	4.5	1.9
	10-15	3.3	1.8	3.1	1.8
	15-20	3.6	1.4	3.1	1.8
	> 20	1.0		2.5	1.7

Cost-Effectiveness of the MDOT CPM Program

A simplified life-cycle cost analysis was conducted to compare the life-cycle costs of a rehabilitation-only strategy versus a preventive maintenance strategy for flexible and composite pavements. A similar analysis could not be conducted for rigid pavements since reliable performance models could not be developed. It should be noted that a rigorous life-cycle cost study was not conducted and the results from this analysis only provide a general idea of CPM cost effectiveness based on the performance models developed in the study and the average statewide rehabilitation and preventive maintenance costs provided by MDOT.

To assist in this cost-effectiveness analysis MDOT provided typical costs associated with maintenance and rehabilitation activities on freeways and non-freeways. These costs are summarized in table 5.13.

Table 5.13. Typical costs of rehabilitation and preventive maintenance.*

	Cost ($/lane-mile)	
	Rehabilitation	**Preventive Maintenance**
Non-Freeway	$510,000	$63,700
Freeway	$693,000	$70,400
Average	$601,500	$67,050

* Provided by Ms. Erin Chelotti, MDOT's CPM Program Manager.

An analysis was then carried out using the (lower) non-freeway costs, the (higher) freeway costs, and the average costs to evaluate the relative effects of varying costs.

Flexible Pavements

For flexible pavements, an analysis period of 34 years was used since this indicates the average pavement age at which the last CPM treatment placed is expected to reach a DI value of 40, based on the performance models developed (see figure 5.10). The simplified life-cycle cost analysis used the non-freeway, freeway, and the average costs to compare rehabilitation to preventive maintenance. The first CPM placed on flexible pavements is expected to extend the pavement life by an average of 8 years, and the rest of the CPM treatments placed after the first CPM treatment are expected to have a combined effect of extending a pavement's service life by approximately 8 years. Approximately 70 percent of the post-first CPM treatments are the second CPM treatments and they can be assumed to account for about 70 percent of the life extension resulting from post first treatments (5.5 years); the remaining CPM treatments placed after the second CPM treatments result in a life extension of around 2.5 years.

Figures 5.12 through 5.14 show a comparison of a rehabilitation strategy versus a preventive maintenance strategy for the non-freeway, freeway, and average costs summarized in table 5.13. For the rehabilitation strategy, it is assumed that every 19 years the pavement receives the same rehabilitation treatment as the previous application with similar performance as described by the pre-treatment model shown in figure 5.10.

For the plots shown in figure 5.12 through 5.14, the x-axis is the maintenance or the rehabilitation activity. To compute the life-cycle costs for the rehabilitation strategy, it was assumed that the costs are distributed evenly over the expected life of the rehabilitation activity (which is approximately 19 years, as described by the model). The analysis period is 34 years and two rehabilitation events occur in the time period. However, since the second rehabilitation treatment is expected to last around 4 years past the analysis period, only the costs for 15 years of the rehabilitation activity are included in the analysis.

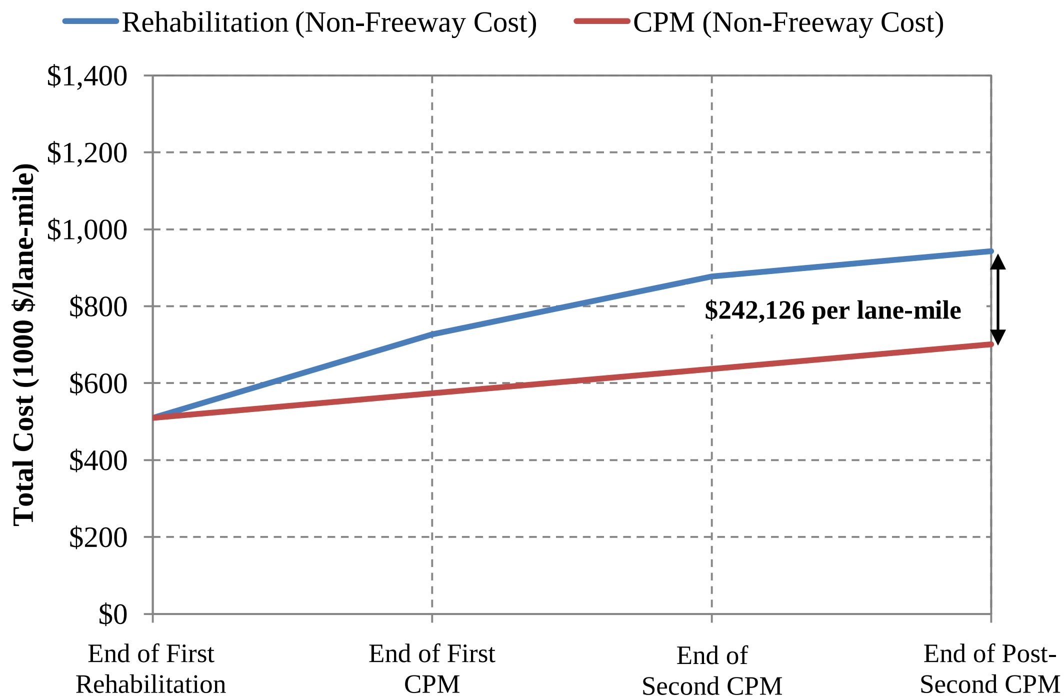


Figure 5.12. Comparison of a rehabilitation strategy versus a CPM strategy for flexible pavements (non-freeway costs).

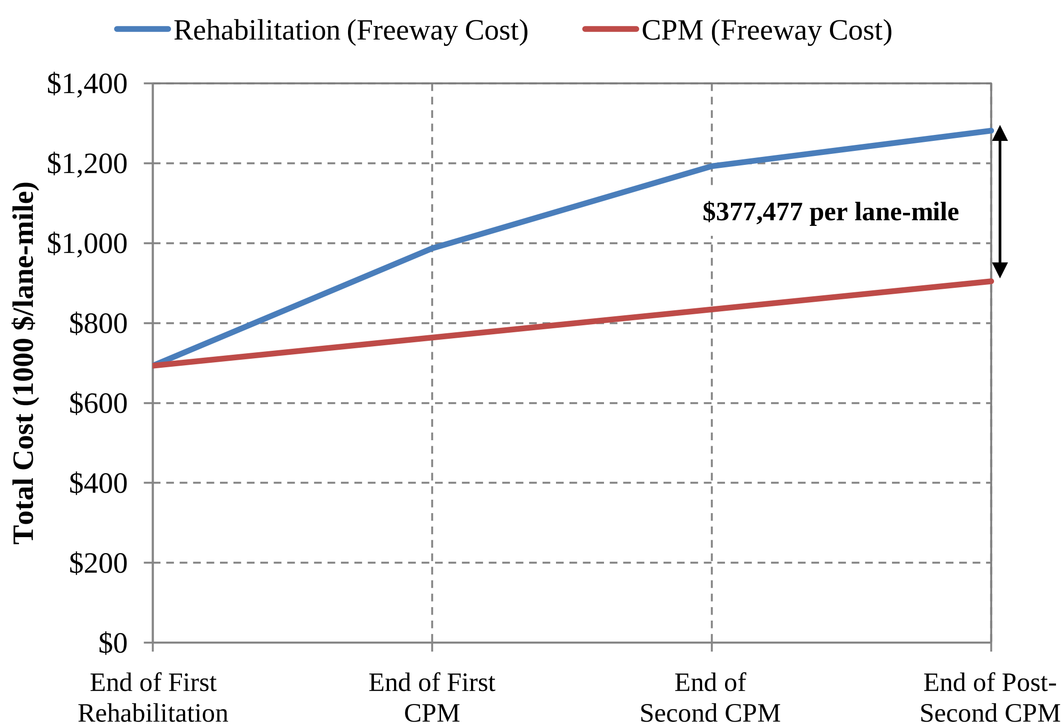


Figure 5.13. Comparison of a rehabilitation strategy versus a CPM strategy for flexible pavements (freeway costs).

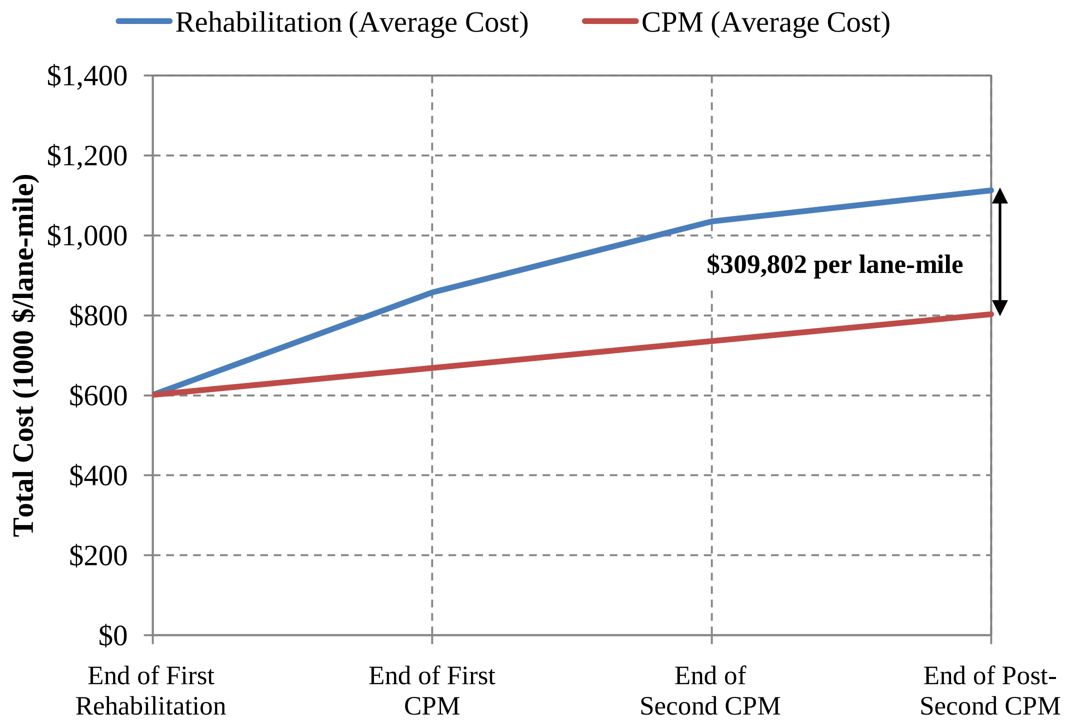


Figure 5.14. Comparison of a rehabilitation strategy versus a CPM strategy for flexible pavements (average costs).

Figures 5.12 through 5.14 indicate that the MDOT's CPM program is definitely a cost-effective strategy. The CPM strategy results in a cost reduction of between $242,126 to $377,477 per lane-mile, with an average cost reduction of $309,802 per lane-mile, compared to a rehabilitation strategy on flexible pavements.

Composite Pavements

For composite pavements, an analysis period of 36 years was used since this represents the average pavement age at which the last CPM treatment placed is expected to reach a DI value of 40, based on the developed performance models (see figure 5.11). As with flexible pavements, a simplified life-cycle cost analysis was carried out using the non-freeway, freeway, and the average costs to compare the relative effects. The first CPM placed on composite pavements is expected to extend the pavement life by an average of approximately 9 years, and the combined effect of the remaining CPM treatments placed after the first CPM treatment are to extend the service life of the pavement by around 6.6 years. Approximately 70 percent of the post-first CPM treatments are the second CPM treatments and they can be assumed to account for about 70 percent of the life extension resulting from post first treatments (4.6 years); the remaining CPM treatments CPM treatments result in a life extension of around 2 years.

Figures 5.15 through 5.17 show a comparison of a rehabilitation strategy versus a CPM strategy for the non-freeway, freeway, and average costs summarized in table 5.13. For the rehabilitation strategy, it is assumed that every 20 years the pavement undergoes the same rehabilitation treatment as the previous one, with similar performance as described by the pre-treatment model shown in figure 5.11. As described earlier, the x-axis in the plots shown in figure 5.15 through 5.17 shows the maintenance or rehabilitation activity.

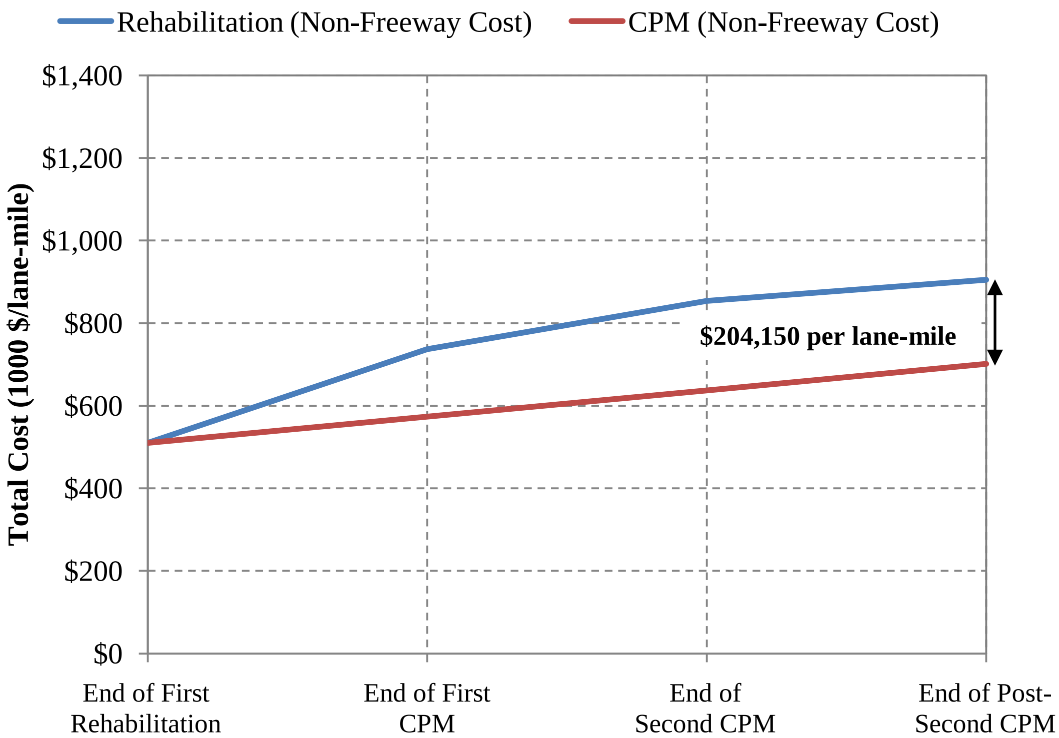


Figure 5.15. Comparison of a rehabilitation strategy versus a CPM strategy for composite pavements (non-freeway costs).

