Maintenance Preservation Solution Matrix (MPSM)

FINAL REPORT

2/21/25

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16. Abstract
The goal of this study was to identify optimal preventative treatment types and timing of treatments throughout the service life cycles of pavements. The research was carried out in two phases. Phase 1 involved a comprehensive literature review to examine factors that influence the service life of pavements, including treatment application timing, traffic volume, climatic conditions, material properties, and pre-treatment conditions. The review also documented both traditional and innovative maintenance practices adopted by peer Departments of Transportation (DOTs). Findings from the literature indicated that the service life of a treatment can vary significantly depending on factors such as traffic, climate, construction methods, and materials. The timing of treatment application was found to be a key factor affecting pavement performance. Additionally, a questionnaire was distributed to gather information on innovative treatments implemented by peer DOTs over the past decade. Responses revealed that techniques such as micropaving, microsurfacing, mastics for crack sealing, and sealcoats were among the most widely used preventative maintenance treatments. Phase 2 focused on studying the optimal types and timing of maintenance treatments commonly applied in Pennsylvania. Treatments considered in this phase included seal coats, crack seals, micro-surfacing, and Novachip. Ten years of performance and construction data were analyzed to develop pre- and post-treatment performance curves. These curves were used to assess service life extension for the treatments across different climatic zones and Business Plan Networks (BPNs). Results showed that the extension of service life due to preventative treatments varied based on climatic zone and BPN. Specifically, treatments applied in warmer climates and to pavement networks with higher maintenance priorities (M&R) resulted in greater service life extensions compared to those applied in colder regions with lower M&R priorities. Additionally, the pretreatment Overall Pavement Index (OPI) and pavement age were found to play a critical role in determining service life extension. When treatments were applied within an optimal range of OPI and age, 2-3-fold increase in service life extension was observed across different preventative treatments. Based on the findings, a preliminary Excel®-based tool was developed to assist in selecting the optimal maintenance treatment types and timings, considering factors such as climatic zones, BPNs, pre-treatment OPI, and pavement age. A one-page implementation guideline was created to help PennDOT make informed decisions about the optimal timing and types of preventative maintenance treatments.

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PennDOT ITQ Research RFQ 220720-Maintenance Preservation Solution Matrix

Final Report

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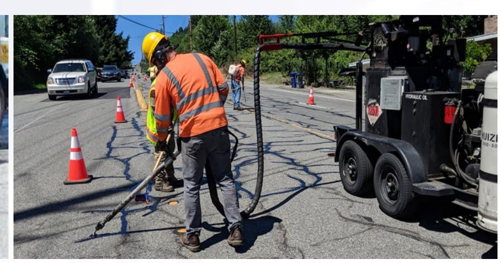

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1 EXECUTIVE SUMMARY

The goal of this study was to identify optimal preventative treatment types and timing of treatments throughout the service life cycles of pavements. The research was carried out in two phases.

Phase 1 involved a comprehensive literature review to examine factors that influence the service life of pavements, including treatment application timing, traffic volume, climatic conditions, material properties, and pre-treatment conditions. The review also documented both traditional and innovative maintenance practices adopted by peer Departments of Transportation (DOTs). Findings from the literature indicated that the service life of a treatment can vary significantly depending on factors such as traffic, climate, construction methods, and materials. The timing of treatment application was found to be a key factor affecting pavement performance. Additionally, a questionnaire was distributed to gather information on innovative treatments implemented by peer DOTs over the past decade. Responses revealed that techniques such as micropaving, micro-surfacing, mastics for crack sealing, and sealcoats were among the most widely used preventative maintenance treatments.

Phase 2 focused on studying the optimal types and timing of maintenance treatments commonly applied in Pennsylvania. Treatments considered in this phase included seal coats, crack seals, micro-surfacing, and Novachip. Ten years of performance and construction data were analyzed to develop pre- and post-treatment performance curves. These curves were used to assess service life extension for the treatments across different climatic zones and Business Plan Networks (BPNs).

Results showed that the extension of service life due to preventative treatments varied based on climatic zone and BPN. Specifically, treatments applied in warmer climates and to pavement networks with higher maintenance priorities (M&R) resulted in greater service life extensions compared to those applied in colder regions with lower M&R priorities. Additionally, the pre-treatment Overall Pavement Index (OPI) and pavement age were found to play a critical role in determining service life extension. When treatments were applied within an optimal range of OPI and age, 2-3-fold increase in service life extension was observed across different preventative treatments.

Based on the findings, a preliminary Excel®-based tool was developed to assist in selecting the optimal maintenance treatment types and timings, considering factors such as climatic zones, BPNs, pre-treatment OPI, and pavement age. A one-page implementation guideline was created to help PennDOT make informed decisions about the optimal timing and types of preventative maintenance treatments.

2 INTRODUCTION

Pavements are subjected to constant traffic load and temperature cycles during its service life. Preventative maintenance treatments are applied to slow down the rate of deterioration and extend pavement service life. In addition, understanding the effect of optimal treatment cycles is essential to maximize pavement performance and optimize long-term maintenance costs.

Preventative maintenance treatments are increasingly used by transportation agencies in the U.S. to preserve and extend the pavement life of the pavement network. Some of the common preventative maintenance treatments used by PennDOT are seal coat, crack seal, micro-surfacing, and Novachip. These treatments are applied in cycles to maintain serviceable condition and extend pavement service life with very low life-cycle cost. Although these treatments are supposed to reduce the life cycle cost of the pavement, that may not be the case if these treatments are not applied at an optimum time intervals. Preventative maintenance treatments are ineffective if applied too late, as structural deficiencies may already have developed in the pavement. Similarly, if applied too early, it may not be as cost efficient (Peshkin et al., 2004). Therefore, determining and maintaining the optimum timing intervals is crucial to maximize the efficiency and cost effectiveness of preventative maintenance. In addition, the effectiveness of preventative maintenance may also depend on other factors including climate condition and traffic level.

Therefore, both factors need to be considered in selecting the appropriate maintenance type and interval time of application.

Considering the interdependencies of various factors playing a crucial role in determining the effectiveness of preventative maintenance treatments, it is important to investigate and analyze maintenance and pavement life cycle data to develop recommended treatment and timing intervals for preventative maintenance treatments. In addition, research is also required to understand any possible relationship between the climate condition, traffic levels and effectiveness of maintenance treatments. It is expected that these investigations will lead to a data-driven decision tree which will allow PennDOT to determine optimum application time intervals of different maintenance treatment. To achieve this goal, following objectives were set:

- Conducting a literature review on optimal types and timings of maintenance treatments used for asphalt and concrete pavements.
- Evaluate the service life extensions of select preventative maintenance treatments for various climate conditions and business plans (BPN).
- Determine the optimum timing of application of different preventative maintenance treatments
- Developing a roadmap for this process.
- Providing initial requirements for an IT solution in accordance with PennDOT requirements.

3 LITERATURE REVIEW

3.1 INTRODUCTION

The Pennsylvania Department of Transportation (PennDOT) is interested in determining the best pavement maintenance strategies for optimizing maintenance cycles and develop recommended treatment and timing intervals for preventative asphalt and concrete maintenance treatments. As a part of this study, a comprehensive literature review was conducted to obtain information related to both tradition and non-tradition maintenance treatments adopted by the Department of Transportations (DOTs) and treatment timings. The literature review includes:

- The effects of traditional maintenance treatments on the surface lives of pavements. The effect of tradition treatments, including but not limited to crack seal, seal coat, chip seal, slurry seal, fog seal was documented.
- The effects of innovative or non-traditional maintenance treatments on the surface lives of pavements. The literature focused on documenting the effect of innovative/non-traditional treatment, including but not limited to micro-surfacing, micro-paving, mastics for patching and crack/joint sealing; and sealcoating on arterials, expressways, or other similar higher-volume routes, and rejuvenator.
- The effect of other factors such as climate, annual average daily traffic (ADT), annual vehicle miles traveled (VMT) and material on optimal types and timings of pavement maintenance treatments.

In addition, a state specific literature search was conducted to document the current management policy adopted by the targeted states. The targeted states were Michigan, Minnesota, Illinois, New York, Ohio, and Wisconsin. The main goal of this task was to document the current pavement treatment policies for these states and conduct a comparative analysis with PennDOT. The analysis also included a review of innovative and non-traditional maintenance treatments piloted or implemented into standard practice by the peer DOTs. Specific treatments included micro-paving, micro-surfacing, mastics for patching and crack/joint sealing, and sealcoating on arterials, expressways, or other similar higher-volume routes. In addition to literature search, a questionnaire survey was conducted among the targeted states to gather information on the practices related to these innovative treatments and any other innovative treatments implemented by the DOTs.

3.2 NATIONWIDE PAVEMENT PRESERVATION PROGRAM

A literature search was conducted to document the pavement treatment practices by the various state agencies in US. Agencies Michigan (MDOT), Minnesota (MnDOT), Ohio (ODOT), Illinois (IDOT), Wisconsin (WDOT), Pennsylvania (PennDOT), Indiana (InDOT), Kansas (KDOT), and Virginia (VDOT). Table 1 summarizes the common treatments used by these agencies.

Table 1. Pavement Treatments Used by Agencies.