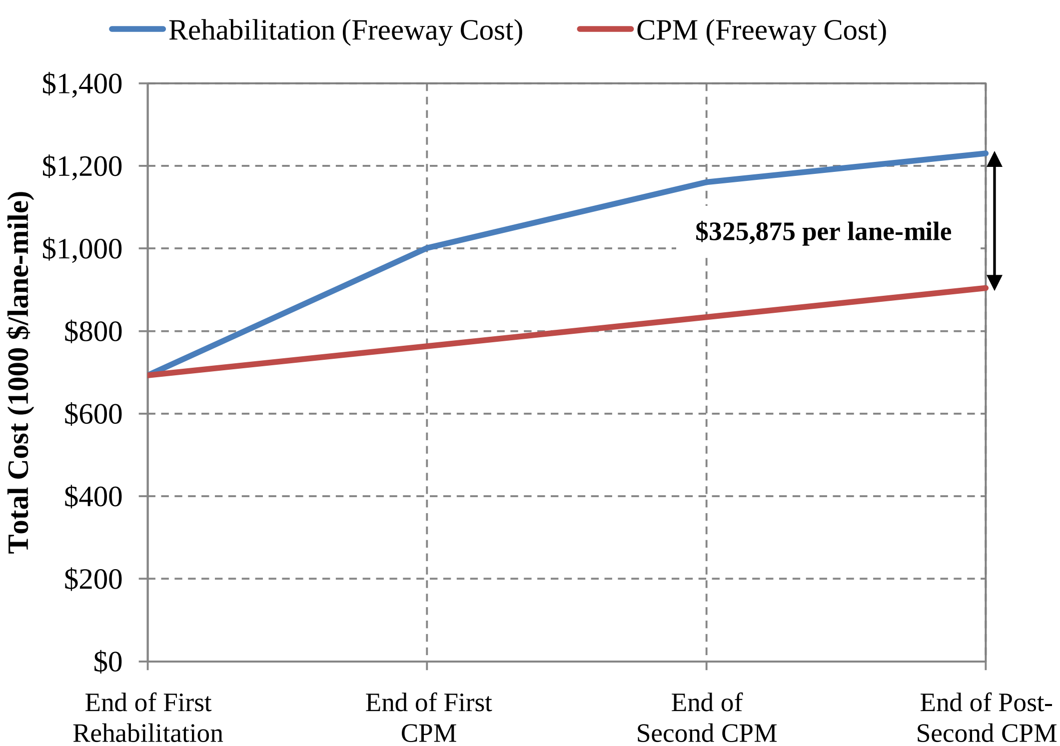


Figure 5.16. Comparison of a rehabilitation strategy versus a CPM strategy for composite pavements (freeway costs).

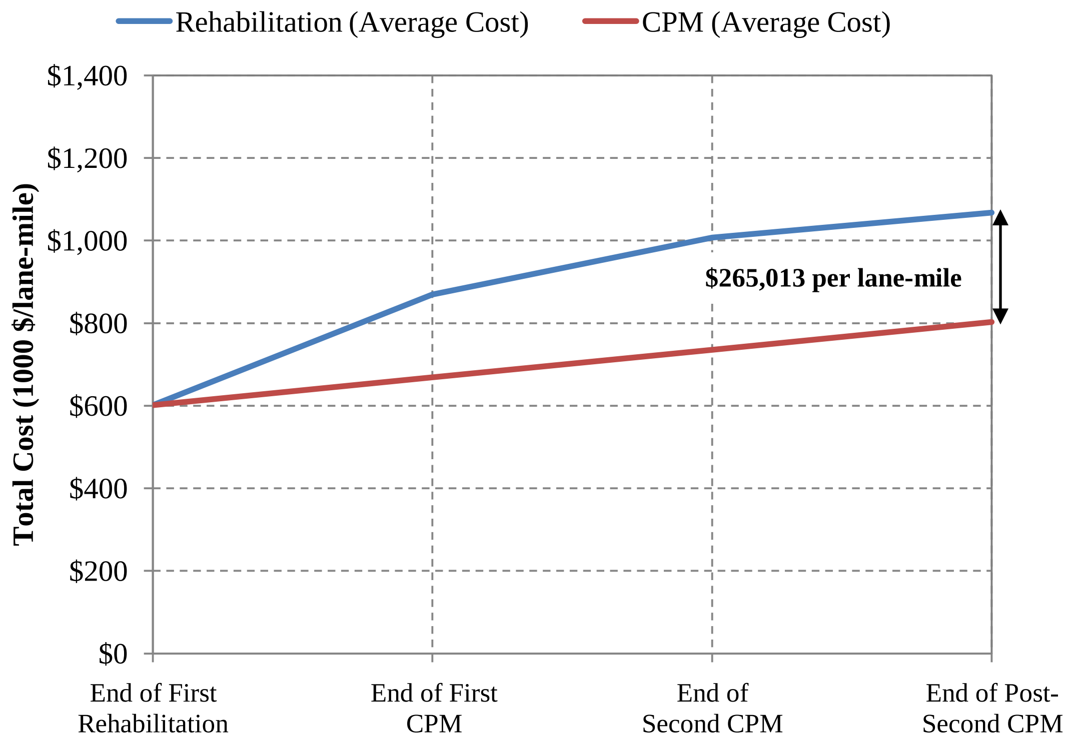


Figure 5.17. Comparison of a rehabilitation strategy versus a CPM strategy for composite pavements (average costs).

Figures 5.15 through 5.17 indicate that the MDOT's CPM program is definitely a cost-effective strategy for composite pavements. The CPM strategy results in a cost reduction from $204,150 to $325,875 per lane-mile, with an average cost reduction of $265,013 per lane-mile compared to a rehabilitation strategy on composite pavements.

Summary

This chapter summarizes the performance of the preventive maintenance treatments used by MDOT as a part of its Capital Preventive Maintenance program. The average pavement service life extension and the benefit area generated by MDOT's CPM treatments are shown in table 5.14.

The CPM treatments (including first and post-first) increase the service life of flexible pavements by around 16 years with an overall benefit area of 73 percent over the pre-treatment pavement performance. For composite pavements, the CPM treatments (including first and post-first) increase the pavement service life by around 15.5 years with an overall benefit area of around 52 percent over the pre-treatment pavement performance.

The DI of the pavements prior to the application of the preventive maintenance treatments averages between 15 and 25, and these values are within the prescribed threshold values in MDOT's CPM manual. This suggests that a vast majority of the projects are being applied on pavements with the true intention of preserving the existing structure, which is essentially the objective of pavement preservation.

Table 5.14. Treatment benefit from the CPM treatments.

Treatment	**Pavement Type**	**Zone**	**Pavement Service Life Extension (years)**	**Benefit Area (%)**
First CPM Treatments	Flexible	All	7.9	38
		Zone 1	7.6	31
		Zone 2	10.2	51
	Composite	All	8.9	32
		Zone 1		
		Zone 2	6.5	32
Post-first CPM Treatments	Flexible	All	8.0	38
		Zone 1		
		Zone 2		
	Composite	All	6.6	20
		Zone 1		
		Zone 2		

A simplified life-cycle cost analysis was conducted to compare a rehabilitation strategy to a CPM strategy. This analysis was conducted using the statewide average rehabilitation and CPM costs provided by MDOT. While this analysis is not rigorous, it does provide a simple way to compare the cost effectiveness of a rehabilitation strategy to that of a CPM strategy. The MDOT CPM program generates average savings of almost $310,000 per lane-mile for flexible pavements, and around $265,000 per lane-mile for composite pavements when compared to a rehabilitation-only strategy while providing service life extensions of around 16 years. The data analyzed in this study show that MDOT's CPM program is helping to preserve existing pavements and delay the need for major rehabilitation or reconstruction activities. It is clear that under observed conditions (i.e., in most cases for the first 20 years of a pavement's life and while the DI is between 0 and 40), preserving existing roads in good condition is economically and environmentally sustainable for MDOT.

6. CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION

Summary

In this project the performance and benefits of various preventive maintenance treatments used by MDOT as a part of its Capital Preventive Maintenance program were evaluated. Regression models were developed to describe the performance of individual treatments as well as the combined performance of the all the treatments included in the MDOT CPM program for which data were available in this study. Ultimately, analyses were carried out on selected CPM treatments for flexible and composite pavements; because of gaps and inconsistencies in the data, reliable performance models could not be developed for all CPM treatments, including any of the preventive maintenance treatments used on rigid pavements.

From the treatments classified as "Pavement Seals" for flexible and composite pavements in the MDOT CPM manual, HMA crack seal is most commonly used by MDOT, followed by microsurfacing, chip seals, ultra-thin HMA overlays, and paver-placed surface seals. From treatments in the "Functional Enhancements" category, non-structural HMA overlays with and without milling were the most commonly used options for flexible and composite pavements. Concrete pavement rehabilitation and joint/crack sealing are the most common treatments used on rigid pavements. The HMA mill and overlay and double microsurfacing treatments provided the longest service life extensions (around 8 and 12 years, respectively). HMA crack sealing was the most commonly used CPM treatment and it provides a service life extension of up to 3 years. The remaining preventive maintenance treatments used by MDOT provided service life extensions ranging from 2 to 7 years.

The cost-effectiveness of the individual treatments was evaluated by an analysis of benefit-cost ratios. Cost effectiveness was determined by calculating a benefit-cost ratio for each treatment, defined as the ratio of the percent area benefit obtained post-treatment compared to the pre-treatment performance divided by the unit cost of the treatment. For flexible pavements, HMA crack seals had the highest benefit-cost ratio when data from all the zones were considered together. Comparing single chip seals, double chip seals, and double microsurfacing, the single chip seals exhibited the highest benefit-cost ratios for flexible pavements (overall and Zone 2). For Zone 1, microsurfacing had a higher benefit-cost ratio than single chip seals. Overall, microsurfacing and HMA overlays (with and without milling) have the lowest benefit-cost ratios for flexible pavements. For composite pavements, microsurfacing has the highest benefit-cost ratios, followed by crack seals, double chip seals, and HMA overlays when all the zones are considered together. Microsurfacing has a higher benefit-cost ratio than HMA overlays (overall and Zone 2).

It should be noted that benefit-cost ratios cannot be used as a stand-alone measure to assess the cost effectiveness of a given preventive maintenance treatment. Treatments like crack sealing exhibit relatively high benefit-cost ratios primarily because of their low unit costs. However, crack sealing is not effective in mitigating all distresses, nor does it provide the same life extension and improvements in functionality to a pavement that a blanket treatment such as a chip seal, microsurfacing, or thin overlay does. When selecting a particular treatment, the agency should consider both benefit-cost ratios and other factors such as the applicability of the treatment for existing pavement conditions, in order to achieve a long lasting preventive maintenance treatment.

Overall, the CPM treatments increase the service lives of flexible and composite pavements by approximately 15 and 16 years, respectively.

The impact of pre-treatment pavement condition and climatic zone was investigated where data were available. Although no conclusive observations could be made on the impact of pre-treatment condition on performance, it was observed that majority of the preventive maintenance treatments are being placed on pavements with DI values that are well below the threshold values prescribed in the MDOT CPM Manual. This suggests that MDOT is proactively applying preventive maintenance treatments to pavements in good condition to preserve that good condition. Since reliable zone-specific performance models could not be developed for all the treatments, no conclusions could be made on the impact of climatic conditions on treatment performance.

The results of this study suggest that MDOT's CPM program provides a great benefit by helping preserve the existing pavement infrastructure and delaying the need for major rehabilitation or reconstruction. This study presented the results from a network-level perspective; in order to understand the performance and benefits obtained from individual treatments in greater detail, a project-level study with a smaller representative sample should be conducted.

Treatment Selection Guidelines

This section presents general guidelines on selecting preventive maintenance treatments. The use of pavement preservation strategies to maintain the condition of the pavement network requires two primary considerations:

- Identifying whether the pavement is an appropriate candidate for preservation.
- Identifying feasible treatments that can be applied.

Appropriate pavement preservation strategies are determined based on the combination of the existing condition of the pavement and the extent and severity of the distresses present. Certain conditions may require a combination of preservation strategies: for example, crack sealing may be required prior to the placement of an HMA overlay to reduce the rate and severity of reflective cracking. Figure 6.1 summarizes a step-by-step process for preservation treatment selection. The key steps are described below.

Gather Data: Selecting the appropriate pavement preservation strategy requires knowledge on the historical pavement information. The critical information needed includes: pavement type, pavement age, design life, traffic, pavement materials, and structure. The pavement type dictates the applicability of treatments. This information is specified in the MDOT CPM manual.

Assess Pavement Condition: In addition to the historical pavement data, the existing condition of the pavement (Distress Index, IRI, rutting, and so on) should be assessed in order to determine if a given pavement section is a suitable candidate for preservation. In addition to the condition indicators, the extent and severity of the distresses should also be evaluated. While a DI value can help to determine whether a pavement is a good candidate for preservation, it does not provide sufficient guidance on the appropriate treatment. The presence of a structural deficiency, drainage problems, and material incompatibility issues are other factors that should be considered before selecting a preservation strategy.

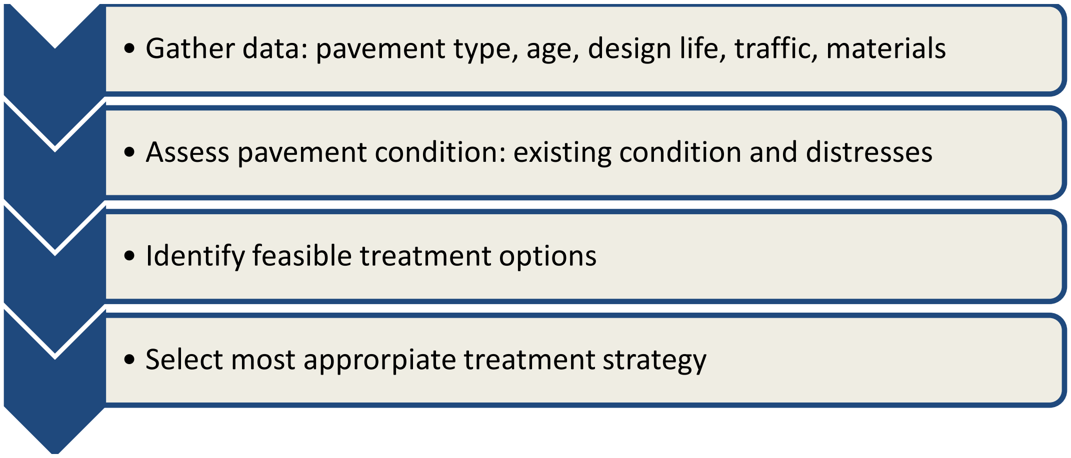


Figure 6.1. Flowchart illustrating steps in selecting an appropriate preventive maintenance treatment.

Identify Feasible Options: The appropriate treatment strategy for pavement sections identified as potential candidates for pavement preservation can be determined by looking at the type and severity of the distresses present on the pavement. General guidelines for determining the recommended treatments for flexible/composite and rigid pavements are provided in tables 6.1 and 6.2, respectively.

The feasibility of the various CPM treatments shown in figures 6.1 and 6.2 in addressing various pavement distresses and their applicability under various levels of traffic are summarized based on typically reported information in the literature. The threshold RSL, DI, RQI, IRI and Rutting values are based on values reported in the MDOT CPM Manual (MDOT 2010).

Select Most Appropriate Treatment Strategy: Once all feasible treatment strategies have been identified, the most appropriate treatment is the one that can provide the greatest benefit for the lowest cost while meeting the constraints of the project. There are several methodologies that can be used to select the most appropriate treatment, but the most widely used is life-cycle cost analysis, which is also used by MDOT for pavement type decisions for reconstruction and major rehabilitation projects. The following summarizes factors that should be considered in the selection of a treatment from feasible options:

- Pavement service life extension.
- Time to the next CPM treatment.
- Benefit over pre-treatment performance.
- Treatment costs.