Type of Treatments \ State and Agencies	Michigan	Minnesota	Ohio	Illinois	Wisconsin	Pennsylvania	Indiana	Kansas	Virginia
Crack Sealing	x	x	x	x	x	x	x		x
Crack Filling	x	x		x	x				
Fog Seal		x		x					x
Rejuvenator				x					
Slurry Seal				x				x	x
Chip Seal	x	x	x	x	x		x	x	x
Cape Seal				x					x
Micro-Surfacing	x	x	x	x		x	x		x
Polymer Modified Asphalt Concrete			x						
Thin Hot Mix Asphalt Overlay	x	x	x	x	x	x	x	x	x
Ultra-Thin Whitetopping (UTW)		x		x	x				x
Cold Milling				x					x
Full Depth Concrete Pavement Repair				x					
Concrete Joint Resealing	x			x	x	x	x		
Concrete Crack Sealing	x			x	x	x			
Diamond Grinding	x			x		x			
Dowel Bar Retrofit	x					x			
Drainage Preservation		x	x	x					
Concrete Pavement Restoration	x	x	x						

3.3 Expected Service Life

Pavement treatments are expected to increase the pavement service life. The amount of increase in pavement service life depends on the selected treatments since the impact different types of treatment on pavement varies significantly. A comprehensive literature review was conducted to document the expected service life associated with various treatments and is presented in Table 2.

As observed from Table 2, the expected service life of a particular treatment can vary based on the agency, and depends on various factors including traffic, climatic conditions, and construction method and materials (Vicentine et al., 2015). Several past studies have also confirmed that the desired service life of a treatment can be achieved only if the treatment is applied at the right time (Peshkin et al, 2004; Bashar 2018).

Table 2. Service Life of Different Treatments.

<table>
<tr><th rowspan="2">Treatment</th><th colspan="5">Expected Treatment Life (year)</th></tr>
<tr><th>Peshkin et al., (2011)</th><th>MnDOT</th><th>MDOT</th><th>NYDOT</th><th>ODOT</th></tr>
<tr><td>Crack filling</td><td>2-4</td><td>1-3</td><td>up to 2</td><td rowspan="2">2-4</td><td>-</td></tr>
<tr><td>Crack Sealing</td><td>3-8</td><td>2-4</td><td>up to 3</td><td>2-3</td></tr>
<tr><td>Fog seal</td><td>-</td><td>2-4</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Slurry Seal</td><td>3-5</td><td>-</td><td>-</td><td>3-5</td><td>-</td></tr>
<tr><td>Micro-surfacing (Single layer)</td><td>3-6</td><td rowspan="2">5-7</td><td>3-5</td><td rowspan="2">5-8</td><td>5-8</td></tr>
<tr><td>Micro-surfacing (Double layer)</td><td>4-7</td><td>4-6</td><td>-</td></tr>
<tr><td>Chip seal (Single course)</td><td>3-7</td><td>-</td><td>3-6</td><td rowspan="2">2-4</td><td>5-7</td></tr>
<tr><td>Chip seal (double course)</td><td>5-10</td><td>-</td><td>4-7</td><td>-</td></tr>
<tr><td>Thin HMA overlay</td><td>5-12</td><td>8-10</td><td>5-10</td><td>5-8</td><td>8-12</td></tr>
<tr><td>Ultra-thin bonded wearing course</td><td>7-12</td><td>7-12</td><td>4-8</td><td>-</td><td>-</td></tr>
<tr><td>Mastic for Crack and Pothole Repair</td><td>-</td><td>2-8</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Seal coat</td><td>-</td><td>5-7</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fibermat</td><td>-</td><td>-</td><td>3-6</td><td>-</td><td>-</td></tr>
<tr><td>Cape seal</td><td>-</td><td>-</td><td>5-7</td><td>-</td><td>-</td></tr>
</table>

3.3.1 Pavement Treatment Application Timings Recommended by Agencies

Pavement treatments applied at the right time during the life cycle of a pavement is considered effective in increasing the pavement's life. Treatments applied too soon may not be cost effective and treatments applied too late may prove to be incapable of extending the service life of the pavement. Therefore, identifying the optimal time for treatment application is crucial for maximizing the treatment benefit. The National Cooperative Highway Research Program (NCHRP) described a systematic methodology to determine the optimal timing of preventive maintenance treatment application for flexible and rigid pavements. A Microsoft® Excel-based tool, OPTime, was developed that allows users to analyze existing pavement treatment performance data applied over a period of time to find the optimal timing of treatment applications. The methodology also provides a means for comparing the performance and costs associated with the application of specific treatments used by state and local highway agencies at various points in the life (or condition) of a pavement (Peshkin et al. 2004). The timing cycles are also influenced by other factors such as climate, traffic, and construction quality, shown in Table 3.

Table 3. Recommended Timing of Applications (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
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

MnDOT follows a two-step process in identifying the right candidate for applying maintenance treatments. The steps involve assessing the pavement condition and evaluating the assessed condition for decision making. Pavement condition assessment includes identifying the various distress types and their respective severity levels. The type of distresses that are required to assess pavement condition include transverse cracking, longitudinal cracking, multiple/ block cracking, alligator cracking, rutting, patching, and raveling, IRI and weathering. In addition, other details obtained from non-destructive test such as Falling weight deflectometer (FWD) and friction, interviewing the maintenance personnel familiar with the road section may prove critical in determining the optimal time to apply preservation treatments. As a rule of thumb, MnDOT uses the following set of criteria for filtering the appropriate pavement section eligible for preservation treatment.

- Are there excessive distresses (large quantities and/or severe levels of distress) on the pavement section or are the distresses a warning sign of an underlying structural problem?
- Has the time for applying a pavement preservation treatment while it is in “good” condition passed?
- Are there other known problems (e.g., material problems, utility issues, drainage issues, or signs of construction problems)?
- Is there a history of pavement problems in this location?

A pavement section is a good candidate for preservation treatment if answers to majority of the questions is ‘No’ and not considered if the answers to majority of the questions is ‘Yes’.

The Michigan Department of Transportation (MDOT) implement their pavement preservation strategy through its capital preventive maintenance (CPM). Based on the life-cycle-cost (LCC), the preservation strategy results in agency cost savings of approximately 25% per lane-mile over the rehabilitation strategy (MDOT 2013). The pavement service life extension, benefit area and benefit-cost ratios were used to analyze the performance of the CPM treatments on flexible and composite pavements. Overall, HMA mill and overlay and microsurfacing treatments provide the longest service life extension (up to 12 years). HMA crack sealing provided a service life extension of up to 3 years.
Bausano et al. 2004 also studied the life expectancy of various preventive maintenance treatments for MDOT using pavement management system data collected since 1992 based on reliability-based

analysis. The primary factor used in analyzing the performance of various preventive maintenance treatments was Distress Index (DI). The life expectancy of each preventive maintenance treatment was identified by plotting the average DI for each treatment over time. The results indicated overall life extension for a thin HMA overlay, and single-layer chip seals were 5 to 10 years, and approximately 3 years, respectively (Bausano et al. 2004). Table 4 represents the service life extensions obtained from MDOT'S various preventive maintenance treatments (MDOT 2010).

Table 4. Service Life Extension for Various 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	NIA
Surface Milling w/Non-Stn1ctural HMA Overlay	5 to 10	4 to 9	NIA
Single Chip Seal	3 to 6	NIA	NIA
Double Chip Seal	4 to 7	3 to 6	NIA
Regular Single Micro-surfacing	3 to 5	NIA	NIA
Multiple or Heavy Single Micro-surfacing	4 to 6	NIA	NIA
Double Micro-surfacing	NIA	Unknown	NIA
Crack Treatment	0 to 3	0 to 3	NIA
Over band Crack Filling	0 to 2	0 to 2	NIA
Ultra-thin HMA Overlay	3 to 6	3 to 6	NIA
Paver Placed Surface Seal	4 to 6	3 to 5	NIA
Full Depth Concrete Pavement Repair	NIA	NIA	3 to 10
Concrete Joint Resealing	NIA	NIA	3 to 5
Concrete Crack Sealing	NIA	NIA	0 to 3
Diamond Grinding	NIA	NIA	3 to 5
Dowel Bar Retrofit	NIA	NIA	2 to 3
Concrete Pavement Restoration	NIA	NIA	7 to 15

In general, ODOT follows the following guideline (Table 5) for selecting the best candidate for crack sealing, chip seal, or micro-surfacing (ODOT 2022).

Table 5. Recommended Guideline for Application Time of Various Treatments by ODOT.

Crack Seal	Chip Seal	Micro-surfacing
• Pavement Type should be flexible or composite. • PCI range within 65-80 • Avoid chip seal if crack face start showing raveling and secondary crack branches. • Crack seal may not be cost effective if more than 5000 lbs per lane mile of materials is required	• Pavement sections must have low traffic volume and low truck counts. • PCI range within 65-80 • Pavements that exhibit debonding, bleeding, or rutting (>3/8-inch [9.5 mm]) problems are not eligible for chip seal	• PCI range within 65-80

Wisconsin Department of Transportation (WisDOT) Highway Maintenance Program improves the statewide pavement system by performing early-life pavement preservation, late-life pavement preservation, and serviceability improvement treatments. Early-life treatments such as crack fills and chip seals are found to be cost-effective and can extend the pavement life when applied early in the life of appropriate pavement types. Late-life treatments such as crack filling, crack sealing, patch and overlay, or chip seals are also beneficial in terms of cost savings and useful to achieve maximum life cycle of the underlying pavement. The serviceability treatments such as patching, rut paving, short segments of overlay, or aggressive base patching/chip seals are feasible when pavements reach conditions of PCI < 45, IRI ≥ 170 inches/mile, and rutting > 4% medium or high severity rutting (WisDOT Manual, 2018).

The various requirements for seal coat, crack seal, micropaving, microsurfacing, mastics and rejuvenators for specific DOTs are documented in Appendix A.

3.3.2 Effect of Application Time on the Service Life

Several studies have been conducted to demonstrate the application timing or pre-existing condition on the service life of the treatment. Rajagopal (2010) performed a comprehensive study in collaboration with Ohio Department of Transportation (ODOT) to determine the optimal timing and cost effectiveness of chip seal and micro-surfacing. The study recommends application of preservation treatments when the benefit-cost (B/C) ratio is maximum. The B/C ratio of the chip seal and micro-surfacing treatments was obtained as the ratio of area under the performance curve and the cost of treatment (shown in Figure 1).

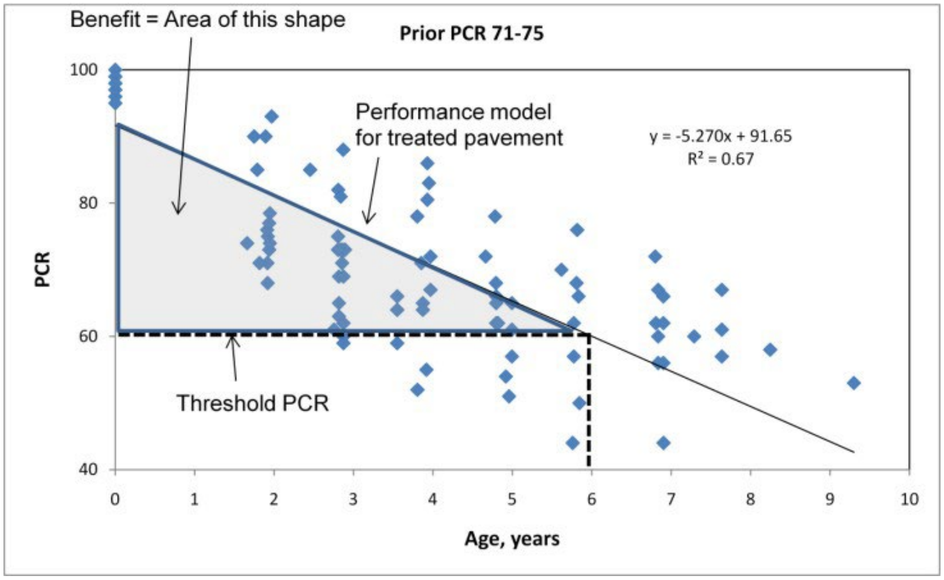


Figure 1. Process of Obtaining B/C Ratio (Rajagopal, 2010).

The study was based on 225 chip seal and 214 micro-surfacing projects in Ohio. Results of the study indicated that chip seal could extend the service life up to 7 years if placed on pavements with a PCI range of 66 to 80. The service life reduced to 4 to 4.5 years when chip was applied on pavements with PCI range of 56 to 65. The maximum B/C ratio was observed when the PCI range before applying chip seal was 71-75.

For micro-surfacing the service life extension was reported to be around 8.5 years if applied on a pavement with PCI greater than 66. On the contrary, the life extension reduced to 3.5 years when micro-surfacing was applied to pavements with PCI range between 56 and 60. Like chip seal, the maximum B/C ratio for micro-surfacing was observed when the PCI before applying microsurfacing was between 71 and 75.

In a recent study, National Center for Asphalt Technology (NCAT) and the Minnesota Department of Transportation's Road Research Facility (MnROAD) investigated the life extending benefit of crack seal, chip seal, and micro-surfacing applied on pavement surface with poor, fair, and good condition. The pavement service life extended by 7.3 and 4.6 years when crack seal was applied on pavement sections in good and fair condition, respectively. However, it was reduced to 1.1 years for pavements in poor condition.

For chip seal, the service life extended by 2.7 years, 5 years, and 0.3 years for pavement sections with good, fair, and poor condition, respectively. Similarly, for microsurfacing, service life extended by 0.5 years, 0.4 years, and 0.3 years for pavement section with good, fair, and poor condition, respectively. It is be noted that the benefits associated with micro-surfacing was not statistically significant as the severity of the distresses associated with the test sections were not significant enough to capture the benefits of micro-surfacing.

Bashar et al., (2018) investigated 51 flexible pavement sections with chip seal and 28 sections with micro-surfacing in Louisiana to identify the optimum timing of application for both treatments. The study observed a pavement service life increase of 6.5 to 10.4 years of with chip seal application.
Results of the study also indicated that the pre-treatment condition was statistically significant in extending the service life. Chip seal was found to be most effective when the pre-treatment PCI was

between 70 and 75. The service life was extended by 4.9 to 8.9 years due to application of micro-surfacing and was most effective on pavements with PCI between 80 and 85. On the contrary, no life extending benefits were observed if micro-surfacing was applied when pre-treatment PCI was more than 90. The study recommended considering annual average daily traffic and pavement thickness as other factors during application of chip seal and microsurface.

Visintine et al., (2015) conducted a comprehensive survey to find out the effect of pre-treatment condition on the service life of the treatment. The study categorized the pre-existing condition into three groups, good (PCI>=80), fair (50<=PCI<80) and poor (PCI < 50). The effect of pre-existing condition on the service life obtained from the survey is summarized in the Table 6. As indicated in Table 6, compared to good pre-treatment condition, the service life of the treatments reduced by 31-36% and 62-64% if the treatments are applied when the pre-treatment condition is fair and poor, respectively.

Table 6. Effect of Pre-Treatment Pavement Condition on Treatment Performance (Visintine et al, 2015).

Pre-Treatment Condition	**Treatment Life Reduction Percentage (compared to good condition), %**		
	Chip Seal	**Slurry Surfacing (Micro-surfacing)**	**Thin HMA Overlays**
Fair	31	35	36
Poor	62	62	64

3.4 Effect of Traffic on Service Life and Recommended Practice

Traffic plays a critical role in dictating the feasibility of the treatment and agencies typically select the various treatment types based on the traffic level of the section. In general, two important factors are considered in selecting the treatment for a certain traffic level:

a. the long-term performance of the treatment considering the traffic level
b. the curing time of the treatment

Traffic volume as well as percentage of truck needs to be considered when selecting the appropriate treatment for a pavement section since the capacity to withstand the traffic level can vary significantly between treatments (Caltrans 2008). The results of several studies have confirmed the effect of traffic level on performance of pavement treatments. In general, studies indicate that treatment involving polymer modified asphalt performs better in high traffic volume roads since the polymer provides better adhesion to the aggregates, resulting in reduction in loss of aggregates (Visintine et al., 2015).
Several agencies impose traffic restrictions on certain treatments. For example, MnDOT recommends application of slurry seal on roadways with AADT<2500 and seal coat application on roadways with AADT < 10,000. For roadways where traffic volume is higher (AADT> 1000), MnDOT recommends using more advanced pavement treatments such as micro-surfacing, cape seal, and HMA overlays. MDOT recommends applying chip seal on low-volume roads where the Average Daily Traffic (ADT) is less than 6,000.

ODOT recommends application of chip seal on low volume road with ADT< 2500 and low truck counts and double course micro-surfacing in for ADT >10,000. Micro-surfacing and fine graded polymer modified is recommended asphalt for flexible pavements, and diamond grinding for concrete pavement with higher traffic levels.

NYDOT recommends application of single course chip seal and slurry seal on low volume roads with truck count less than 10%. For high volume traffic roads, NYDOT recommends opting for micro-surfacing or polymer modified HMA overlays. A NCHRP study conducted by Peshkin et al., (2004) documented the effect of traffic volume and truck count on different treatments which is summarized in in Table 7.

Table 7. Effect of Traffic Level on Treatments (Peshkin et al., 2004).

Treatment Type	**Effect of Traffic Volume**
Crack fill/ seal	Performance is not significantly affected by traffic volume
Fog seal	Wearing increases with increase in ADT and truck count
Slurry seal	Wearing increases with increase in ADT and truck count
Scrub seal	Recommended to apply where ADT < 7500
Micro-surfacing	Good performance observed at any traffic level
Chip seal	Recommended on low volume and low speed roads
Thin HMA overlays	Performance is not affected by traffic volume
Ultra-thin friction courses	Performance is not affected by traffic volume

Treatment curing time will need to be considered before selecting the treatment, especially when high level of traffic is expected. Treatments with less curing time is preferred on sections with high traffic since the treated section can be opened to the traffic quickly after treatment application.
However, treatments with longer curing time are avoided in areas with high traffic. Peshkin et al., (2011) summarized the industry practice for selecting treatments for various traffic levels, as shown in Table 8.

Table 8. Usage of Treatments at Different Traffic Levels (Peshkin et al, 2011).