Table 6.1. Treatment selection guidelines for flexible and composite pavements.

Pavement Conditions	Parameters	HMA Overlay (non-structural)	HMA Mill and Overlay (non-structural)	Ultra-Thin HMA Overlay	Single Chip Seal	Double Chip Seal	Single Micro-surfacing	Multiple/ Heavy Single Micro-surfacing	Double Micro-surfacing	Paver Placed Surface Seal	Crack Treatment	Overband Crack Filling
Alligator/ Fatigue Cracking [1]	Low	F	F	F	F	F	F	F	F	F	F	F
	Moderate	NR	NR	NR	NR	F	NR	NR	NR	NR	NR	NR
	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Block Cracking	Low	F	F	F	R	R	R	R	R	R	R	R
	Moderate	NR	NR	NR	F	F	NR	NR	F	F	R	R
	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR	F	F
Bleeding	Low	R*	R*	R	R	R	R	R	R	R	NR	NR
	Moderate	F	F	F	F	F	R	R	R	R	NR	NR
	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Longitudinal and Transverse Cracking [2]	Low	R**	R**	F	R	R	R	R	R	R	R	R
	Moderate	R**	R**	NR	F	F	F	F	F	F	R	R
	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR	F	F
Rutting [3]	Low	R*	R*	F	F	F	R	R	R	R	NR	NR
	Moderate	R	R	NR	NR	NR	R	R	R	F	NR	NR
	Severe	NR	NR	NR	NR	NR	F	F	R	NR	NR	NR
Weathering/ Raveling	Low	R	R	R	R	R	R	R	R	R	NR	NR
	Moderate	R	R	F	R	R	R	R	R	R	NR	NR
	Severe	R*	R*	NR	F	R	F	F	R	R	NR	NR
Ride	Poor	R	R	F	F	F	F	F	F	F	NR	NR
Friction	Poor	R	R	R	R	R	R	R	R	R	NR	NR
ADT	< 5,000	R	R	R	R	R	R	R	R	R	R	R
	10,000	R	R	R	R	R	R	R	R	R	R	R
	> 10,000	R	R	R	F	F	F	F	R	F	R	R
Flexible Pavement Condition Thresholds	RSL	3	3	7	6	5	10	5		5	10	7
	DI	40	40	30	25	30	15	30		30	15	20
	RQI	70	80	54	54	54	54	54		62	54	54
	IRI	163	212	107	107	107	107	107		132	107	107
	Rutting	0.50	1.00	0.13	0.13	0.13	1.00	1.00		0.25	0.13	0.13
Composite Pavement Condition Thresholds	RSL	3	3	7		5			5	5	10	7
	DI	25	30	20		15			15	15	5	20
	RQI	70	80	54		54			54	62	54	54
	IRI	163	212	107		107			107	132	107	107
	Rutting	0.50	1.00	0.13		0.13			1.00	0.25	0.13	0.13

R - Recommended treatment for the specified pavement condition. However, care must be taken to ensure that all critical distress types are addressed by the selected treatment.

F - Feasible treatment but depends upon other project constraints including other existing distresses.

NR - Treatment is not recommended to correct the specified pavement condition.

R* - Recommended treatment when used with milling prior to treatment.

R** - Used in combination with crack treatment.

1- Preservation treatments do not correct alligator cracking. Of the treatments, chip seals are most appropriate at addressing the alligator cracking.

2 - If longitudinal and transverse cracking are present without other distresses, crack filling or treatment is recommended.

3 - If stable rutting is present without other distresses, microsurfacing or mill and overlay are the recommended treatment.

Table 6.2. Treatment selection guidelines for rigid pavements.

Pavement Conditions	**Parameters**	**Crack Sealing**	**Joint Resealing**	**Full-Depth Repairs**	**Diamond Grinding**	**DBR [1]**	**CPR [2]**
Corner Breaks	Low	R	NR	NR	NR	NR	R
	Moderate	R	NR	F	NR	NR	R
	Severe	NR	NR	R	NR	NR	R
D-cracking	Low	NR	NR	NR	NR	NR	R
	Moderate	NR	NR	F	NR	NR	R
	Severe	NR	NR	R	NR	NR	R
Faulting	Low	NR	R	NR	F	NR	F
	Moderate	NR	F	NR	R	R	R
	Severe	NR	NR	NR	R*	R	R
Joint Seal Damage	Low	NR	F	NR	NR	NR	F
	Moderate	NR	R	NR	NR	NR	F
	Severe	NR	R	NR	NR	NR	R
Longitudinal Cracking	Low	NR	NR	NR	NR	NR	F
	Moderate	R	NR	F	NR	NR	F
	Severe	F	NR	R	NR	NR	R
Pumping	All	NR	F	NR	NR	F	R
Spalling	Low	NR	F	NR	NR	NR	F
	Moderate	NR	F	NR	NR	NR	R
	Severe	NR	NR	F	NR	NR	R
Transverse Cracking	Low	NR	NR	NR	NR	NR	F
	Moderate	R	NR	F	NR	F	F
	Severe	F	NR	R	NR	R	R
Ride	Poor	NR	NR	NR	R	F*	R
Skid	Poor	NR	NR	NR	R	NR	R
ADT	< 5,000	R	R	R	R	R	R
	5,000 – 10,000	R	R	R	R	R	R
	> 10,000	R	R	R	R	R	R
Pavement Condition Thresholds	RSL	10	10	7	12	10	3
	DI	15	15	20	10	15	40
	RQI	54	54	54	54	54	80
	IRI	107	107	107	107	107	212

R - Recommended treatment for the specified pavement condition. How ever, care must be taken to ensure that all critical distress types are addressed by the selected treatment.

R* - Recommended w hen used in conjunction w ith DBR.

F - Feasible treatment but depends upon other project constraints including other existing distresses.

F* - Feasible treatment if poor ride is a result of undow eled joints or faulted transverse (mid-slab) cracking.

NR - Treatment is not recommended to correct the specified pavement condition.

1 - DBR (Dow el Bar Retrofit) is normally used in combination w ith diamond grinding.

2 - CPR (Concrete Pavement Restoration) includes joint and surface spall repairs, joint/crack sealing, full depth repairs and diamond grinding.

A matrix summarizing these factors from the data analysis conducted in this study is shown in table 6.3 for flexible and composite pavements. As discussed in Chapter 3, due to data inconsistency issues and the lack of data in some cases, a similar analysis could not be conducted for rigid pavements.

The following are some of the other factors that should typically be considered when selecting the most appropriate preventive maintenance strategy:

- Availability of quality materials and contractors.
- Time of construction (weather conditions).
- Initial investment.
- Pavement noise.
- Facility downtime.
- Environmental sustainability.

Future Research Directions

Based on the results of this research study, the following recommendations are offered for future research or actions on the part of MDOT:

- A project-level analysis should be conducted on a select sample of all treatments (both good and poor performers) to better explain their performance and to improve specifications.
- It is recommended that MDOT select a few sections from each of the treatments used and designate them as test sections. In addition to helping estimate pavement life extensions and general treatment performance, the optimum timing and condition for placement of various treatments could also be studied. Such sections would also help in determining the impact of traffic and environment on the performance of the preventive maintenance treatments.
- Training workshops on the proper treatment placement techniques can be conducted to ensure consistent performance.

Recommended Implementation Plan

Suggestions for implementation are included in Appendix C to this report. These suggestions focus on recommended changes to the CPM Manual and to the data collection practices and various databases where pavement-related data are stored.

Concluding Remarks

In this project the performance and benefits of various preventive maintenance treatments used by MDOT as a part of its CPM program were evaluated, as was the overall effectiveness of MDOT's CPM Program. MDOT's Distress Index was used as the primary measure of performance, and the concept of service life extension from the application of various treatments was also considered. The benefit of applying selected CPM treatments was calculated by comparing the improvement in pavement performance as modeled by the increase in the DI over time compared to the change in DI over time of the same category of pavement without preservation.

The findings document when various CPM treatments are cost effective as well as when in the life of a pavement CPM may no longer provide a benefit. The results should help decision makers to apply MDOT's CPM program as well as develop improved guidance for its implementation.

Table 6.3. Other performance and cost factors to be considered during treatment selection.

Treatments	Average Pavement Life Extension (Years)		AverageTime to Next CPM Tretment (Years)		Percent Benefit over Pre-Treatment Performance		Average Unit Cost (per yd^2)
	Flexible Pavements	Composite Pavements	Flexible Pavements	Composite Pavements	Flexible Pavements	Composite Pavements	
HMA Overlay (non-structural)	3.6 to 4.0	2.2 to 4.2	6.5 to 6.9	4.5 to 7.8	35 to 49	12 to 21	$3.59
HMA Mill and Overlay (non-structural)	7.8 to 7.9	3.6 to 8.5	5.6 to 8.2	5.0 to 5.5	49 to 79	26 to 68	$4.34
Ultra- Thin HMA Overlay			2.3 to 2.7				$2.29
Single Chip Seal	2.7 to 6.6		5.5 to 5.6	4.7	15 to 63		$1.31
Double Chip Seal	6.9	1.9	4.6 to 7.3	5.7	40	32	$2.27
Single Micro-surfacing							$1.56
Multiple/ Heavy Single Micro-surfacing							
Double Micro-surfacing	1.8 to 7.8	9.8 to 11.6	5.3 to 5.5	2.8 to 5.8	22 to 61	49 to 56	$2.35
Paver Placed Surface Seal				3.1			$4.70
Crack Treatment	0.6 to 2.8	0.9 to 2.1	4.2 to 5.0	5.2 to 8.0	4 to 12	5 to 21	$0.26
Overband Crack Filling							$0.29

Notes:

(1) Data available for this study was insufficient to populate the cells shaded in grey. Information on typical life-extensions for the treatments that could not be evaluated in this study is available in the MDOT CPM Manual (MDOT 2010). Conversions for crack treatment and HMA mill and OL to costs per yd^2 are explained previously.

(2) The average pavement life extension statistics have been derived using the performance models developed in this study. The pavement life extensions were derived using the Distress Index as the only performance indicator. It is recognized that a CPM treatment can be triggered by any of a number of different performance indicators, such as rutting, friction, or IRI, and it is understood that analyzing performance solely based on a composite measure such as the DI has some inherent limitations.

(3) Since ultra-thin HMA overlays and paver-placed surface seal treatments are relatively newer treatments in the MDOT CPM program, the average time to the next CPM values reported may be lower than actual values since around 60 percent of the projects were still in service as of 2010.

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APPENDIX A. ANNOTATED BIBLIOGRAPHY

Baladi, G. Y., T. Svasdisant, T. Van, N. Buch, and K. Chatti. 2002. "Cost-Effective Preventive Maintenance: Case Studies." *Transportation Research Record 1795.* Transportation Research Board. Washington, DC. p. 17-26.

With most of the highway systems in place, emphasis has shifted from design and construction to preservation and expansion. Unfortunately, the engineering skills, knowledge, and experience required to preserve the systems are significantly different than those required to originally design and build the systems. The experience gained in the initial phase, although important, is not in itself sufficient to preserve the systems. Pavement preservation is defined as the sum of all activities undertaken to provide and maintain serviceable roadways. This includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects. A cost-effective pavement preservation program requires a systematic and comprehensive engineering management of, and a solution to, pavement network problems. Preventive maintenance (PM) is defined by the American Association of State Highway and Transportation Officials as the "planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity)." Hence, PM actions must be taken on pavements in relatively good condition. The development and implementation of a cost-effective PM program faces several obstacles: political debate, budget constraints, lack of education, and the existing practice of "worst pavements are first." Some state highway agencies have overcome these obstacles, and they are harvesting the success of their PM programs. The state of the practice of three agencies--those of Arizona, Montana, and Pennsylvania--is presented and discussed.

Bausano, J. P., K. Chattti, and R. C. Williams. 2004. "Determining Life Expectancy Of Preventive Maintenance Fixes For Asphalt-Surfaced Pavements." *Transportation Research Record 1866.* Transportation Research Board. Washington, DC.

A large performance data set from in-service pavements was used in conducting a reliability-based analysis to determine the life expectancy (performance) of several preventive maintenance (PM) fixes. The distress index (DI)--the main pavement performance indicator used by the Michigan Department of Transportation--was used in the analysis. Probability distributions of DI values were developed at successive years after the PM application for five fixes: nonstructural bituminous overlay, surface milling with a nonstructural bituminous overlay, single chip seal, multiple-course microsurfacing, and bituminous crack seal. Reliability tables were then developed to express the probability that a given PM treatment would reach the performance threshold after n years; these tables therefore provide the pavement life expectancy for a given PM treatment at various reliability levels. A highway agency can use these tables to select PM strategies on the basis of expected life extensions.

Belshe, Mark, Kamil E. Kaloush, Jay S. Golden, Michael S. Mamlouk, and Patrick Phelan. 2007. "Asphalt-Rubber Asphalt Concrete Friction Course Overlays as Pavement Preservation Strategy for Portland Cement Concrete Pavement." *Transportation Research Board 86th Annual Meeting.* 07-1916. Transportation Research Board. Washington, DC.

The Arizona Department of Transportation's (ADOT) "Quiet Pavements" projects have been highly successful with the traveling public in addressing roadway noise. In placing a thin layer, usually less than 1", of Asphalt Rubber - Asphaltic Concrete Friction Course (AR-ACFC) over existing Portland Cement Concrete Pavement (PCCP), ADOT has reduced the noise impact to the surrounding neighborhoods from urban freeways by as much as 4 to 6 decibels. The use of specialized pavement mixtures to address a purely quality-of-life issue is dynamic and innovative, and the program has been remarkably well received by the taxpayers and users of the roadway network. However, one unintended consequence of the overlay program may be to significantly extend the life of the PCCP due to mitigation of daily thermal variances. By adding an additional, easily maintained layer, or "blanket", over the PCCP, the underlying material will experience higher low temperatures and lower high temperatures. It is well known that temperature variations significantly lessen with depth, and the addition of even just a ¾" AR-ACFC layer may favorably affect the lower reaches. Thermally induced stresses to PCCP can be very damaging, and anything that would lessen the temperature swings would be very beneficial. Given the large investment in the PCCP infrastructure by ADOT for the Phoenix metropolitan freeway system, the dividends of extended pavement life and lowered maintenance costs could result in a substantial savings. This study included a field instrumentation effort with pavement temperature sensors to quantify the thermal behavior of the PCCP with and without the AR-ACFC overlays. Using established formulas for calculating the thermally induced curling stresses, the benefit to the overall pavement behavior is modeled, and the overlay strategy viewed as a pavement preservation tool is summarized.

Bhattacharya, Biplab B., Michael P. Zola, Shreenath Rao, Karl Smith, and Craig Hannenian. 2009. "Performance of Edge Drains in Concrete Pavements in California." *National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 145-160.

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Bolander, Peter W. 2005. "Seal Coat Options: Taking Out the Mystery." *First National Conference on Pavement Preservation*. *Transportation Research E-Circular No. E-C078.*

Many seal coat treatments and products are available for today's parking lot or road facility manager to provide an aesthetic surface or use for preventative maintenance. In order to understand what treatment to use it is imperative to understand how these treatments differ. This ranges from understanding their basic bitumen components to the typical additives used to the sand or aggregate sizes unique to each seal coat treatment. The Pacific Northwest Region of the U.S. Department of Agriculture Forest Service (USDA-FS) has applied many seal coat treatments and has found that successful seal coats can be applied if the components are understood, if the components are compatible, if they are applied to the appropriate surface, and if proper construction methods are followed. To assist facility managers in their seal coat treatment decision making process the basic components are addressed for each seal coat treatment as well as recommended locations of use, application rates, and construction tips based on the past experiences of the Pacific Northwest Region of the USDA-FS.