<table>
<tr><th rowspan="3">Treatment</th><th colspan="2">Treatment Usage</th></tr>
<tr><th>Rural</th><th>Urban</th></tr>
<tr><th>(ADT >5,000 vpd)</th><th>(ADT >10,000 vpd)</th></tr>
<tr><td>Crack filling</td><td>Extensive</td><td>Extensive</td></tr>
<tr><td>Crack sealing</td><td>Extensive</td><td>Extensive</td></tr>
<tr><td>Slurry seal</td><td>Limited</td><td>Limited</td></tr>
<tr><td>Micro-surfacing</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>Chip seals</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>Ultra-thin bonded wearing course</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>Thin HMA overlay</td><td>Extensive</td><td>Extensive</td></tr>
<tr><td>Cold milling and Overlay</td><td>Extensive</td><td>Extensive</td></tr>
<tr><td>Ultra-thin HMA overlay</td><td>Limited</td><td>Extensive</td></tr>
</table>

Treatment	Treatment Usage	
	Rural	**Urban**
	(ADT >5,000 vpd)	**(ADT >10,000 vpd)**
Hot in-place HMA recycling	Limited	Limited
Cold in-place recycling	Moderate	Moderate
Profile milling	Moderate	Moderate
Ultra-thin whitetopping	Limited	Limited

3.4.1 Effect of Climatic Condition on Service Life and Recommended Practice

Past studies have indicated that certain climatic condition may affect the performance of pavement treatments as well as the application timing. Certain treatments such as micro-surfacing, micro-paving, chip seal, and seal coats are susceptible to weather conditions such as rain or extreme temperature immediately after placement. Significant loss in service life is reported if such treatments are exposed to extreme weather immediately after construction (Peshkin et al., 2011; Croteau et al. 2005).

The feasibility of selecting a treatment may depend on the climatic condition at the time of application. The curing time of the mixture relies on temperature and humidity at the time of application and certain treatments that involve using asphalt emulsion can only be applied under limited temperatures and humidity conditions. In general, high temperature and low humidity are desired for faster curing. Curing time is critical for pavements with high traffic volume where faster curing time would reduce the time required to open the treated section to traffic. For example, slurry seal requires several hours of sun light and warm temperature for curing. If such conditions are not met, slurry seal is not recommended as a treatment. This applies to micro-surfacing/micro-paving or chip seal if slow-setting emulsion is used.

Climatic condition at the time of placement also dictates material selection for certain treatments, including micro-surfacing, micro-paving, and chip seal. If these treatments are applied on sections where the time of opening to traffic is relatively short, the use of quick setting emulsion is recommended over the slow setting emulsion for the mix design (Caltrans, 2008).

In general, the recommended industry practice is to apply the emulsion-based pavement treatments during the day and during warm temperatures and apply hot asphalt binder-based treatments both during day and night times (Peshkin et al., 2011). Moreover, selection of treatment should consider climatic region where the agency is located as well as the traffic level of the pavement section. An NCHRP study conducted by Peshkin et al., 2011 summarized the choice of treatments for roadways with high traffic volume of different agencies in three climatic regions, including deep-freeze (northern-tier states, freezing index (FI) >400), moderate-freeze (middle-tier states, 50 < FI ≤ 400), and no-freeze (southern-tier states and portions of coastlines, FI ≤50). The treatments used by the agencies in different climate zones are presented in Table 9.

Table 9. Use of Various Pavement Treatment Options at Different Climate Zone (Peshkin et al, 2011).

Climatic Region	Crack fill	Crack seal	Slurry seal	Micro-surfacing		Chip seal		With polymer	Thin HMA overlay
				Single course	Multiple course	Single course	Multiple course		
Rural									
Deep freeze	E	E	N	M	M	E	E	E	E
Moderate freeze	E	E	M	E	M	M	L	L	E
No freeze	M	M	L	M	L	M	M	M	M
Urban									
Deep freeze	E	E	N	M	M	M	M	M	E
Moderate freeze	E	E	M	E	E	M	L	L	E
No freeze	E	E	M	M	L	M	M	M	M

Note: E=Extensive use (used by > 66% of respondents); M = Moderate use (used by 33%-66% of respondents); L=limited use (used by < 33% of respondents)

The long-term performance of the selected treatment is also significantly affected by the climatic condition. For example, studies have reported issues with thermal cracking related to thin HMA overlays, especially more prominent in colder regions (Peshkin et al., 2011). While treatments such as chip seal and micro-surfacing are applied in all climatic regions, studies have reported performance concerns in areas where snow plowing is required frequently (Gransberg, 2010).
Treatments such as crack seal and crack fill may exhibit poor performance if exposed to extreme temperatures. Studies have indicated that at low temperature, sealant with poor quality materials results in inadequate flexibility and extendibility. Moreover, the sealant cannot resist flow and softening which could result in cracking (Al-Qadi et al., 2012). Peshkin et al., (2004) summarized the effect of climate on treatments which is presented in Table 10.

Table 10. Effect of Climate on Treatments (Peshkin et al., 2004).

Treatment Type	Effect of Climate
Crack fill/ seal	Performs well in all climates. Best performance observed in dry and warm climate
Fog seal	Performs well in all climatic conditions.
Slurry seal	Performs effectively in all climatic conditions. Most effective in dry and warm condition
Scrub seal	Performs effectively in all climatic conditions. Most effective in hot and arid condition
Micro-surfacing	Performs effectively in all climatic conditions. Most effective in dry and warm condition. Not recommended to apply during cool temperature
Chip seal	Performs effectively in all climatic conditions
Thin HMA overlays	Performs effectively in all climatic conditions
Ultra-thin friction courses	Performs effectively in all climatic conditions

3.4.2 Effect of Material Properties on Service Life and Recommended Practice

The quality of the materials plays a critical role in the performance of pavement treatments. Importance must be given in selecting the aggregate and binder type since the adhesion of the mixture is governed by the aggregate and binder type. Studies have indicated that the physical properties of aggregate and the quality of the asphalt binder plays a crucial role in determining the quality of the mixture design of chip seal and micro-surfacing (Shuler et al., 2010; Gransberg, 2010). Since the physical properties of the aggregates dictate the overall service life of the treatment, the aggregate source plays an important role in the treatment performance. An NCHRP study conducted by Gransberg (2010) suggested a list of physical properties to be considered to achieve a satisfactory service life for micro-surfacing.

- Geology: to determine the compatibility with the emulsion.
- Shape: to ensure the necessary interlocking between adjacent aggregate. Fractured aggregate faces interlocks better compared to rounded surface.
- Texture: to form bond with the emulsion. Rougher surface forms better bond with emulsion.
- Age and Reactivity: the aggregates must be freshly crushed since a freshly crushed surface has higher surface charge which help the reaction rate.
- Cleanliness: the aggregate must be free of deleterious materials such as clay, dirt, dust, or silt.
- Soundness and Abrasion Resistance: the aggregates must be sound and resistant to abrasion to withstand freeze-thaw cycles.

The study also reported the effect of emulsion type on the performance of micro-surfacing. A nationwide survey conducted as a part of the study indicated that stability, binder content, and viscosity are the most important properties. In addition, the use of polymer modified asphalt is expected to enhance the performance of micro-surfacing.

Decker (2014) conducted an NCHRP study that involved documenting the best practices of crack seal/fill. The study reported concerns related to crack sealant at very low and very high temperatures depending on the sealant type. At low temperatures, poor sealant materials fail to achieve bonding to have adequate flexibility and extendibility. Moreover, the sealant may not resist flow and softening which could result in cracking. The study recommends following the procedure established by Al-Qadi etal., (2012) in selecting the proper binder grade for sealant to prevent issues related to high and low temperature. The study developed performance-based grading system (Table 11) for sealants called SG grade where the low temperature grade properties were evaluated through direct tension test, bending beam rheometer (BBR) test, and adhesion, and dynamic shear rheometer (DSR) test was conducted to evaluate the high temperature properties. Results of the study is shown in Table 11. Similar to Superpave PG grades for asphalt binder, SG grades can be used to meet the environment requirement to ensure the quality of sealant material.

Table 11. Available Sealant Grade for High and Low Temperature (Al Qadi et al, 2012).

High Temperature	Low Temperature
46	-46
52	-40
58	-34
64	-28
70	-22
76	-16
82	-10

3.5 Selection Criteria for Treatments Recommended by Agencies

MnDOT follows five steps in selecting the optimum pavement preservation treatment. The steps include (MnDOT 2020):

1. Gather pavement information,
2. Assess pavement condition,
3. Evaluate pavement data,
4. Identify feasible preservation treatments,
5. and Select preservation treatment

MnDOT relies on various factors to identify the ideal pavement preservation treatment. The information includes pavement construction history, pavement performance data, pavement design life, traffic data, and structural properties. Information related to pavement construction history and design life are important since preservation will be less cost effective if the pavement is near the end of its design life. Knowing the structural and material properties may help provide key information in selecting the preservation treatment that will work well with the current pavement section. MnDOT also suggests incorporating traffic information, especially truck count as a key factor in the selection process for pavement preservation treatments. Guidelines, recommended by MnDOT for determining recommended and feasible treatments are provided in Table 12.

Table 12. Pavement Treatment Selection Criteria by MnDOT (MnDOT, 2020).

Pavement Conditions	Severity Level	Crack Filling	Crack Sealing	Micro-surfacing	Chip Seal	Thinlay	Thin HMA Overlay	UTBWC	Rut Filling	Micro Milling	Fog Seal	Mastic
Transverse Cracking	Low	R	R	R	R	R	R	F	NR	R	F	NR
	Medium	R	R	F	F	F	NR	NR	NR	F	NR	R
	High	F	F	NR	NR	NR	NR	NR	NR	F	NR	R

Table 12. Pavement Treatment Selection Criteria by MnDOT (MnDOT, 2020), continued.

Pavement Conditions	Severity Level	Crack Filling	Crack Sealing	Micro-surfacing	Chip Seal	Thinlay	Thin HMA Overlay	UTBWC	Rut Filling	Micro Milling	Fog Seal	Mastic
Longitudinal Cracking	Low	R	R	F	F	F	F	F	NR	R	F	NR
	Medium	R	F	F	F	F	F	F	NR	F		F
	High	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	F
Longitudinal Joint Cracking	Low	F	F	F	F	F	F	F	NR	F	NR	NR
	Medium	NR	NR	F	NR	NR	NR	NR	NR	NR	NR	NR
	High	NR	NR	F	NR	NR	NR	NR	NR	NR	NR	NR
Multiple Cracking	Low	R	R	R	R	F	F	F	NR	R	F	
	Medium	R	R	NR	F	NR	NR	NR	NR	F	NR	F
	High	F	F	NR		NR	NR	NR	NR	NR	NR	NR
Alligator Cracking	Low	F	F	F	F	F	F	F	NR	NR	NR	NR
	Medium	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	High	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Rutting	Low	NR	NR	R	F	F	F	F	R	R	NR	NR
	Medium	NR	NR	R	F	F	F	F	R	F	NR	NR
	High	NR	NR	F	NR	NR	NR	NR	F	NR	NR	NR
Raveling and Weathering	Low	NR	NR	R	R	F	F	F	NR	R	R	NR
	Medium	NR	NR	R	R	F	F	F	NR	F	F	NR
	High	NR	NR	F	F	NR	NR	NR	NR	NR	NR	NR
patching	Low	F	F	F	F	F	F	F	NR	F	NR	R
	Medium	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	F
	High	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
RQI	3-4	R	R	R	R	R	R	R	NR	R	F	F
	2-2.9	F	F	F		R	R	R	NR	R	NR	F
	1-1.9	NR	NR	NR	NR	NR	NR	NR	NR	F	NR	F
ADT	<2500	R	R	R	R	R	R	F	R	R	NR	R
	2500-10000	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R
	>10000	NR	NR	F	F	NR	NR	NR	NR	NR	NR	F
Friction	Poor	NR	NR	R	R	R	R	R	NR	R	NR	NR

R = Recommended
F = Feasible
NR = Not Recommended

When multiple preservation treatments are feasible, MnDOT recommends carrying out benefit cost analysis to select the best treatment method. In addition to the benefits and costs of the feasible treatments, the selection of the appropriate preservation treatment also includes considering the following project constraints that affect treatment selection.

1. Availability of qualified contractors,
2. Availability of quality materials,
3. Agency practice or local preference,
4. Time (of year) of construction,

5. Initial costs,
6. User preferences,
7. Pavement noise,
8. Facility downtime, and
9. Surface friction.

MDOT utilizes both pavement condition data and visual inspection to select the optimal timing for various maintenance treatments. The pavement condition data includes International Roughness Index (IRI), Distress Index (DI), Remaining Service Life (RSL), and rut depth. Table 13 summarizes the MDOT criteria for selecting different pavement treatments.

Table 13. Treatment Selection Criteria Recommended by MDOT.

Treatment Type	Pavement Type	Minimum RSL (years)	DI	IRI	Rut	Traffic (AADT)
Crack Seal/Fill	Flexible	10	<15	<107	<1/8"	NA
	Composite	10	<5	<107	<1/8"	
Chip Seal	Flexible	5 (double) 6 (single)	<30 (double) <25 (single)	<107	<1/8"	<6000 (recommended)
	Composite	5 (double)	<15	<107	<1/8"	
Fibermat	Flexible	5 (Type B) 6 (Type A)	<30 (Type B) <25 (Type A)	<107	<1/8"	NA
	Composite	5 (Type B) 6 (Type A)	<25 (Type B) <15 (Type A)	<107	<1/8"	
Micro-surfacing	Flexible	5 (Multiple or heavy single) 6 (Regular single)	<30 (Multiple or heavy single) <15(Regular single)	<107	<1"	NA
	Composite	5 (Double)	<15	<107	<1"	
Cape Seal	Flexible	6	<25	<107	<1/2"	NA
	Composite	5	<15	<107	<1/2"	
Ultra Thin HMA Overlay	Flexible	5	<30	<132	<1/4"	NA
	Composite	5	<20	<132	<1/4"	
Paver Placed Surface Seal	Flexible	5	<30	<132	<1/4"	NA
	Composite	5	<20	<132	<1/4"	
Non-Structural HMA Overlay	Flexible	3	<40	<163	<1/2"	NA
	Composite	3	<25	<163	<1/2"	

The Ohio department of transportation (ODOT) also developed guidelines (Table 14) for selecting the pavement preventive maintenance treatments that include the description and purpose, pavement condition considerations, traffic constraints, design considerations, seasonal construction limitations, unit cost for estimating the anticipated performance and service life. ODOT's available preventative maintenance treatments are crack sealing, chip seals, microsurfacing, polymer-modified asphalt concrete, thin hot mix overlays, concrete pavement restoration (CPR), and drainage preservation.

Table 14. Pavement Treatment Selection Guideline Recommended by ODOT (ODOT, 2001).

Pavement Applications		**Crack Sealing**	**Chip Seal**	**Micro-Surfacing**	**Polymer Modified Asphalt Concrete**	**Thin Hot Mix Overlay**	**Concrete Pavement Restoration**	**Drainage Preservation**
Pavement Surface	Concrete	✓					✓	✓
	Asphalt	✓	✓	✓	✓	✓		✓
Reasons For	Friction		✓	✓	✓	✓		
	Rideability			✓	✓	✓	✓	
	Raveling	✓	✓	✓	✓	✓		
	Rutting			✓	✓	✓		
	Cracking	✓	✓		✓	✓	✓	
	Oxidation		✓	✓	✓	✓	✓	
	Water	✓	✓	✓	✓	✓		✓
Traffic	Low Volume (<2500 ADT)	X	X	X	X	X	X	X
	High Volume (>2500 ADT)	X		X	X	X	X	X
	Maximum Speed < 45 MPH				Type A			
Average Life (years)		1 - 4	5 - 8	5 - 8	7 - 12	8 - 12	7 - 12	1 - 5

In Illinois, the appropriate treatment strategy is determined based on the type and severity of existing pavement distresses. The preservation treatments for flexible and rigid pavements and the guidelines for determining recommended and feasible treatments are presented in Table 15 and Table 16. As observed, the guidance for treatment selection considers various attributes including distress levels, ride, friction, traffic levels, and relative cost.

Table 15. Treatment Selection Guideline for Flexible Pavement by IDOT (Illinois DOT, 2012).

Pavement Conditions	Parameters	Crack Sealing	Joint Resealing	Diamond Grinding	Diamond Grooving	Full-Depth Repairs	Partial-Depth Repairs	LTR 1	Cross Stitching	Subsealing/ Undersealing	Drainage Preservation
	Moderate	NR	R	NR	NR	NR	NR	NR	NR	NR	NR
	Severe	NR	R	NR	NR	NR	NR	NR	NR	NR	NR
Longitudinal Cracking	Light	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Moderate	R	NR	NR	NR	F	NR	NR	R	NR	NR
	Severe	F	NR	NR	NR	R	NR	NR	F	NR	NR
Pumping	All	NR	F	NR	NR	NR	NR	F	NR	R	R
Spalling	Light	NR	F	NR	NR	NR	F	NR	NR	NR	NR
	Moderate	NR	F	NR	NR	NR	R	NR	NR	NR	NR
	Severe	NR	NR	NR	NR	F	R	NR	NR	NR	NR
Surface Distress	Light	NR	NR	F	NR	NR	NR	NR	NR	NR	NR
	Moderate	NR	NR	F	NR	NR	F	NR	NR	NR	NR
	Severe	NR	NR	F	NR	NR	F	NR	NR	NR	NR
Transverse Cracking	Light	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Moderate	R	NR	NR	NR	F	NR	F	NR	NR	NR
	Severe	F	NR	NR	NR	R	NR	R	NR	NR	NR
Ride	Poor	NR	NR	R	NR	NR	NR	F*	NR	F	F
Skid	Poor	NR	NR	R	R	NR	NR	NR	NR	NR	NR
Relative Cost	($ to $$$$)	$	$	$$	$$	$$$$	$$$	$$$	$$$	$$	Varies

Table 16. Treatment Selection Guideline for Concrete Pavement by Illinois DOT (Illinois DOT, 2012)

Pavement Conditions	Severity Levels	Crack Filling	Crack Sealing	Fog Seal	Sand Seal	Scrub Seal	Rejuvenator	Slurry Seal	Micro-surfacing	Chip Seal	Cape Seal	CIR	HIR	Thin HMA Overlay	Ultra-Thin Friction Course	UTW	Cold Mill	Drainage Preservation
	2,500 – 10,000	R	R	F	F	F	F	F	R	R	R	R	R	R	R	R	R	R
	> 10,000	R	R	NR	NR	NR	NR	NR	R	F	R	NR	R	R	R	R	R	R
Relative Cost	($ to $$$$)	$	$	$	$$	$$	$$	$$	$$	$$	$$	$$$	$$$	$$$	$$$	$$$$	$	Varies

R - Recommended treatment for the specified pavement condition. Care must be examined in making sure that all critical distress types are addressed by the selected treatment. R* - Recommended when used in conjunction with LTR and/or Subsealing/Undersealing.
F - Feasible treatment but depends upon other project constraints including other existing distresses.
F* - Feasible treatment if poor ride is a result of undoweled joints or faulted transverse (mid-slab) cracking. NR - Treatment is not recommended to correct the specified pavement condition. 1 - LTR (Load Transfer Restoration) is normally used in combination with diamond grinding.