Burnham, Thomas and Bernard Izevbekhai. 2009. "Retrofit Dowel Bars in Jointed Concrete Pavement--Long-Term Performance and Best Practices." *National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 161-182.

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Fog seals are a method of adding asphalt to an existing pavement surface. Their purpose is to improve sealing or waterproofing, prevent further stone loss by holding aggregate in place, or improve the surface appearance. Inappropriate use of fog seals can lead to slick pavements and tracking of excess material. Fog seals are designed to coat, protect, and/or rejuvenate the existing asphalt binder. This report discusses fog seal project selection, fog seal materials and specifications, fog seal construction process, and trouble shooting. Appendices offer suggested field considerations.

Chan, Arthur, Gregory Keoleian, and Eric Gabler. 2008. "Evaluation of Life-Cycle Cost Analysis Practices Used by the Michigan Department of Transportation." ***Journal of Transportation Engineering*****. Vol. 134 No. 6. American Society of Civil Engineers. pp 236-245.**

Life-cycle cost analysis (LCCA) has become a common practice in road construction at the state level during the past decade in the United States. It enables pavement engineers to conduct a comprehensive assessment of long-term costs, and ideally agency highway funding can be allocated more optimally. Michigan Department of Transportation (MDOT) has adopted LCCA in the pavement selection process since the mid-1980s, yet its application in actual projects has not been reviewed. Using case studies, this paper seeks to analyze MDOT's accuracy in projecting the actual costs over the pavement service life and choosing the lowest-cost pavement alternative. Ten highway sections in Michigan were chosen and grouped into four case studies. Their estimated and actual accumulated costs and maintenance schedules were compared. While results indicate that MDOT LCCA procedure correctly predicts the pavement type with lower initial construction cost, actual costs are usually lower than estimated in the LCCA. This outcome may be partly because the cost estimation module in MDOT's model is not site specific enough. Refinements to its pavement construction and maintenance cost estimating procedures would assist MDOT in realizing the full potential of LCCA in identifying the lowest cost pavement alternatives for the pavements studied.

Chang, Jia-Ruey, Dar-Hao Chen, and Ching-Tsung Hung. 2005. "Selecting Preventive Maintenance Treatments in Texas: Using the Technique for Order Preference by Similarity to the Ideal Solution for Specific Pavement Study-3 Sites." ***Transportation Research Record 1933.*** **Transportation Research Board. Washington, DC. pp 62-71.**

Although the cost-effectiveness of preventive maintenance (PM) treatments for pavement is important, literature addressing this issue is limited. Even under the well-controlled Federal Highway Administration (FHWA) long-term pavement performance (LTPP) study, incomplete data and sections exist. Criteria for selecting PM treatments often conflict and have to be compromised. The multiple criteria decision-making (MCDM) method is one of numerous approaches available for resolving variations of results. The technique for order preference by similarity to ideal solution (TOPSIS), an MCDM method, was used to analyze successfully all 14 specific pavement study (SPS)-3 sites in Texas. The distress score (DS), international roughness index (IRI), and treatment costs were used as criteria to determine the cost-effectiveness of various PM treatments (thin overlay, slurry seal, crack seal, and chip seal). With TOPSIS, the cost-effectiveness of these treatments can be quantified, with variations caused by subjective judgment thus minimized. When all criteria were considered, the most and least cost-effective methods were chip seal and slurry seal, respectively. When cost was not considered, the most and least effective methods were chip seal and crack seal, respectively. The chip seals performed the best. Chip seals had the most forgiving qualities of all the methods, and they yielded no reflection of the cracking that preceded the treatment applications. The evaluation based on TOPSIS provides a viable option for engineers determining the best PM treatments for pavement in need of maintenance.

Chen, D-H., D-F. Lin, and H-L. Luo. 2003. "Effectiveness of Preventative Maintenance Treatments Using Fourteen SPS-3 Sites in Texas." ***Journal of Performance of Constructed Facilities*****. Vol. 17 No. 3. American Society of Civil Engineers.**

14 Texas SPS-3 test sites were studied to determine effectiveness of preventative maintenance treatments (PMTs). These sections were built on 4 highway classifications (IH, US, SH, and FM) in different climates and with different levels of traffic and subgrade support. Almost all 14 SPS-3 sites were given PMTs (thin overlay, slurry seal, crack seal, and chip seal) in Fall 1990. The distress score concept used by the Texas Department of Transportation (TxDOT) was adopted in this study to judge the effectiveness of PMTs. TxDOT has used this concept since the early 1980s, though the utility factors have been revised few times. The distress score quantifies the visible surface wear due to traffic and environmental influences. Only very few sections experienced premature failures on the SPS-3 sites in Texas. In many cases, superior underlying pavement conditions have been found. The chip seal has the most sites in which it is rated the best performer. The chip seals performed well on a wide range of pavement conditions. In fact, chip seals have the highest distress score for both high and low traffic areas. When initial cost is considered, crack seal provides the best alternative for low traffic routes that have a sound underlying pavement structure. For high traffic routes, chip seal is a better choice. However, a thin overlay is the most effective for rut resistance. Since the thin overlay has the highest initial cost, it is best used on high traffic routes where rutting is a major concern. If rutting is not a concern, chip seal is the best choice for a high traffic area. The treatments applied to US84 sections were too late and did not reach 7 years of life as normally was expected, which reconfirms that the timing for PMT is very important.

Cooper, Samuel B. Jr. and Louay N. Mohammad. 2005. "Performance Evaluation of Novachip Surface Treatment in Louisiana." ***First National Conference on Pavement Preservation. Transportation Research E-Circular No. E-C078.***

The Novachip (Trademark) is a surface treatment process that was developed in France in 1986. This process increases skid resistance and seals old pavement surfaces, and since 1986 has been used widely in Europe on high-speed, high-volume roadways. This paper documents the 5-year performance of two surface treatment types: the Novachip (Trademark) and conventional mill and overlay treatments on routes with similar average daily traffic (ADT) and service life. Three projects located on state route LA-308 in Lafourche Parish were selected for this evaluation. The performance indicators considered included rutting, alligator cracking, random cracking, transverse cracking, and smoothness as determined by international roughness index (IRI). A Life-Cycle Cost Analysis (LCCA) was conducted in order to compare the Novachip (Trademark) surface treatment process with the conventional surface treatment process of mill and overlay. In general, both surface treatments provided similar performance indicators as measured by rutting, cracking (alligator, random, transverse), and IRI. Based on the LCCA, the Novachip (Trademark) surface treatment provided significant cost savings when compared to the conventional surface treatment process of mill and overlay.

Croteau, J., P. Linton, J. K. Davidson, and G. Houston. 2005. "Seal Coat Systems in Canada: Performances and Practice." ***Annual Conference of the Transportation Association of Canada*****. Calgary, Alberta.**

This paper describes how seal coat systems have been used in Canada and other countries for many decades. In fact, the development of the seal coat system is closely associated with the increased usage of the automobile. Today, seal coating it is the most common type of roadway surfacing in Canada. Seal coat is a thin wearing course made of superimposed layers of aggregate and bituminous binder. This type of treatment may be used to restore the surface characteristics of existing worn out roadway or to waterproof and preserve an existing roadway. They may be applied onto an existing bound material or an unbound road base. This type of treatment forms an impervious thin overlay over an existing bound or unbound surface. Seal coat systems may be divided into two families of treatments: the chip seal system and graded seal systems. Chip seals combine the application of a layer of calibrated chips onto a layer of a cationic rapid setting bitumen emulsion while the graded seals are systems that combine the application of a dense graded or gap graded aggregate onto a layer of anionic high float type bitumen emulsion. Each system may be applied as a single application or a multiple application. Seal coat systems may be applied at spread rates that range from 14 kg/m2 for a single chip seal applied onto an existing bituminous surface to 40 kg/m2 for a double high float seal treatment applied onto an unbound granular base. Many parameters such as the traffic and the existing surface conditions must be taken into account in the design of a specific seal coat system for a given roadway. Field adjustments are also very important; field conditions such as ambient temperature, the time of the year, the sun/cloud conditions must be taken into account as well. The success of this type of treatment is not only associated with the selection of an optimal design but also with the close attention to the local conditions during the field application. This paper presents an overview of the seal coating technologies and a discussion on the state of the practice including, design practices, construction procedures of these surface treatments in Canada and abroad. In addition, the paper introduces new concepts related to the selection of seal coating systems as well as the emerging chip sealing systems now available in North America.

Cuelho, E., R. Mokwa, and M. Akin. 2006. "Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice." Project #8117-26. Minnesota Department of Transportation.

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, the District of Columbia 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 preventive 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.

Davies, R. M. and J. Sorenson. 2000. "Pavement Preservation: Preserving our Investment in Highways." *Public Roads*. Vol. 63 No. 4. Federal Highway Administration. p. 37-42.

Highway agencies are redefining their objectives, requiring them to focus on preserving and maintaining rather than expanding the existing highway system. As a component of system preservation, pavement preservation is aimed at preserving the investment in the highway system, extending pavement life, and meeting the customers' needs. It is the timely application of carefully selected surface treatments to maintain or extend a pavement's effective service life. In addition to establishing a pavement-preservation philosophy, other issues must be addressed to ensure the proper implementation of a pavement-preservation program. A major hurdle in establishing a pavement-preservation program is dedicated funding. The success of a pavement-preservation program is based on selecting the right treatment for the right pavement at the right time. To determine the optimal timing, performance standards and indices for various treatment types need to be established through research and the collection of performance data. In the future, pavement contractors may be required to guarantee the performance of a pavement for a specified service life. Pavement preservation must be integrated into the overall pavement management system (PMS) to allow highway officials to manage pavement conditions as part of managing their resource allocations. By using an integrated PMS, a manager can select the proper proportion of preventive maintenance, corrective maintenance, rehabilitation, and reconstruction that optimizes available dollars and extends the service life of the pavements within the system.

Davis, L. 2003. "Protecting Roads in the Desert: Chip Sealing over Fabric Retards Reflective Surface Cracks." ***TR News.*** **No. 228. Transportation Research Board. Washington, DC.**

In 1987, the County of San Diego, California, Department of Public Works developed test sections on Yaqui Pass Road to evaluate the performance of several surface treatments. The goal was to find a treatment to retard reflective surface cracks under desert conditions. While all of the treatments used sealed the road surface well, only chip seal over fabric eliminated reflective surface cracks. Moreover, a 30-year life-cycle cost analysis showed that the annual cost was one-half that of chip sealing with crack sealing. This article provides further details on the fabric properties, fabric placement, chip seal placement and product performance.

Davis, Lita. 2005. "Chip Sealing over Fabric in Borrego Springs, California." ***First National Conference on Pavement Preservation. Transportation Research E-Circular No. E-C078.***

This paper discusses the County of San Diego's practice of placing pavement reinforcing fabric, followed by chip sealing and fog sealing, on roads located in the county's desert area of Borrego Springs, California. Due to extreme desert temperature variations and exposure to flash floods, surface cracks on the asphalt road surface are a routine occurrence, and crack sealing is a constant road maintenance issue. The cost to seal the numerous surface cracks reduces the funds needed to apply a surface treatment to the entire road surface. In 1987, the county conducted a study of placing various surface treatments on desert roads to determine which address surface cracks and also seal the entire road surface. It was found that placing pavement reinforcing fabric, immediately prior to placing a chip seal, prevented surface cracks from reflecting through the new road surface treatment, and prevented moisture from penetrating into the pavement and underlying base. It was also discovered that considerable savings were experienced by not having to crack seal before or after the placement of the pavement reinforcing fabric. This paper addresses the placement of pavement reinforcing fabric, in conjunction with chip sealing and fog sealing, via contracts awarded to private construction firms on a competitive bid basis. Life-cycle cost analysis is also addressed.

Erwin, Tara and Susan L. Tighe. 2008. "Safety Effect of Preventive Maintenance: A Case Study of Microsurfacing." ***Transportation Research Record 2044*****. Transportation Research Board. Washington, DC. pp. 79-85.**

Various North American transportation agencies have implemented several preventive maintenance techniques to improve pavement performance and safety. The York Region, located northeast of Toronto, Ontario, Canada, has been resurfacing and remedying pavements with microsurfacing treatments to improve the pavement surface conditions, but without a good understanding of how the treatment affects road safety. With data made accessible by the region, a before-and-after study was done, with the goal of gaining an understanding of how microsurfacing and resurfacing treatments affect road safety. The study concludes that microsurfacing and resurfacing can have a positive safety effect, with crash reduction factors as high as 54%. However, those activities are sensitive to the influence of treatment year data (which may be an anomaly period) and average annual daily traffic per lane. Generally, the findings illustrate that microsurfacing has a positive safety effect on locations susceptible to a number of conditions: regular occurrence of wet or slick (not dry) road surface conditions, a trend toward severe crashes, frequent intersection-related crashes, and a high occurrence of rear-end crashes. Findings of this study have opened the door to additional research; integration of safety under the pavement umbrella seems so logical and yet has barely been explored. For now, the crash reduction factors derived from the study can be applied by the region of York and by other jurisdictions to make more sound decisions at the network level when selecting pavement maintenance treatments.

Federal Highway Administration. 2002A. "Fog Seal Application." FHWA-IF-03-001.

This pavement preservation checklist describes tasks and responsibilities to consider when applying fog seal to pavements. It discusses preliminary responsibilities, preapplication inspection responsibilities, project inspection responsibilities, cleanup responsibilities, and common problems and solutions.

Federal Highway Administration. 2002B. "Microsurfacing Application." FHWA-IF-03-002.

This pavement preservation checklist describes tasks and responsibilities to consider when applying microsurfacing to pavements. It discusses preliminary responsibilities, pre-seal inspection responsibilities, project inspection responsibilities, cleanup responsibilities, and common problems and solutions.

Galehouse, L. 2002. "Strategic Planning for Pavement Preventive Maintenance: Michigan Department of Transportation's 'Mix of Fixes' Program." ***TR News*****. No. 219. Transportation Research Board. Washington, DC. p. 3-8.**

The Michigan Department of Transportation's pavement maintenance program uses a "mix of fixes" approach to meet the public expectations of safe, smooth, and well-maintained roads. This strategy combines long-term fixes (reconstruction), medium-term fixes (rehabilitation), and short-term fixes (preventive maintenance), with the emphasis on preventive maintenance. By applying cost-effective treatments to correct minor pavement deficiencies before the problems become major, the state is able to extend pavement service life and optimize available funds to meet network condition needs.

Geoffroy, D. N. 1996. "Cost-Effective Preventive Pavement Maintenance." ***NCHRP Synthesis of Highway Practice 223*****. Transportation Research Board. Washington, DC.**

This synthesis will be of interest to highway agency executive management including administrative, budget, and finance personnel; pavement design, construction, and maintenance engineers; and maintenance operations personnel, including supervisors and maintenance crew leaders. This synthesis describes the state of the practice with respect to setting a coherent strategy of cost-effective preventive maintenance for extending pavement life. This report of the Transportation Research Board describes the practices of state, local, and provincial transportation agencies that are attempting to minimize the life-cycle costs of pavements and are identifying, during the design of the pavement rehabilitation, reconstruction, or construction projects, the future preventive maintenance treatments and the timing and funding for those treatments. It includes a review of domestic literature and a survey of current practices in North America. The appendices include a primer on pavement design and construction, the benefits of preventive maintenance of pavements, a summary of the questionnaire data collected, a simulation of pavement management strategies, and an example process to demonstrate the cost-effectiveness of preventive maintenance.

Gransberg, Douglas D. 2005. "Chip Seal Program Excellence in the United States." *Transportation Research Record 1933*. Transportation Research Board. Washington, DC. pp. 72-82

A survey of U.S. public highway and road agencies that use chip seals as a part of their roadway maintenance program was developed and conducted to identify best practices in chip seal design and construction. A total of 72 individual responses from 42 U.S. states and 12 U.S. cities and counties were received; of those, nine respondents reported that they were getting excellent results from their chip seal programs. Those responses were grouped together and analyzed by the case study method to identify trends that lead to consistently excellent chip seal results. The study found that the successful chip seal programs had much in common. They use chip seals as a preventive maintenance tool, applying them to roads before distress levels were classified as moderate. They require their contractors to use the latest technology, and they exploit advances in material science such as the use of modified binders. And most of them use chip seals on both high- and low-volume roads.

Gransberg, Douglas D.. 2009A. "Comparing Hot Asphalt Cement and Emulsion Chip Seal Binder Performance Using Macrotexture Measurements, Qualitative Ratings, and Economic Analysis." *Transportation Research Board 88th Annual Meeting*. 09-0411. Transportation Research Board. Washington, DC.

This paper reports the results of a chip seal research project in Texas where the researchers are using quantitative, qualitative and economic means to compare hot asphalt cement and emulsion chip seal binder performance on rural roads. The Transit New Zealand T/3 "sand circle" test was used to measure the change in average texture depth over time for the two binder types and these measurements were then correlated with a qualitative windshield survey and Texas Department of Transportation's Pavement Management Information System ratings. The results demonstrate the value of quantitatively characterizing the preseal surface condition as a benchmark against which to compare new chip seal performance. They also show that relying on purely qualitative pavement ratings can introduce errors into the pavement management system. The project found that those roads, regardless of the binder type used, that had poor preseal conditions and low macrotexture showed early loss of macrotexture and premature flushing after a reseal. It also found that the emulsion chip seals lost their macrotexture over time more slowly than the hot asphalt cement chip seals. Finally, an economic analysis of the two sample sets showed the emulsion chip seals to be the more cost effective alternative for maintaining satisfactory macrotexture over time.

Gransberg, Douglas D.. 2009B. "Life-Cycle Cost Analysis of Surface Retexturing with Shotblasting as a Pavement Preservation Tool. *Transportation Research Board 88th Annual Meeting*. 09-0409. Transportation Research Board. Washington, DC.

This paper explores the economics of replacing chip sealing and thin hot-mix asphalt overlays for highways with surface retexturing using the same shotblasting technology that is used on airport pavements. This technology is able to restores both the microtexture and macrotexture on pavements that have lost skid resistance due to polishing. An economic analysis of typical highway is conducted to determine the life cycle costs of using various options for the hypothetical project. The study utilizes the Federal Highway Administration pavement life cycle cost methodology and reports the results in Net Present Value basis to compare each skid restoration alternative. The analysis is conducted on two levels. First a traditional deterministic life cycle cost analysis is completed and it is followed by a stochastic analysis of life cycle cost using a Monte Carlo simulation. The paper concludes that shotblasting is an economically viable alternative to traditional methods for restoring lost skid resistance. It also allows the desired engineering objective to be achieved without the consumption of additional asphalt binder or aggregate thus making it an environmentally sustainable alternative as well.

Grove, Jim, Jim Cable, and Peter Taylor. 2009. "Concrete Pavement Patching--Simpler Can Be Better." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. p. 358.**

No abstract available.

Hansen, K. 2004. "Pavement Preservation through Prevention." ***HMAT, Hot Mix Asphalt Technology.*** **Hot Mix Asphalt Technology.**

Hot mix asphalt (HMA) overlays are the most versatile pavement preservation techniques available. The advantages include added structural capacity, sealed cracks, improved ride, enhanced skid resistance, noise reduction, and improved drainage. The thickness of overlays can vary, depending on strength and capacity needs. The thickness and condition of the existing pavement determine the increase in structural value. The article gives examples of non- typical HMA overlays that have been developed and used. It describes how Smoothseal, a thin dense-graded overlay was used in Ohio; the use of asphalt rubber, which is a blend of liquid asphalt and ground tire rubber, in Arizona; and an ultra-thin overlay application in Michigan.

Hicks, R. G., T. V. Scholz, and J. Moulthrop. 2001. "Preventive Maintenance Versus Reconstruction: Life Cycle Cost Analysis of Various Options." ***National Pavement Preservation Forum II: Investing in the Future.*** **FHWA-IF-03-019. Federal Highway Administration.**

Life cycle cost analysis is increasingly being recognized by public agencies as an effective tool to assist in the selection of construction, maintenance, and rehabilitation treatments. The Federal Highway Administration has developed a life cycle cost analysis methodology that will likely become the standard in the industry in the USA. The methodology can be used to evaluate the life cycle costs strategies including preventative maintenance, rehabilitation, and reconstruction. For preventative maintenance treatments to be more widely accepted, they must not only extend the life of the existing pavement, but also be shown to be cost effective, i.e., lower life cycle cost than the alternates. This paper presents: 1) an identification of preventative maintenance treatments and their benefits; 2) a description of the life cycle cost analysis process utilized in this study; and 3) comparative results that evaluate the life cycle cost for pavements that receive preventative maintenance treatments applied early on in the life of the pavement compared with those that receive only major rehabilitation/reconstruction strategies. The findings indicate that preventative maintenance at early stages in a pavements life is cost effective in all of the scenarios studied. However, the reader should be aware that the estimated lives and costs used in this study are based on presently available information and engineering judgment. Deviations from these values could affect the final conclusions.

Hossain, Shabbir and Celik Ozyildirim. 2009. "Evaluation of Concrete Pavement Repair using Precast Technology in Virginia." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements.*** **April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 335-348.**

No abstract available.

Irfan, Muhammad, Muhammad Bilal Khurshid,, and Samuel Labi. 2009. "Service Life of Thin Hot-Mix Asphalt Overlay Using Different Performance Indicators." ***Transportation Research Board 88th Annual Meeting.*** **09-2359. Transportation Research Board. Washington, DC.**

The use of thin hot-mix asphalt (HMA) overlay as a preventive maintenance treatment is gaining wide acceptance in the United States and abroad. Pavement management and maintenance practitioners seek quantitative means to assess the effectiveness of this and other treatments in order to plan, program and budget for pavement preservation in the long term. This paper synthesizes past studies on thin HMA overlay service life and discusses the service life of thin overlay treatments applied in a state in the mid-western United States in 2001-2006. The study, carried out separately for three functional classes: Interstates, non-Interstate National Highway System (NHS), and Non-NHS, uses three performance indicators: International roughness index (IRI), pavement condition rating (PCR), and Rut depth. The study finds that the thin HMA treatment service life is 7-10 years (on the basis of IRI); 7-11 years (on the basis of PCR); 8-11 years (on the basis of Rut depth). These values are based on the application of following thresholds: 110 in/mi (IRI), 85 (PCR), and 0.25 in. (Rut depth), respectively. Using the survival model, a probabilistic approach was tested to capture the stochastic nature of the post-overlay deterioration and thus to investigate the variability in the life of that treatment. Furthermore, the results suggest that the service life of thin HMA overlays is non-linearly related to traffic loading and that differences in climatic severity can have significant impact on the service life of the treatment.

Jain, P. K., A. K. Jain, and C. Kamaraj. 2008. "Pavement Preservation Utilising Cost Effective Crumb Rubber Modified Bitumen Seals: A Pilot Study." ***ARRB Conference, 23rd*****. Adelaide, South Australia.**

A pilot study is conducted to investigate the techno-economic feasibility of application of crumb rubber modified bitumen (CRMB) as stress alleviating membrane (SAM) and substitute to thin hot mix overlay. This study aims at optimization of blend of bitumen and crumb rubber (CR), design of blending system for preparation of blend at site, optimization of quantity of blend to be used with respect to severity of cracks and distress. Findings of the study reveal that 10 per cent CR powder by weight of binder, having 0.15-0.60 millimetre (mm) size, is an optimum blend. The periodic performance study of test sections indicate that performance of single coat SAM is comparable to 25 mm thick hot mix overlay and may last for about 3-4 years on a busy National Highway. Also, it uses 66 per cent less bitumen and saves 58 per cent of the cost of maintenance. The details are discussed in the paper.

Jung, Youn su, Dan G. Zollinger, and Thomas J. Freeman. 2009. "Evaluation and Decision Strategies for the Routine Maintenance of Concrete Pavement." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements.*** **April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 117-132.**

No abstract available.

Kennedy, Kevin. 2005. "Warranty Administration in the Michigan Department of Transportation's Capital Preventive Maintenance Program." ***First National Conference on***

***Pavement Preservation*. *Transportation Research E-Circular E-C078.* Michigan Department of Transportation. pp. 114-119.**

Preventive maintenance (PM) is a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without substantially increasing structural capacity. The Michigan Department of Transportation (MDOT) established its Capital Preventive Maintenance (CPM) program to preserve the structural integrity and extend the service life of the state trunkline network through a series of construction contracts. The program was initiated in 1992 with an approximate budget of $8 million and has grown to $77 million in 2004. Future budgets are projected to be $81 million in 2005, $85 million in 2006, and $89 million in 2007. In addition, there will be $43 million of additional Preserve First funds spent on PM in 2005-2007. Preserve First is a program that puts increased emphasis on preservation of MDOT's existing transportation system rather than expanding it. It was instituted in 2003 due to budgetary concerns and the department's goal of having 90% of roads in good condition by 2007. Warranties play a major role in the department's CPM program. With the growing number of warranty projects, the task of administering warranties and tracking the status of warranties is becoming increasingly important and increasingly difficult. Recognizing the importance of uniform criteria for administering warranties and reporting on warranties, the department created the Statewide Warranty Administration Team and has developed the Statewide Warranty Administration Database (SWAD). SWAD has been operational since October 2003. Through a series of canned reports that are produced monthly, it allows the department to track when warranty inspections are due, when warranties expire, and warranties that have had corrective action completed. These reports provide information on a statewide basis and also can break down information by region and by individual offices within a region (transportation service centers). The reports list projects with warranties (active and closed), total number of warranties (active and closed), warranties in conflict resolution, warranties requiring inspections (interim and final), and warranties with corrective action completed. In addition, SWAD allows the department to obtain detailed information on individual warranties. Contractors are also allowed access to the database to assist them in managing their warranty projects. The information provided to contractors is for informational purposes only and contractors must agree to a disclaimer stating such before entering SWAD. Tracking warranties in the CPM program aids the department in making good decisions regarding project selection. The department has an annual call for projects in which the regions submit candidate projects for road and bridge projects. CPM projects are submitted only a year in advance to try to ensure that the right fixes are being done on the right pavements at the right time. By tracking performance of warranty projects through SWAD, the department can determine where corrective action has been needed and determine areas of concern regarding performance. This is important to verify the appropriateness of project selections and to maximize the life extension of the CPM fixes and improve overall network pavement condition.

Kim, Y Richard and Jaejun Lee. 2008. "Quantifying the Benefits of Improved Rolling of Chip Seals." FHWA/NC/2006-63. Federal Highway Administration.

This report presents an improvement in the rolling protocol for chip seals based on an evaluation of aggregate retention performance and aggregate embedment depth. The flip-over test (FOT), Vialit test, modified sand circle test, digital image processing technique, and the third-scale Model Mobile Loading Simulator (MMLS3) are employed to evaluate the effects of the various rolling parameters and to measure chip seal performance. The samples used to evaluate the chip seal rolling protocol were obtained directly from field construction. In order to determine the optimal rolling protocol, the effects of roller type, number of coverages, coverage distribution on the sublayers of a multiple chip seal (i.e., the split seal and triple seal), and rolling pattern are evaluated using the results of aggregate retention performance tests, the modified sand circle method, and the digital image process. It is found that two types of roller, the pneumatic tire roller and the combination roller, are recommended as the optimal rollers for the chip seal. In addition, it is found that the optimal number of coverages for the chip seal is three coverages. Moreover, the performance of the triple seal without coverage at the bottom layer does not affect the aggregate retention performance, although the split seal does require coverage at the bottom layer. Finally, it is found from the MMLS3 results that the delayed rolling time between the spreading of the aggregate and the initial rolling significantly affects the aggregate loss, and that the delayed rolling time is related to the aggregate moisture condition and the ambient temperature. Effects of different rolling patterns are investigated based on the delayed rolling time and roller speeds, and recommendations are developed for two- and three-roller scenarios.

Kreis, Doug, Lenahan O'Connell, and Brian Howell. 2005. "Long-Term Maintenance Needs Planning." KTC-05-25/RSS8-02-IF. University of Kentucky, Lexington.

This research contributes to Kentucky's knowledge base of long-term maintenance needs in two parts. Part 1 presents an estimate of the average revenue needed to maintain four categories of highway in the first fifteen years after each is built or resurfaced. Total maintenance costs per mile for four types of facilities in five annual average daily traffic (AADT) volume categories were estimated. The results suggest that Kentucky is not resurfacing all its roads in a timely manner. Part II presents background information on preventive maintenance programs in the states. A review of the states found two recurring themes. The first was the widespread adoption of two types of preventive measures: thin overlays and crack sealing. The second theme was the adoption of maintenance schedules to ensure timely maintenance. The report recommends the development of a routine pavement maintenance program with three elements: (1) more timely resurfacing, (2) scheduled inspections of drainage and ditching, and (3) crack sealing. It is also recommended that the Kentucky Transportation Cabinet adopt the American Association of State Highway and Transportation Officials (AASHTO's) recommended performance criteria and targets for sub-drainage assets.

Kucharek, Anton S., J. Keith Davidson, Peter Linton, and Ted Phillips. 2007. "Resurfacing of Highway 127 in Ontario Using a High Performance Double Chip Seal." ***Fifty-Second Annual Conference of the Canadian Technical Asphalt Association (CTAA).***

This paper, from the proceedings of the 52nd Annual Conference of the Canadian Technical Asphalt Association (CTAA), reports on a project that used high-performance, double-chip seal for the resurfacing of Highway 127 in Ontario, Canada. Highway 127 is a two-lane roadway between Maynooth and Highway 60 in Eastern Ontario which carries 1,600 Average Annual Daily Traffic (AADT) with 8.5 percent commercial vehicles. Prior to 2006, the pavement surface consisted of moderate to severely oxidized hot-mix asphalt, with non-uniform, heterogeneous sections. The Ministry of Transportation, Ontario (MTO) Eastern Region chose to use double chip seal treatment for a 16.4 km section of this road as a way to improve surface characteristics but also as a holding strategy before having to proceed with full road rehabilitation. The project included aggregate-binder compatibility testing and surface treatment performance testing. The seal used a CRS-2P emulsion with Ontario Provincial Standard Specification (OPSS) 304 Class 1 aggregate for the first lift and a 1/4-1/8" chip for the second lift. The authors describe the stages of this project, outlining the laboratory work and the several design methods incorporated, and emphasizing how the project parameters led to adjustments in binder application rates. They conclude by discussing the construction stage, including equipment calibration, materials application and process control, traffic control and logistical aspects.