3.6 Questionnaire Responses

One of the key objectives of this task is to review the standard practice adopted by peer agencies in implementing different traditional and non-traditional pavement treatments. To this end, ARA prepared a questionnaire to develop an understanding of typical and innovative maintenance treatments utilized by state agencies, and availability of pavement management system data pertaining to the maintenance treatments.

ARA submitted the questionnaire to Illinois DOT, Michigan DOT, Minnesota DOT, New York DOT, Ohio DOT, and Wisconsin DOT. Responses were received from Michigan DOT, Minnesota DOT, New York DOT, and Ohio DOT, and are documented in Appendix B.

Details of the innovative treatments utilized by the various DOTs, and available PMS data is shown in the tables below.

Table 17. Typical Maintenance Treatments in Various DOTs.

State DOT/Treatments	Micro-Paving	Micro-Surfacing	Mastics	Sealcoat
Michigan	x	x	x	x
Minnesota	x	x	x	x
New York	x	x	x	
Ohio		x	x	

Table 18. Innovative Maintenance Treatments Used by Various DOTs.

State DOT	Innovative Treatments				
Michigan	Void Reducing Membrane	Scrub Seal	Microsurface (fiber and soft binders)		
Minnesota	Scrub Seal	Slurry Seal	Spray-Applied Rejuvenator Seal		
New York	Heat Scarification	Joint and Crack Seal			
Ohio	Chip Seal	Fine Grade HMA OL	Dowel Bar Retrofit	Longitudinal Cross Stitching	RRCM (Rapid Repair)

Table 19. PMS Data Availability.

PMS Data/State	Michigan	Minnesota	New York	Ohio
Overall Performance Index (OPI)		x		x
International Roughness Index (IRI)	x	x		x
Asphalt material Type	x	x		x
Wearing surface Age	x	x		
Existing completed maintenance activities		x		
Average Daily Traffic (ADT) and truck percentage	x	x	x	
Business Plan Network (BPN) and functional classification	x	x		
Lowest Life Cycle Cost (LLCC) treatment options	x	x		

3.7 Innovative Treatment Adopted by Agencies

Details of selected innovative treatments adopted by the various state agencies, as reported in the questionnaire responses, is shown in the following sections.

3.8 Void-reducing asphalt membrane (VRAM)

VRAM is a hot-applied polymer modified asphalt membrane. VRAM is applied at the longitudinal joint of asphalt pavement to reduce the air void and moisture permeability, thereby reducing deterioration at the longitudinal joint. VRAM tends to reduce the air void at the longitudinal joint by filling up 50-70% of the air void (Williams et al., 2020). Literature indicates that several agencies have utilized VRAM to enhance the performance of longitudinal joints. Williams et al., (2020) conducted a research project to investigate the effect of VRAM on the longitudinal joint in asphalt pavement for MnDOT using J-Band, a commercially available VRAM product. The results of the study indicated that the longitudinal joint with VRAM showed higher bond and surface energy along with Enhanced cracking resistance at the joint. In addition, VRAM was found to reduce the permeability and air void of the asphalt pavement near the longitudinal joint.

Illinois DOT carried out an experimental study to understand the long-term effect of VRAM (Trepanier et al., 2022). Several control test sections and test section with VRAM were constructed for this purpose in 2001 to 2003. The evaluation of these test sections after twelve years revealed that sections with VRAM performed significantly better at the longitudinal joints compared to the control sections. The laboratory experiment indicated that sections with VRAM had higher cracking resistance and decreased permeability. Overall, a three-to-five-year service life extension was observed for pavement sections with VRAM. The material properties for VRAM used in this study is shown below in Table 20.

Table 20. PMS Data Availability.

Test	Requirement
DSR at 88˚C-G*/sinδ,kPa	1
Creep Stiffness at -18˚C Stiffness (S), Mpa m-value	300 max 0.3 min
Ash%	1-4
Elastic Recovery, 25˚C, %	70 min
Separation of polymer, diff in R&B, ˚C	3 Max

PennDOT has recently conducted a series of trial studies from 2018 through 2022 to examine the long-term efficacy of VRAM. Thirteen trials were constructed, including four in District 5, two in District 4, and one each in Districts 1, 2, 3, 6, 8, 11, and 12. The first two trial sections were constructed in 2018 and the first trial section was evaluated 5 years after construction. Results of the visual inspection indicated that the section with VRAM performed significantly better compared to the control section. The performance of the second trial section was reviewed after 3 years from the construction by taking cores from the pavement with and without VRAM application for laboratory testing. Three types of laboratory tests were conducted, including Air void, Permeability test, and IDEAL-CT for cracking resistance. The test results indicated that cores with VRAM had reduced air void and permeability, and higher cracking resistance compared to cores from control section. The preliminary results indicated 3 years of extended life for each mile for pavements with VRAM application.

3.8.1 Spray Applied Rejuvenator

Spray applied rejuvenator is a cost-effective treatment that can enhance the durability of pavement by reducing the effect of aging on asphalt pavement. Rejuvenators are designed to penetrate asphalt pavement to a certain depth and chemically combine to create a durable and flexible surface. There are mainly two types of rejuvenators: (a) petroleum based (b) bio based (Blanchette et al.,2020). Rejuvenators do not add any structural capability and needs to be applied while the pavement is in a good condition (PCI>70) to achieve optimum performance (Blanchette et al.,2020; Ghosh et al.,2016). Literature review suggests that a very limited number of research projects have been conducted on spray applied rejuvenators, and the service life of pavement can be extended by a maximum 18 months (Ghosh et al.,2016).

Scrub Seal: Scrub seal involves application of polymer modified asphalt emulsion that is brimmed into the voids and cracks of pavement followed by application of layer of aggregates. An NCHRP study conducted by Peshkin et al. (2004) reported that scrub seal is appropriate for all types of weather conditions. Scrub seal is known for addressing distresses such as transverse, longitudinal, and block cracking. In addition, it can prevent raveling and moisture infiltration. Since scrub seal does not add any structural capacity, it cannot address distresses such as fatigue cracking. The typical life extending period for scrub seal is reported to be 1 to 3 years.

Scrub seals are typically applied on low traffic volume roads with ADT less than 7500 (Peshkin et al.,2004). However, MnDOT recommends applying scrub seal on pavements with ADT less than 2500 and ride quality index (RQI) within 3 to 4. In addition, the presence of alligator, high severity longitudinal and transverse crack should be minimal at the time of scrub seal application. Based on MnDOT's experience, scrub seal can extend the service life by 6 to 7 years.

3.8.2 Longitudinal cross stitching

Longitudinal cross stitching is performed on concrete pavement to keep the longitudinal cracks or joints tight for an extended period. The process involves anchoring deformed reinforcement bar by drilling at a prescribed angle and spacing. Several research projects have been carried out to investigate the effect of longitudinal stitching on the cracks and joint. For example, highway cross stitching was done on I-70 in Utah in 1985. The conditions of the stitched section were evaluated after 15 years and was compared with the control section. The results indicated that cracks with stitching performed significantly better compared to the non-stitched cracks. The lane separation and settlement of slabs were also found to be less frequent when the cracks were stitched. Similar results were also observed for research projects carried out on I-70 in both Kansas and Missouri. In both projects no major longitudinal crack related distresses were identified (Darter 2017). Survival analysis conducted in these projects indicated that the typical service life of longitudinal cross stitching is around 10-20 years. Longitudinal cross stitching can be applied in pavement of all ages. However, the following points needs to be considered before the application (Darter 2017).

- For relatively newer concrete pavements, cross stitching is applied when development of early cracks is observed. In addition, joints should be stitched in case the tie bars are missing.
- For relatively older pavements, stitching should be applied as soon as the cracks start to deteriorate. The joints should be stitched as soon as they start opening to achieve best possible outcome.

3.8.3 Dowl Bar Retrofit

Efficient load transfer is key to prevent joint related distresses in concrete pavement, such as faulting, pumping, and joint spalling. Dowel bar retrofit is a method of restoring the load transfer mechanism of old concrete pavement when the dowel bar is absent or the existing dowel bars do not provide sufficient load transfer across traverse joints. In general, the dowel bar retrofit process includes (ODOT, 2022):

(a) sawing slots of proper size,
(b) cleaning the slot,
(c) Injecting filler materials to seal the crack and filler board,
(d) placing dowel bar (typical diameter of 1-1/2 inch) and the filler board,
(e) filling the slot with cementitious materials,
(f) Consolidating, finishing, and curing the cementitious material, and
(g) sawing joint

Several studies have been conducted to investigate efficacy of dowel bar retrofit. The results of studies unanimously agree that dowel bar retrofit can significantly improve faulting and joint spalling (Odden et al., 2003; Pierce et al., 2003; Pierce et al., 2010). Studies have also indicated that the dowel bar retrofit is recommended before faulting reaches more than 1/8 inch (3mm), and average faulting, IRI, and panel cracking is around 0.3 mm, 145 in/mi, and 5 percent, respectively (Pierce et al., 2010).