Labi, Samuel, Godfrey Lamptey, Sravanthi Konduri, and Kumares C. Sinha. 2005. "Analysis of Long-Term Effectiveness of Thin Hot-Mix Asphaltic Concrete Overlay Treatments." ***Transportation Research Record 1940.*** **Transportation Research Board. Washington, DC. pp. 3-12.**

Thin hot-mix asphalt (HMA) concrete overlays are preventive maintenance treatments used to address minor distresses, increase ride quality, and extend pavement life. This paper determines the long-term effectiveness of such treatments by using three measures of effectiveness: treatment service life, increase in average pavement condition, and area bounded by the performance curve. For each measure of effectiveness, the pavement performance indicators used are the international roughness index (IRI), rutting, and pavement condition rating (PCR). For each measure of effectiveness and performance indicator, treatment benefits were found to lie within a wide range because of the effect of varying levels of weather severity, traffic, and route type. The service life of the treatment ranges from 3 to 13 years (IRI performance indicator), 3 to 14 years (rutting), and 3 to 24 years (PCR). When the increase in average pavement condition is used as the measure of effectiveness, the results show that such treatments offer 18% to 36% decrease in IRI, 5% to 55% reduction in rutting, and 1% to 10% increase in PCR. For the area enclosed by the performance curve, thin HMA overlay effectiveness ranges from 40 to 360 IRI years (where IRI is in inches per mile), 0.13 to 0.76 RUT years (where RUT is in inches), and 7 to 130 PCR years (where PCR is on a 0 to 100 scale). The wide ranges of thin HMA overlay effectiveness for each combination of measure of effectiveness and performance indicator is suggestive of the sensitivity of the treatment effectiveness to levels of traffic loading and weather severity, and route type. The effectiveness of thin HMA overlay treatments is of interest to pavement professionals and is a vital input in the quest for cost-effective long-term pavement preservation practices.

Labi, S., G. Lamptey, S-H Kong, and Charles Nunoo. 2006. "Long-Term Benefits of Microsurfacing Applications in Indiana - Methodology and Case Study." ***Transportation Research Board 85th Annual Meeting.*** **06-2390. Transportation Research Board. Washington, DC.**

Microsurfacing is a relatively new technology. As such, there is great interest in assessing its efficacy as a preventive maintenance treatment. This paper investigates the long-term benefits of microsurfacing applications at various highway sections in Indiana. The measures of effectiveness (MOE) used are treatment life, increase in average condition, and area bounded by the treatment performance curve. Each MOE was expressed separately in terms of three performance indicators - surface roughness (IRI), Pavement Condition Rating (PCR), and Rutting (RUT). The results show that for each MOE and performance indicator, the treatment effectiveness is influenced by climate, traffic loading, and highway class. The results also show that the effectiveness of microsurfacing is most perceptible when rutting is used as the performance indicator. When treatment service life is used as the MOE, microsurfacing effectiveness ranges from 2-10 years (on the basis of the IRI performance indicator); at least 15 years (on the basis of rutting); and 4-15 years (on the basis of PCR). When the increase in pavement condition is used as the MOE, the treatment is seen to offer 7-27% and 90-96% reductions in surface roughness and rutting, respectively, and a 2-7% increase in PCR. Finally, when the area enclosed by the microsurfacing performance curve is used as the MOE, it is seen that this treatment offers benefits of 30-258 IRI-years, 15-67 RUT-years, and 18-56 PCR-years (IRI in inches per mile, RUT in inches, and PCR in units on a 0-100 scale). The case study results generally demonstrate that microsurfacing is a promising treatment in addressing rutting and in extending pavement life in general.

Labi, S., M. I. Mahmodi, C. Fang, and C. Nunoo. 2007. "Cost-Effectiveness of Microsurfacing and Thin Hot-Mix Asphalt Overlays: Comparative Analysis." ***Transportation Research Board 86th Annual Meeting.*** **07-3265. Transportation Research Board. Washington, DC.**

Microsurfacing and thin hot mix asphalt (HMA) overlays are categories of flexible pavement preventive maintenance that involve an aggregate-bituminous mix laid over the entire carriageway width. This paper presents and demonstrates a methodology for comparing the long-term cost effectiveness of two competing pavement treatments using three measures of effectiveness (MOE) - treatment service life, increase in average pavement condition, and area bounded by the performance curve, and two measures of cost - agency cost only and total cost (agency plus user costs). Only non-interstate pavement sections are considered in the study, and each MOE is expressed in terms of International Roughness Index (IRI) values. For all measures of treatment effectiveness where costs are expressed only in term of agency cost, irrespective of climate severity and traffic loading, it was found that microsurfacing is consistently more cost-effective compared to thin HMA overlays,. An exception occurs when increase in pavement condition is used as the MOE and when both traffic volume and climate severity are high. Under these conditions, thin HMA overlay appears to be more cost-effective. The superiority of microsurfacing in terms of cost is most evident when treatment life is the measure of effectiveness and least evident when increased pavement condition is used. Microsurfacing also appears to be more cost-effective under low traffic loading and low climatic severity. The study methodology results offer significant implications in the field of pavement design, engineering and management. Highway agencies are continuously striving to develop decision trees and matrices for intervention, and it is sought to carry out these tasks on the basis of rational cost and effectiveness analysis rather than subjective opinion. The development of such decision mechanisms can facilitate the design of preventive maintenance strategies for more cost-effective decisions that are based on life-cycle costs and benefits.

Lee, D. and K. Chatti. 2001. "Development of Roughness Thresholds for Preventive Maintenance Using PMS Data from In-Service Pavements." ***Fifth International Conference on Managing Pavements*****.**

In this paper, 462 pavement sections from thirty-seven projects in Michigan were analyzed to investigate the interaction between pavement surface roughness and distress. The main hypothesis of this research is that an increase in roughness leads to higher dynamic axle loads, which in turn can lead to a tangible acceleration in pavement distress. If this relationship is established, then it will be possible to plan a preventive maintenance (PM) action to smooth the pavement surface. Such a PM action is bound to extend the service life of the pavement by several years. The objectives of this research were to: (1) test the above hypothesis; (2) develop a roughness threshold; and (3) determine the optimal timing of the PM action. The selected projects include thirteen rigid, fifteen flexible and nine composite pavements. The Ride Quality Index (RQI) and Distress Index (DI) were used as measures of surface roughness and distress, respectively. The analysis showed good relationships between dynamic load-related distress and roughness for rigid and composite pavements (R^2 = 0.739 and 0.624); however for flexible pavements there was significant scatter (R^2 = 0.375). A logistic function was used to fit the data. Roughness thresholds were determined as the RQI-values corresponding to peak acceleration in distress. These were determined to be 64 for rigid pavements and 51 for composite pavements. A model for selecting the optimal timing of PM action was developed based on the reliability concept. The model uses actual RQI growth rates from 1382 rigid-pavement sections.

Lei, A. 2001. "Adding to the Tool Box: Paver-Placed Surface Seals for Strategic Pavement Maintenance." ***National Pavement Preservation Forum II: Investing in the Future*****. FHWA-IF-03-019. Federal Highway Administration.**

For the past five years the City of San Jose has been engaged in a strategic effort to improve the pavement condition of its street network. From the onset of the program, the primary challenge has been the need to optimize limited resources by utilizing the preservation techniques that have the most impact in increasing the service life of the network. This has required that the "tool box" used in the City's pavement preservation efforts be continuously examined and augmented with more effective techniques. Prior to 1999, the preservation techniques predominantly used in the City's maintenance program were chip seal for local streets, slurry seal for arterial and collector streets and pavement resurfacing for both categories if warranted. In 1999 a new maintenance treatment called "paverplaced surface seal" was assimilated into the maintenance toolbox. Asset management requires that effective maintenance treatments be employed. Carefully assimilating new pavement preservation materials and processes into the maintenance toolbox should be part of the process. For the City of San Jose the paver-placed surface seal preservation technique is now an integral part of the preventative maintenance toolbox. Assimilating this new and innovative technique into the pavement maintenance program has resulted in savings to the pavement recovery program.

Lukanen, Erland O. 2007. "Preservation Effects on Performance of Bituminous over Aggregate Base Pavements in Minnesota." ***Transportation Research Record 1991.*** **Transportation Research Board. Washington, DC.**

Use of the Minnesota Department of Transportation pavement management data to evaluate the effect of pavement preservation activities on pavement performance is described. Evaluation focuses on bituminous over aggregate base pavements constructed between 1985 and 2005. Pavement data were initially divided into subsets of data: one for pavements with no preservation and the other for pavements that received preservation. The subset that included preservation activities was further subdivided for comparison into those that received thin mill and overlay or thin overlays and those that did not. Data analysis showed that preservation improved pavement performance and that thin overlays and thin mill and overlays were the preservation treatments that provided the greatest performance improvements but were used for the poorest performing pavements.

Mamlouk, M. S. and John P. Zaniewski. 2001. "Optimizing Pavement Preservation: An Urgent Demand for Every Highway Agency." ***International Journal of Pavement Engineering*****. Vol. 2 No. 2. Gordon and Breach Science PUB.; Taylor & Francis Limited. p. 135-148.**

Preventive maintenance (PM) can both improve quality and reduce the expenditures for a pavement network. PM is based on the concept that periodic, inexpensive treatments, such as seals, are more economical than infrequent, high-cost procedures such as reconstruction. This paper presents a step-by-step procedure for selecting the appropriate PM treatment for asphalt pavement and evaluating the optimal timing for that treatment under different pavement, traffic, and climatic conditions. The information provided here can be a useful tool for highway engineers and superintendents in developing a PM program to maximize the cost-effectiveness of maintenance treatments. Typical examples of pavement distresses are presented showing appropriate treatments that can be used. A model is also presented to provide the basis for analysis of the cost-effectiveness of a pavement PM program.

Morian, D. A., J. A. Epps, and S. D. Gibson. 1997. "Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations, National Report." FHWA-RD-96-208. Federal Highway Administration. Washington, DC.

This report presents an evaluation of the performance of Strategic Highway Research Program (SHRP) SPS-3 and SPS-4 experiment sites based on field reviews after 5 years of performance. Condition evaluation of the sections and Expert Task Group performance estimates are the basis for treatment assessments.

Morian, Dennis A., James W. Mack, Tanveer Chowdhury. 2005. "The Role of Pavement Preservation in Privatized Maintenance." ***First National Conference on Pavement Preservation. Transportation Research E-Circular No. E-C078.***

The concept of privatized maintenance took hold in the late 1980s when the Virginia Department of Transportation awarded the first such contract, and within 2 years a second contract, for the preservation of 350 centerline miles of Interstate highways 95 (I-95), I-77, and I-81 in Virginia. The idea of these privatized maintenance contracts was to provide the contractor a fixed level of funding, and to establish a minimum pavement performance level that had to be maintained. While some sections required rehabilitation work, maximizing the use of pavement preservation strategies for suitable pavement sections is a key to successfully managing a pavement system with fixed funds. This paper discusses the application of pavement preservation strategies such as timely crack sealing, chip seals, and microsurfacing, and the valuable role pavement preservation has played in achieving the pavement performance and budget management objectives of privatized maintenance contracts. The discussion includes criteria for identifying the appropriate application of specific pavement preservation treatments. Pavement performance monitoring information from the project pavement management system is also provided, documenting the success of these treatments in preserving pavement condition level in a cost-effective manner, while at the same time providing an excellent tool for cash flow management.

Outcalt, W. 2001. "SHRP Chip Seal." CDOT-DTD-R-2001-20. Colorado Department of Transportation.

This report is a follow-up to an earlier study that examined the effectiveness of preventive maintenance treatments. The Colorado test site consisted of three 250 m long test sections and one untreated 250 m long control section. Section I used lightweight chips made of expanded shale having a unit weight 60% of the standard chips. Sections II and III used standard weight chips. HFRS-2P emulsion was applied at 0.35 gal/sq yd on all sections. Chips were applied at the rate of 12 lb/sq yd on Section I and at the rate of 25 lb/sq yd on Sections II and III. Section III included a fog seal of HFRS-2P emulsion diluted 1:1 and applied at 0.05 gal/sq yd. The site was evaluated visually and through the use of skid testing, falling weight deflectometer, and profilograph equipment. The following results are based on observations of this site over a four-year period. Both lightweight and standard chip seals extend the life of the pavement by postponing environmentally induced cracking. The advantages in the use of lightweight chips would be reduced windshield damage compared with standard chips, and lower haul costs because they weigh less than 50% of standard chip weight. There is no apparent long term advantage to applying a fog coat over a standard chip seal. The K.J. Law skid trailer readings for all sections were high (from 55.9 to 62.5). There was no measurable rutting in all sections. In general, the treated sections were in better condition than the untreated section at the time of the final evaluation in August of 2001. There is very little chip loss in any of the three test sections, except for some small areas in the standard chip section, where a piece of farm equipment was apparently dragged on the surface for a short distance. There is no bleeding or rutting. In the summer, many cracks, in all three test sections, partially reseal due to traffic action.

Peshkin, David G. 2006. "Assessment of Research Project SPR 371, Maintenance Cost Effectiveness Study." FHWA-AZ-06-371. Applied Pavement Technology, Incorporated; Arizona Department of Transportation; Federal Highway Administration. 54 p.

In 1995, the Arizona Department of Transportation (ADOT) initiated research project SPR 371, "Maintenance Cost Effectiveness Study". That project identified the maintenance surface treatment alternatives suitable for evaluation by ADOT, developed a consensus on which alternatives to test, evaluated the performance and cost effectiveness of those treatments, and identified procurement issues that inhibit effective pavement maintenance. As part of that study, during a period from 1999 to 2002, over 200 bituminous test sections were constructed at different locations in Arizona, including wearing courses (Phase I), surface treatments (Phase II), and sealer-rejuvenators (Phase III). While a significant effort was made to develop and construct the test sections associated with the various experimental Phases, there has been less success in monitoring these test sites and either drawing appropriate conclusions about performance and closing them out, or continuing treatments and monitoring the test sites, as was originally planned. In this report, available documentation and data from the "Maintenance Cost Effectiveness Study" were collected and reviewed. The overall experimental phases are described, each experiment and test site is summarized, and recommendations are made for either continuing the Phase or closing it out and drawing appropriate conclusions. Overall, the potential of the findings from these various experiments to contribute to more cost effective pavement preservation practices, better specifications and construction practices, and even more cost-effective agency practices, are all reasons for better documenting these experiments and concluding them according to a rational research plan.

Peshkin, David G., Todd E. Hoerner, and Kathryn A. Zimmerman. 2004. "Optimal Timing of Pavement Preventive Maintenance Treatment Applications." ***NCHRP Report No 523*****. Transportation Research Board, National Research Council. Washington, DC.**

This report describes a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements. The methodology is also presented in the form of a macro-driven Microsoft (registered trademark) Excel Visual Basic Application--designated OPTime--available to users by accessing the National Cooperative Highway Research Program (NCHRP) website (http://trb.org/news/blurb_detail.asp?id=4306). The methodology is based on the analysis of performance and cost data and applies to any of the treatments and application methods that are used by highway agencies. A plan for constructing and monitoring experimental test sections is also provided to assist highway agencies in collecting the necessary data if such data are not readily available. The report is a useful resource for state and local highway agency personnel and others involved in pavement maintenance and preservation.

Peshkin, David G., Angie Wolters, Cesar Alvarado, and Jim Moulthrop. 2009. "Pavement Preservation for High Traffic Volume PCC Roadways: Phase 1 Findings from SHRP 2 Project R26." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****." April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 133-144.**

No abstract available.

Pierce, Linda M. 2009. "Load Transfer Restoration--A Survey of Current Practice and Experience." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 207-222.**

No abstract available.

Pool, P. A. 2001. "Preventive Maintenance is Key to Pavement Preservation." ***National Pavement Preservation Forum II: Investing in the Future*****. FHWA-IF-03-019. Federal Highway Administration.**

The California Department of Transportation (Caltrans) is transitioning from the "worst first" and reactive mode to preserving and maintaining their pavement. Caltrans maintains an integrated Pavement Management System (PMS) and Geographic Information System. These databases identify pavement conditions and needs. The GIS maps are used to display the pavement needs, project type, and project locations. Caltrans is also in the process of implementing the departments Pavement Asset Management System. Caltrans is developing family curves to group pavements with similar characteristics; this process will assist Caltrans in and establishing a statewide Pavement Condition Index (PCI). The PCI will work in conjunction with the International Ride Index (IRI), and the Pavement Condition Survey (PCS) in establishing performance goals for Caltrans pavements. These components will assist the department with project selection, project timing, and cost-effective treatments and strategies, while optimizing maintenance and construction dollars. Caltrans continues to improve their efforts in preserving the state highways, with innovative strategies for preventive maintenance and pavement preservation, while identifying the optimal timing for treatments and repairs.

Priya, R., Karthik K. Srinivasan, and Amrithalingam Veeraragavan. 2008. "Sensitivity of Design Parameters on Optimal Pavement Maintenance Decisions at the Project Level." ***Transportation Research Record 2084*****. Transportation Research Board. Washington, DC. pp. 47-54.**

Sensitivity analyses are important parts of both studying complex systems and measuring the variation in input parameters on the response. They are useful to decision makers for understanding the robustness of the optimal solution that they are to adapt to variations of the parameters of the problem. The sensitivity of the optimal solution of a project-level pavement management problem is analyzed, and the robustness of the optimal solution to the interventions and the timing, cost, and benefit are investigated. The input parameters, which affect the optimal maintenance solution, are identified as the structural and functional condition parameters (defined in terms of deflection and roughness, respectively, at the beginning of the analysis period), traffic volume, growth rate, and discount rate. The problem of computing the optimal treatment and timing for a given budget level is modeled as a mixed integer nonlinear optimization problem and solved by using a computationally efficient network-optimization technique. The benefits are evaluated by considering the pavement performance and are quantified as the area between the performance curve and the threshold values. The optimal budget required for pavements in different structural and functional conditions as well as traffic levels is presented. The effect of initial pavement condition on the optimal maintenance actions as well as their timings is studied. The result of the sensitivity analysis showed that the cumulative standard axle loads and traffic growth rate have a significant effect on the selection and timing of rehabilitation and preventive maintenance actions. The effect of the discount rate on the maintenance management decisions is also presented.

Rawool, S. and R. Stubstad. 2009. "Effect of Diamond Grinding on Noise Characteristics

of Concrete Pavements in California." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 235-248.**

No abstract available.

Romero, Pedro and Doug Anderson. 2005. "Life Cycle of Pavement Preservation Seal Coats." UT-04.07. Utah Department of Transportation.

The use of preservation seals on asphalt pavements is a crucial part of any effective pavement management program. It is important to optimize the use of available budgets to extend the life of our pavements as much as possible. The nation's highway system is one of our most valuable assets. Analysis of the performance of surface treatments on Utah pavements indicates that Open Graded Surface Courses (OGSC) have an average life, based on skid resistance of almost 9 years and that Chip Seal Courses (CSC) have a significantly longer life. Out of all the factors analyzed, traffic has the most significant effect on the performance of the treatment. Factors such as aggregate source and asphalt supplier were also investigated but lack of data prevented from reaching any significant conclusion. Based on the relative cost of both treatments and the performance observed through this study, it is recommended that Utah Department of Transportation (UDOT) expand the use of CSC to certain roads with average annual daily traffic counts (AADTs) up to 20,000 vehicles and continue the existing procedure of using CSC in highway sections with AADTs below 5,000. It is also recommended that UDOT modify the existing policies and limit the use of OGSC where the running speeds are 55 mph or greater and AADTs are in excess of 25,000 vehicles. Medium volume facilities (5,000 to 25,000 AADT) should be sealed with treatments new to UDOT but proven in other states. An initial cost analysis showed that the implementation of the changes suggested as part of this report will result in savings of over $2 million per year in the maintenance budget, thus allowing for better use of resources while still serving the traveling public.

Ruranika, Malaki Musa and Jerry Geib. 2007. "Performance of Ultra-Thin Bounded Wearing Course (UTBWC) Surface Treatment on US-169 Princeton, MN." MN/RC 2007-18. Minnesota Department of Transportation.

This report evaluates the performance of 1999 and 2000 ultra-thin bounded wearing course (UTBWC) surface treatment on US-169 in Princeton, Minnesota. The UTBWC consisted of gap graded coarse aggregate hot mix asphalt over a heavy asphalt emulsion layer and it was placed at an average thickness of 3/8 ". For comparison purposes, a control section was established to assess the performance of the overlay. This section continues to be maintained using standard sealing and patching techniques. The surface roughness and condition of these sections have been monitored on yearly basis. The overall performance of the UTBWC sections has been very good, while the control section is currently in need of major rehabilitation. The UTBWC appears to provide an economical choice for pavements in need of minor rehabilitation. In addition, UTBWC may prove beneficial as a preventive maintenance option. It should be considered for all sections with minor cracking and roughness distresses that do not stem from subgrade problems. Nationwide research has shown that UTBWC reduces deterioration caused by weathering, oxidation, and traffic, and provides good skid resistance, reduced rolling noise, reduction of hydroplaning, and back spray from roadway. UTBWC does not increase the structural capacity of the pavement, however, the use of UTBWC on new pavements as a wearing course could be considered.

Senadheera, S. 2006. "Surface Treatments in Asphalt Pavements - A Systems View." ***10th International Conference on Asphalt Pavements.*** **August 12 To 17, 2006. Quebec City, Canada.**

Many highway agencies of the world use surface treatments in their pavements, both as preventive maintenance treatments and as wearing courses in new construction and rehabilitation. The primary advantages of surface treatments are their low cost and rapidity of construction, both of which are extremely important to highway agencies. This paper looks at surface treatments in pavement engineering from a systems viewpoint by discussing the characteristics of surface treatments including its proper use, design, materials selection, contractor expertise, construction processes, quality control, pavement performance and most importantly, training of personnel. To understand the role of surface treatments in pavement engineering, it is important to adopt a systems approach that takes into consideration all the factors indicated above. The author was involved in two comprehensive constructability reviews of surface treatments in preventive maintenance and new construction of asphalt pavements adopted a systems approach and involved the development and delivery of training programs to pavement professionals. In addition, the author has conducted research studies involving the selection of materials for surface treatments, and on quality control and quality assurance of asphalt binders in these applications.

Shatnawi, S., M. Stroup-Gardiner, and R. Stubstad. 2009. "California's Perspective on Concrete Pavement Preservation." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO.**

No abstract available.

Shuler, Scott. 2006. "Evaluation of the Performance, Cost-Effectiveness, and Timing of Various Preventive Maintenances: Interim Report." CDOT-DTD-R-2006-6. Colorado State University, Fort Collins; Colorado Department of Transportation; Federal Highway Administration.

This research is being conducted to evaluate the performance of various preventive maintenance treatments over time and under different environmental conditions to assess the economics of each treatment type. The first three tasks of this research are nearing completion. Task 1 is a review of the state of the practice for preventive maintenance. This review includes a conventional literature survey and interviews of maintenance and construction personnel throughout the state. Task 2 is a draft manual of best practices of pavement preventive maintenance and Task 3 includes selection and construction of full-scale test pavements for field evaluation of various preventive maintenance treatments. Results of Task 1 indicate there are three primary techniques utilized in Colorado for preventive maintenance of asphalt pavements and three for concrete pavements. For asphalt pavements these are: 1) crack sealing, 2) chip seals, and 3) thin hot mix asphalt overlays. For concrete pavements these are: 1) joint resealing, 2) cross-stitching, and 3) micro-grinding. Task 2 has resulted in a preliminary draft of what will become a best practices manual for the preventive maintenance techniques currently used in Colorado as well as additional methods used by other agencies. Full scale test sections were constructed as part of Task 3 in 2005 and some additional test sections previously constructed were also included for measurement of future performance. These test sections include crack sealing, chip seals, thin overlays, joint resealing, cross-stitching and micro-grinding. This in an interim report of research in progress. Implementation is not warranted at this time.

Shuler, Scott. 2008. "A Study of Chip Seal Performance at High Elevation." ***International Sprayed Sealing Conference, 1st*****. Adelaide, South Australia.**

Chip seals are used extensively in the US for preventive maintenance. However, damage due to snow plows, wet and cold weather and extensive solar radiation contribute to poorer performance than at lower elevations. Therefore, an experimental program was begun to evaluate these and other factors affecting long term performance of chip seals. Fog seals are often placed on chip seals in the US immediately after chip sealing, but the benefits have not been well documented. Also, chip seals often do not adhere to reflective paint marking after sealing. This paper describes an experimental pavement constructed to evaluate the performance of a chip seal placed at the top of Poncha Pass (elevation 9012 ft/2745 m) and also at the bottom of the pass (elevation 6825 ft/2081 m) to evaluate the benefits of fog sealing and removal of reflective paint markings prior to sealing. Twenty test sections were constructed in all to evaluate the performance of the seals with and without fog sealing, with and without paint removal, with controls. Results indicate that fog sealing may be effective when placed after chip sealing and that reflective paint removal is the only effective method to assure against chip loss due to reflective paint.

Shuler, Scott. 2009. "Short-Term Performance of Three Crack Sealants in Three Climates Using Several Installation Techniques." ***Transportation Research Board 88th Annual Meeting*****. 09-0689. Transportation Research Board. Washington, DC.**

One of the most effective methods of asphalt pavement preservation is crack sealing. Sealing cracks in asphalt pavements helps reduce moisture and debris infiltration into the pavement structure resulting in increased life expectancy of the pavement. However, there are many crack sealants and several methods of installation available. To help answer this question an experiment was designed to evaluate performance of three crack sealants placed in three environments using three distinct installation procedures and two methods of crack filling resulting in three factorials with eighteen treatments per location. Each supplier of crack sealant was instructed to bring the materials, equipment and personnel necessary to successfully install each of the products in six cracks per each of the treatment combinations for a total of 108 cracks per location. The objective of the experiment was to determine short and long term performance characteristics of each combination of material, method and location. Two methods were used to measure performance. These included evaluating the amount and severity of cracking as a function of the original filled crack length, and the Sealant Condition Number. Results indicate that performance suffers when the heat lance is used in preparation of crack filling at the temperatures utilized and that performance improves when the sealant is squeegeed over the crack after air blowing or routing. Routing the crack prior to sealing appears to improve performance. The surprisingly poor five month performance of some of the crack sealant methods indicates that some pavements may not be sealed as well as some believe.

Smith, K. L., L. Titus-Glover, M. I. Darter, H. L. Von Quintus, R. N. Stubstad, and John P. Hallin. 2005. "Evaluation of the Cost Benefits of Continuous Pavement Preservation Design Strategies versus Reconstruction." FHWA-AZ-05-491. Applied Research Associates, Incorporated; Arizona Department of Transportation; Federal Highway Administration.

The Arizona Department of Transportation (ADOT) has traditionally employed continuous pavement preservation (consisting of a myriad of treatment options that cost-effectively address existing pavement problems) as part of an overall design strategy to maintain the highest levels of service for highway users. However, with concern about the effects of continual weakening of substructure material layers on preservation treatment performance and cost, ADOT sponsored a study to determine the cost-effectiveness of the continuous preservation approach as compared to a reconstruction strategy. Another goal of the study was to determine the break-even point for the continuous preservation and reconstruction strategies (i.e., after how many rehabilitation treatments does reconstruction becomes equally cost-effective as continuous preservation). Using inputs such as pavement performance/life estimated primarily through pavement survival analysis, best estimate unit costs derived from historical data, work zone-related user costs, and a specified analysis period and discount rate, the total life-cycle costs for each of four alternative strategies (one continuous preservation strategy, three reconstruction strategies) for each 15 commonly occurring pavement scenarios in Arizona were determined and compared. The results of the analysis showed a consistent reduction in total life-cycle costs with a corresponding increase (from 0 to 2) in the number of rehabilitations between original construction and the first reconstruction event. Results also showed that for 9 of the 15 scenarios, total life-cycle costs associated with the third reconstruction alternative (i.e., two rehabilitations occurring prior to the first reconstruction event) were within 3 percent (sometimes higher, sometimes lower) of the total life-cycle costs of the continuous preservation strategy. Hence, the break-even point between the two strategies typically occurs after two to three cycles of rehabilitation.

Smith, K. L., L. Titus-Glover, M. I. Darter, H. Von Quintus, R. Stubstad, and L. Scofield. 2005. "Cost-Benefit Analysis of Continuous Pavement Preservation Design Strategies Versus Reconstruction." ***Transportation Research Record 1933*****. Transportation Research Board. Washington, DC. pp. 83-93.**

The Arizona Department of Transportation (ADOT) has traditionally employed continuous pavement preservation as part of an overall design strategy to maintain the highest levels of service for highway users. Concerned about the effects of continual weakening of substructure material layers on preservation treatment cost and performance (i.e., more extensive and more frequent preservation activities), ADOT sponsored a study to determine the cost-effectiveness of the continuous preservation approach as compared with a reconstruction strategy. One goal of the study was to determine the break-even point for the two strategies (i.e., after how many rehabilitation treatments reconstruction becomes as cost-effective as continuous preservation). With inputs such as (a) service life estimates, (b) best estimates of unit costs, (c) work zone-related user costs, and (d) the typical analysis period and discount rate used by ADOT, the total life-cycle costs for four alternative strategies were determined and compared for the 15 commonly occurring pavement scenarios in Arizona. The results of the analysis showed a consistent reduction in total life-cycle costs as the number of rehabilitation treatments performed between original construction and reconstruction increased from none to two. Results also showed that for nine of the 15 scenarios, total life-cycle costs associated with the third reconstruction alternative (two rehabilitations occurring prior to the first reconstruction event) were within 3% of the total life-cycle costs of the continuous preservation strategy. Hence, the break-even point occurs when two to three rehabilitation treatments are performed prior to reconstruction.

Tayabji, Shiraz, Neeraj Buch, and Erwin Kohler. 2009. "Precast Concrete Pavement for Intermittent Concrete Pavement Repair Applications." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO. pp. 317-334.**

No abstract available.