3.9 Literature Review Conclusions

A literature review was conducted as part of this study to obtain information related to both tradition and non-tradition maintenance treatments adopted by select Department of Transportations (DOTs) and treatment timings.

The effect of treatment application time, traffic, climatic conditions, and material properties on service life was evaluated as part of this literature review. The expected service life of a particular treatment can vary based on the agency, and depends on various factors including traffic, climatic conditions, and construction method and materials. Treatment application times also plays an important factor in pavement performance. For example, the pavement service life is extended by applying certain treatments early in the life when pavements are in ‘good’ and ‘fair’ condition.
Traffic volume will influence the performance of certain treatments like Fog seal, slurry seal, scrub and chip seals, while these treatments tend to perform well in all climatic conditions.

In addition, the selection criteria used by select DOTs (Illinois, Ohio, Michigan, and Minnesota) and requirements for seal coat, crack seal, micropaving, microsurfacing, mastics and rejuvenators was documented. Agencies consider pavement distress information (type and severity), IRI, traffic ADT, and RSL in selecting the optimal timings for various treatments.

In addition, a questionnaire was provided to select DOT's to determine new and innovative treatments used by DOT's in the last 10 years and the availability of PMS data for further analysis. Based on the questionnaire responses, several treatments (void reducing asphalt membrane, rejuvenators, longitudinal cross stitching, and dowel bar retrofit) were identified as potential new and innovative treatments for further analysis. Micropaving, microsurfacing, mastics and sealcoats were utilized by all DOTs. Minnesota, Michigan and Ohio DOT were willing to provide PMS data to evaluate the treatment timings of select maintenance treatments.

4 ANALYSIS AND DEVELOPMENT OF PROCESS

4.1 Research Approach

The main objective of this section was to determine service life extensions related to different preventative treatments commonly used by PennDOT. To this end, the considered treatments were seal coat, crack seal, micro-surfacing, and Novachip. The obtained results from this section were used to derive conclusions and recommendation to select most optimal treatment types and timings of preventative treatments. The overall research approach for this study is outlined in Figure 2. The description of the listed steps is provided in the following sections.

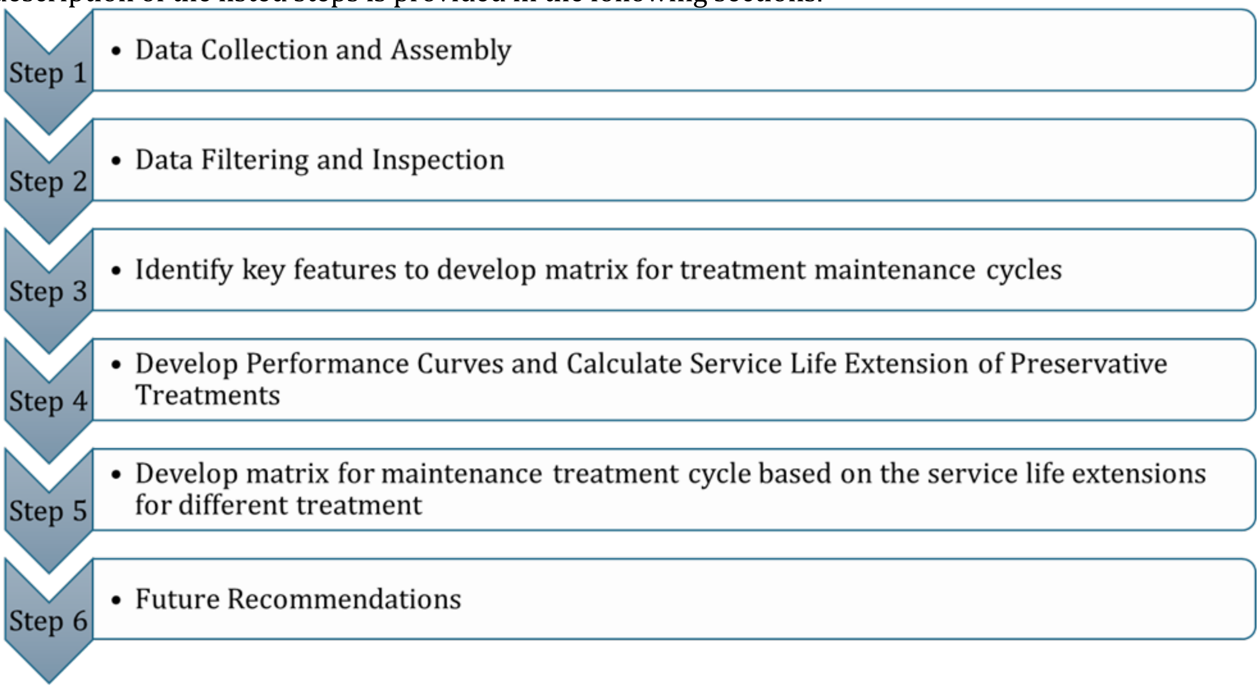


Figure 2. Research Approach.

4.2 Data Collection and Assembly

ARA received the following databases from PennDOT for data analysis.

- historical performance data from 2011 to 2021,
- pavement layer information and construction date, and
- treatment types and construction date for various treatments.

All databases included key fields that were used to combine these databases into one master database. The common features included: district, county, route no, segment begin, and segment end. These features were joined together to create a unique ID for the pavement section. For each unique ID, following features were extracted from the two databases:

A) County,
B) Business plan (BPN),
C) Overall Performance Index (OPI),
D) Construction date of the treatment, and
E) Construction date of the last major rehabilitation

The initial list of treatments assembled for analysis included:

1. Seal Coat-Single Application
2. Seal Coat-Double Application
3. Crack Sealing
4. Micro-surfacing (Mixed Up with Slurry seal data)
5. Cold-In-Place Recycling
6. Joint Sealing (Concrete Roads)
7. Fog Seal
8. Scratch and Seal
9. Slurry Seal
10. Novachip

Due to limited data availability, it was not feasible to include all the treatments for analysis. Following discussion with the PennDOT project team, treatments chosen for this study represent the most frequently used maintenance treatment in Pennsylvania. The selected treatments included seal coat-single application, crack sealing, micro-surfacing, and Novachip.

4.2.1 Data Filtering and Inspection

The final dataset for analysis was compiled after a rigorous filtering process. The filtering was done based on a set of assumptions. These assumptions were made to tackle several issues faced analyzing the database. The assumptions and the corresponding issues that were tackled with the assumptions are described below. The final list of preventative maintenance treatments for analysis included seal coat, micro-surfacing, crack seal and Novachip.

- The performance models were developed based on the performance data from 2011 to 2021.
- Typically, OPI decreases with age as the pavement deteriorates unless a treatment is applied. In cases where OPI increased with age without any work done, the data was eliminated from analysis.
- A section was included for analysis only if the considered treatment was the first applied treatment after any major rehabilitation. For example, if two pavement sections were constructed in year 2000, one received micro-surfacing in year 2013 and the other micro-surfacing in years 2005 and 2013, only the first section was considered for analysis to eliminate any bias due to previously applied treatments, sections that had received treatment/treatments between the construction year and 2011, was not included in the analysis.
- Only the sections that were reconstructed or rehabilitated on or after 2000 were included in the database.
- The pavement surface age was calculated from the year of last major rehabilitation. If a subsequent treatment was applied, data after the application of the treatment was not included in the analysis.

4.2.2 Key Features Identification

To evaluate the effect of traffic and climate on pavement preservation treatment timing, the dataset was divided based on the various climatic zones and traffic classifications in Pennsylvania (PA).
Based on the climatic zones in PA, all counties were divided into two major climatic zones (Figure 3). In cases where counties were part of both climatic zones, the climate zone with greater influence was selected for analysis. The list of counties in Pennsylvania with corresponding climate zones are presented in Table 21.

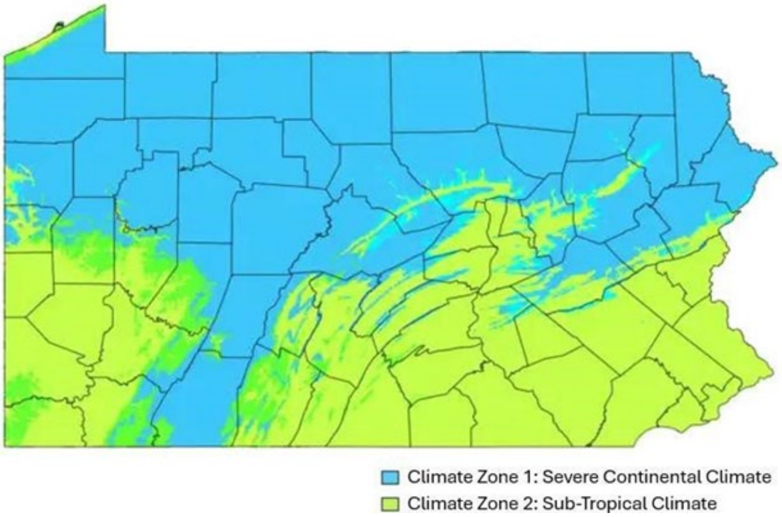


Figure 3. Climate Zones of Pennsylvania.

Table 21. Counties and Climate Zones.