Transportation Research Board. 2005. "Preservation of Roadway Structures and Pavements." ***Transportation Research Record 1933.*** **Washington, DC. 133 p.**

This Transportation Research Record contains 14 papers. These papers address the following topics: bridge inspection and evaluation; bridge management tools; managing and evaluating pavement efforts; and crack sealants and Long Term Pavement Performance (LTPP) program results.

Uzarowski, Ludomir, Michael Maher, and Gary Farrington. 2005. "Thin Surfacing - Effective Way of Improving Road Safety within Scarce Road Maintenance Budget." ***2005 Annual Conference of the Transportation Association of Canada*****. Transportation Association of Canada.**

This paper describes how the timely application of preventive maintenance treatments, including thin surfacings, extends the service life of asphalt pavements. Numerous books and technical papers provide descriptions of various types of thin surfacings and other preventive maintenance treatments and show their ability to extend pavement performance curves. However, there is generally a lack of practical examples of thin surfacing applications, including costs involved, the benefits and in what circumstances they should be used for best return on investment. This paper describes the treatments including costs and user benefits, indicates limitations of particular treatments, and provides practical examples of the use of thin surfacings. The benefits include road safety improvements, mainly surface texture and frictional characteristics and correcting surface irregularities.

Wei, C. and S. Tighe. 2004. "Development of Preventive Maintenance Decision Trees Based on Cost-Effectiveness Analysis: An Ontario Case Study." ***Transportation Research Record 1866.*** **Transportation Research Board. Washington, DC. p. 8-19**

Various transportation agencies have begun to consider implementing preventive maintenance (PM) strategies as part of their regular pavement management programs. To determine whether a PM strategy is more cost-effective than a conventional maintenance strategy, various technical and economic analyses were carried out. Currently, most agencies have limited information on the cost-effectiveness (CE) and long-term performance of PM strategies, so it is difficult to determine when and where these treatments should be used. The use of PM treatments based on a CE calculation and analysis is examined, and a decision tree (including treatments and strategies) is developed for each functional pavement class of the Ontario road network. Pavement data from the Ministry of Transportation of Ontario are used to perform a CE calculation for each suggested PM treatment and strategy. On the basis of a comparison and analysis of CE calculation results, guidance is provided on the right treatment, time, and strategy cost level for each functional pavement PM program within the Ontario environment. The results are summarized in the form of a decision tree.

White, Craig and David K. Hein. 2009. "Optimization of Concrete Maintenance to Extend Pavement Service Life." ***National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements*****. April 21-24, 2009. Federal Highway Administration. St. Louis, MO.**

No abstract available.

Wood, Thomas J. and Roger C. Olson. 2007. "Rebirth of Chip Sealing in Minnesota." ***Transportation Research Record 1989.*** **Transportation Research Board. Washington, DC.**

Chip sealing is a common form of pavement preservation used by most cities and counties and by the Minnesota Department of Transportation (MNDOT). MNDOT, working in partnership with the Minnesota Local Road Research Board, was able to rejuvenate the chip seal program in Minnesota. Efforts to improve the performance of chip sealing as a pavement preventive maintenance treatment are discussed. The discussion covers chip seal design, aggregate

characteristics, and training efforts, and the successes of MNDOT, counties, and cities are documented.

Yau, Jyh-Tyng, Eddie Yein Juin Chou, Jyh-Dong Lin, and Jianxiong Yu. 2008. "Pavement Overlay Effectiveness and Optimal Timing Determination Using Receiver Operating Characteristic Curve and Data Envelopment Analysis." ***Transportation Research Board 87th Annual Meeting*****. 08-0436. Transportation Research Board. Washington, DC.**

This study uses the Receiver's Operating Characteristic (ROC) curve and Data Envelopment Analysis (DEA) methods to analyze the factors that affect the performance of asphalt concrete overlays on flexible pavements. The ROC curve method is used to compare the relative importance of the parameters and to determine the appropriate overlay timing. Pavement performances after overlays are categorized as either effective or ineffective, in order to satisfy the binary outcome required by the ROC method. The DEA method is used to help distinguish the effective overlays from the ineffective ones based on the pavement conditions within the first six years after overlay. The results show that timing of overlay and snowfall amount are important to overlay effectiveness for both high traffic and low traffic volume pavement, while overlay thickness is important only for high traffic volume pavements. The optimal condition threshold to perform overlay is slightly higher on low traffic volume pavements than on high traffic volume pavements. Thin (2 inches or less) overlays are not effective on high traffic volume pavements.

APPENDIX B. TREATMENT BENEFIT CALCULATIONS

In this study, the benefit associated with a preventive maintenance treatment was determined using three measures:

- Pavement service life extension (in years).
- Area bounded by performance curve.
- Benefit-cost ratio.

The pavement service life extension is the difference between the expected service life computed using the post-treatment performance models and the expected service life computed using the pre-treatment performance models (do-nothing curve). The service life is computed for a threshold DI value, and in this study a threshold DI value of 40 was chosen to evaluate the performance benefits. This threshold was chosen for two reasons: (a) the majority of the data for preventive maintenance treatments were between a DI value of 0 and 40, so using the models to predict performance for pavement conditions worse than a DI of 40 may not be reliable; and (b) the threshold DI used by MDOT for major rehabilitation activities is 50. Preventive maintenance treatments in general are not expected to perform well for pavements with DI values worse than 50 and the maximum benefit from preventive maintenance is expected to be realized for CPM treatments applied up to DI values of 40.

The benefit area associated with a treatment is determined by comparing the post-treatment area with the total area under the pavement performance curve. The benefit is quantified as the difference between the overall post-treatment area and the associated do-nothing area. The computed benefit area was normalized by presenting it as a percentage benefit over the pre-treatment performance area so that the benefits of various treatments relative to the pre-treatment performance could be compared. The pre- and post-treatment areas were computed using numerical integration techniques (trapezoidal rule).

$$\text{Percent Area Benefit} = \frac{\text{Pre - Treatment Area}}{\text{Post - Treatment Area}}$$

The concept of pavement service life extension and benefit area is illustrated in figure B-1.

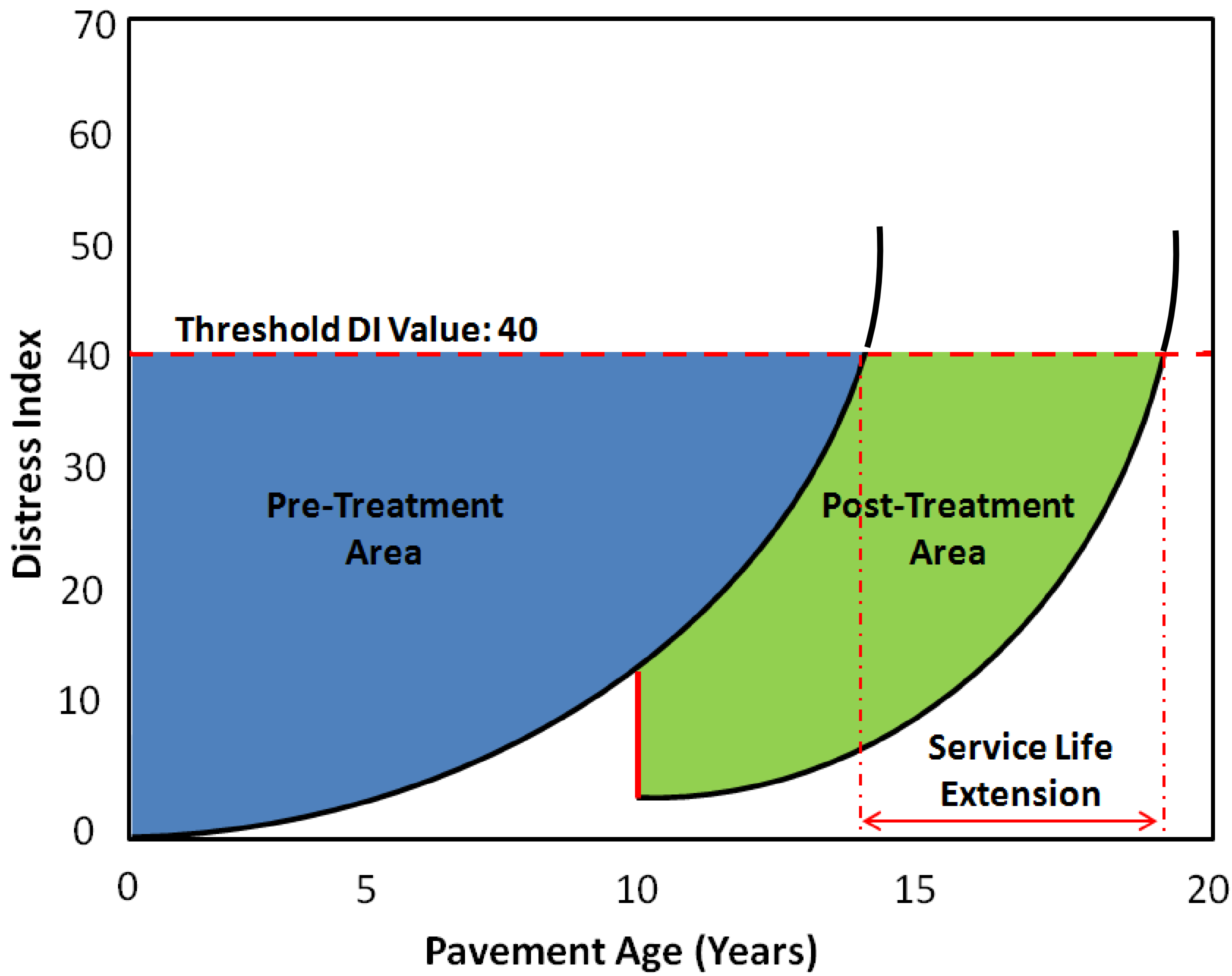

Figure B-1. Illustration of pavement service life extension and benefit area.

The benefit-cost ratio was computed as the ratio between the unit cost of the treatment and normalized benefit area. The higher the benefit-cost ratio, the more cost-effective a treatment is.

$$\text{Benefit-Cost Ratio} = \frac{\text{Percent Benefit Area}}{\text{Unit Cost of Treatment}}$$

APPENDIX C. IMPLEMENTATION PLAN

The initial implementation plan submitted as part of the research proposal is shown in figure C-1. It is recognized that the research discussed in this report does not constitute a standard or include recommendations for wholesale changes in MDOT practice. However, as a result of this project the researchers have revisited the initial implementation plan and offer the following suggestions to MDOT as they relate to the *Capital Preventive Maintenance* Manual and the agency's data collection practices.

Capital Preventive Maintenance Manual

- Add reference to this study in the CPM Manual.
- Verify life extensions for each treatment in the Manual based on this project's findings and decide whether modifications are appropriate.
- Add guidance on selecting treatments based on a determination of benefit-cost ratios, life extensions, and other factors identified in the final report.
- Incorporate tables 6.1, 6.2, and 6.3 into the Manual and develop a process to update the guidance contained therein as CPM program practices continue to be monitored.

Data Collection Practices

Moderate Effort:

- Use consistent labeling of CPM treatments so that they match the treatments covered in the CPM Manual. This will improve the ability to track these treatments and conduct future analyses.

Significant Effort

- Implement a common method of identifying the location of pavement segments across MDOT databases to facilitate creating datasets with complete information.
- Develop a database check so that a segment is flagged when performance measures improve without the application of a treatment.
- Record pre-treatment condition. Information on the pre-treatment condition is essential in determining the impact of the treatment placement as well as in determining after the fact whether the pavement was a good candidate for the applied treatment.

While some changes to MDOT's existing practices can be accomplished without any significant changes, other changes that involve modifications to the pavement management systems database and data collection methodologies are expected to involve significant effort. It is estimated that perhaps 400 to 600 hours of MDOT staff time is required. If MDOT is interested in promoting the use of the CPM Manual based on considerations of benefit-cost ratios and other treatment selection guidelines it will be necessary to develop guidance, perhaps including a training course or online tutorial. It is not expected that this would represent a substantial effort. Finally, MDOT should consider updating this study in 2 to 3 years, preferably after database changes are made to streamline such analyses.

MDOT Michigan Department of Transportation

MICHIGAN DEPARTMENT OF TRANSPORTATION
OFFICE OF RESEARCH AND BEST PRACTICES
IMPLEMENTATION PROJECT RECOMMENDATION (IPR)
FOR INITIAL SUBMISSION WITH RESEARCH PROBLEM STATEMENT

RBP OFFICE OF RESEARCH & BEST PRACTICES

Initiation

ORBP#:	ORE0910	**Date Developed:**	3/7/2013	**Focus Area:**	Maintenance and Operations
Title:	The Cost Effectiveness of the MDOT Preventive Maintenance Program				
Brief Description:	This study is intended to evaluate and rank the cost effectiveness of the treatments used in MDOT's preventive maintenance program as well as MDOT's CPM program through an analysis of available cost and performance data. The results will be summarized in a final report.				
Product source or partial list of relevant documentation:	**Not applicable**				

Planning

Office of Primary Responsibility (OPR) for implementation:	
Implementation Director (ID):	TBD
Implementation level proposed (may choose more than one, provide details)	
Use in test sections on projects	
Use in trial project	A trial project may be developed for use by a Region for a specified period of time. This is not viewed as essential to overall successful implementation. In a trial project, any new guidance on treatment use would be followed by an evaluation of the results. If the actual recommendations are implemented and the results are evaluated this could take a long time. Instead, an alternate approach is to develop annual programs using current and proposed guidelines and then have a panel compare the results to evaluate which they think is more likely to improve the cost effectiveness of MDOT's preventive maintenance practices.
Region-wide use	
Statewide use or statewide impact	The results should be implementable at the State level, as they will be applicable to <u>all</u> Regions. This is best accomplished by revising the CPM and perhaps holding several workshops on implementation of the revisions. The workshops would provide a project overview, highlight the changes that were recommended and why, and then illustrate the use of the treatment matrix to generate a more cost effective CPM program.
Other	

Work plan - MDOT portion

Tasks:	1	Modify CPM manual per project recommendations
	2	Develop implementation plan, which may include a trial effort by one or more regions.
	3	Construct new test sections or identify existing sections for project-level analysis.
	4	Conduct regional training and outreach activities.
Deliverables:	1	Modifications to MDOT's CPM
	2	Training workshops.
Termination Date:		5 years

Work plan - Investigator portion, if needed:

Sole Source Investigator Name or Competitive RFP?		
Tasks:	1	Development of recommendations for altering or modifying MDOT's CPM
	2	Recommendations for trial projects to evaluate revised CPM
	3	Development of training/workshop materials for use by MDOT in disseminating project recommendations
Deliverables:	1	Project Final Report
	2	Implementation Plan
	3	Modified guidance on preventive maintenance treatment use, including a matrix reflecting treatment selection recommendations
	4	Recommendations for changes to the procedures, policies, and/or specifications of MDOT's CPM Program
	5	ORBP Newsletter Article
Termination Date:		September 30, 2012

IPR budget. Provided breakdown by fiscal year.	FY 2012	FY 2015
MDOT Budget Items (describe)		
Training and Outreach Activities		$ 50,000
Update MDOT CPM Manual		$ 25,000
Other - (Construct new test sectios, identify existing projects;MDOT salaries and travel excluded)		$ 100,000
Total budget for MDOT portion (fixed figure)		$ 175,000
Total budget for investigator portion (estimate)	TBD	TBD
Total IPR budget	$ -	$ 175,000

Figure C-1. Proposed implementation plan.