County Name	County Number	Climate
BRADFORD	8	1
CAMBRIA*	11	1
CAMERON	12	1
CARBON*	13	1
CENTRE*	14	1
CLARION*	16	1
CLEARFIELD	17	1
CLINTON*	18	1
CRAWFORD	20	1
ELK	24	1
ERIE*	25	1
FOREST	27	1
JEFFERSON	33	1
LACKAWANNA*	35	1
LUZERNE*	40	1
LYCOMING*	41	1
MCKEAN	42	1
MERCER*	43	1
MIFFLIN*	44	1
MONROE*	45	1
PIKE*	51	1
POTTER	52	1
SCHUYKILL*	53	1
SOMERSET*	55	1

County Name	County Number	Climate
SULLIVAN	56	1
SUSQUEHANNA	57	1
TIOGA	58	1
VENANGO	60	1
WARREN	61	1
WAYNE	63	1
WYOMING*	65	1
ADAMS	1	2
ALLEGHENY	2	2
ARMSTRONG*	3	2
BEAVER	4	2
BEDFORD*	5	2
BERKS*	6	2
BLAIR*	7	2
BUCKS	9	2
BUTLER*	10	2
CHESTER	15	2
COLUMBIA*	19	2
CUMBERLAND	21	2
DAUPHIN*	22	2
DELAWARE	23	2
FAYETTE*	26	2
FRANKLIN	28	2
FULTON	29	2
GREENE	30	2
HUNTINGDON*	31	2
INDIANA*	32	2
JUNIATA*	34	2
LANCASTER	36	2
LAWRENCE*	37	2
LEBANON	38	2
LEHIGH	39	2
MONTGOMERY	46	2

In addition to climatic zone, the life extension of preventative treatments was also analyzed based on Business Plan Network (BPN). Following are the BPNs considered for this study, as defined by PennDOT:

- BPN 1 – Interstates,
- BPN 2 – National Highway System (NHS) Non-Interstates,
- BPN 3 – Non-NHS routes with Average Daily Traffic (ADT) >=2000 and
- BPN 4 – Non-NHS routes with ADT <2000.

4.2.3 Development Performance Models and Calculate Service Life Extension

The concept of performance model development for pre-treatment and post-treatment OPI data and service life extension is illustrated in Figure 4. To develop performance models the pre- treatment and post-treatment OPI data were plotted separately against pavement age. The final data points included for developing the models were obtained after carrying out the filtering process described in section 3.1.2. The performance models were obtained by fitting linear regression models to pre-treatment OPI and post-treatment OPI to obtain pre-treatment and post- treatment performance models, respectively. As mentioned earlier, only the OPI of the first application of maintenance treatment was considered to develop the performance models for the maintenance treatment. Once the performance models were established, the service life corresponding to OPI of 60 (Morian, 2011was calculated based on both pre-treatment and post- treatment performance models. OPI of 60 was selected based on the threshold for 'poor' category for pavement sections in BPN 4. The service life extension of the preventative maintenance treatment was calculated as the difference between the service life at OPI of 60 for the pre-, and post-treatment models.

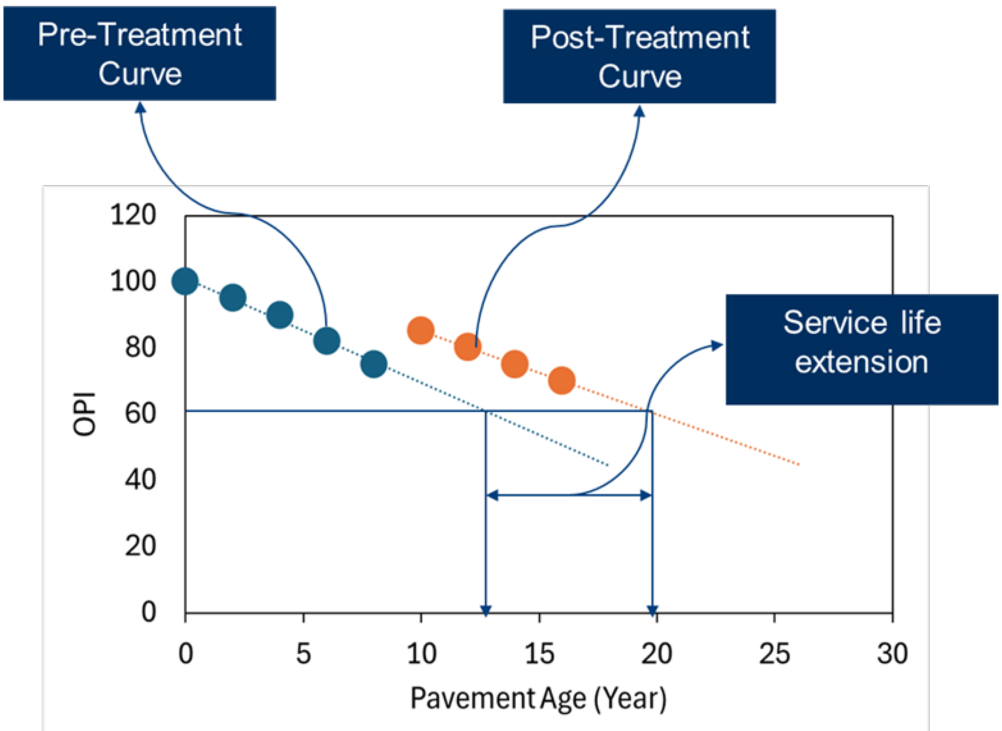


Figure 4. Service Life Extension Using Performance Models.

4.2.4 Development of matrix for maintenance treatment cycle based on the service life extensions and Future Recommendations

Following the methodology described in the section 2.5, the service life extension analysis was performed for all maintenance treatment selected for this study based on the key features including climate zones and BPNs. In addition, service life extension analysis was conducted based on pre-treatment OPI and pre-treatment age to obtain the optimum timing of application for the selected maintenance treatments. Results of the analysis were used to derive a decision tree to help the counties identify the maintenance cycle for preservative treatments for various climates and traffic conditions.

4.3 Preventative Maintenance Treatment Performance

4.3.1 Descriptive Statistics

Figure 5 through Figure 8 outlines the summary of the sections included for developing the performance models for the selected preservative maintenance treatments. The criteria of selecting the sections to be included for further analysis is presented in section 3.1.2. Figure 5 shows the number of sections across different BPNs. As indicated by Figure 5, majority of the crack seal, and micro-surfacing are applied in BPN 2, BPN 3, and BPN 4. All the included seal coats sections are applied in BPN 3 and BPN 4, which are non-national highways. Majority of Novachip sections, included in this study were from BPN 1.

Figure 6 shows the distribution of the preventative treatments across the two climate zones. As indicated by Figure 6, majority of the Novachip sections are in climate zone 1. Other preservative treatments were equally distributed between climate zone 1 and climate zone 2.

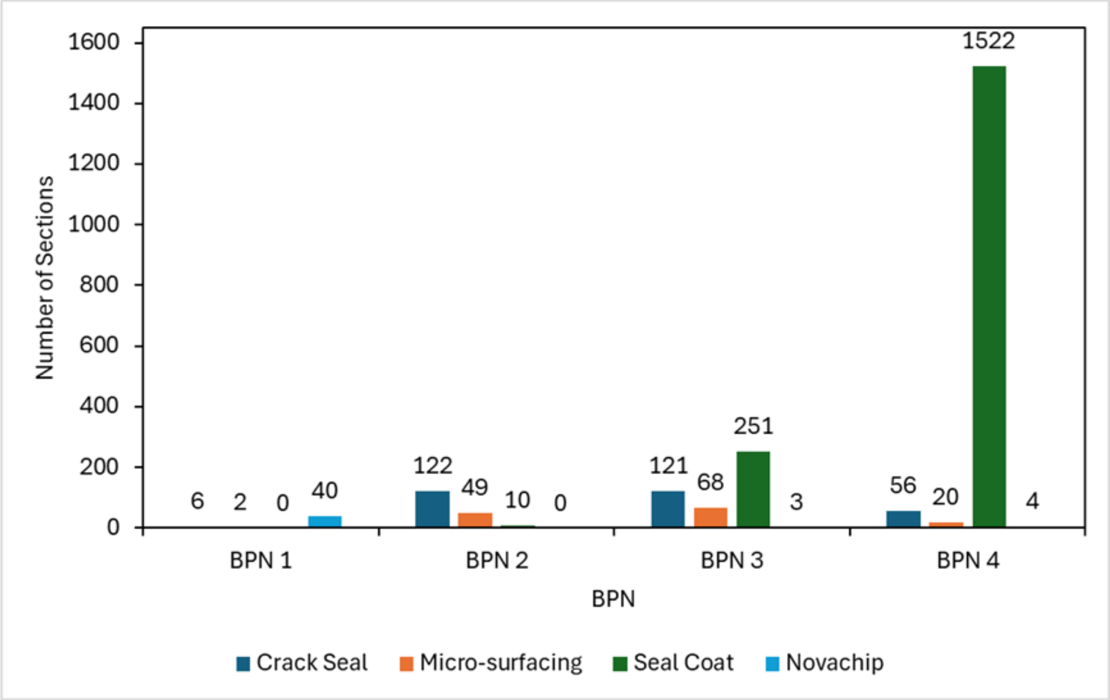


Figure 5. Number of Sections and Treatments in Each BPN.

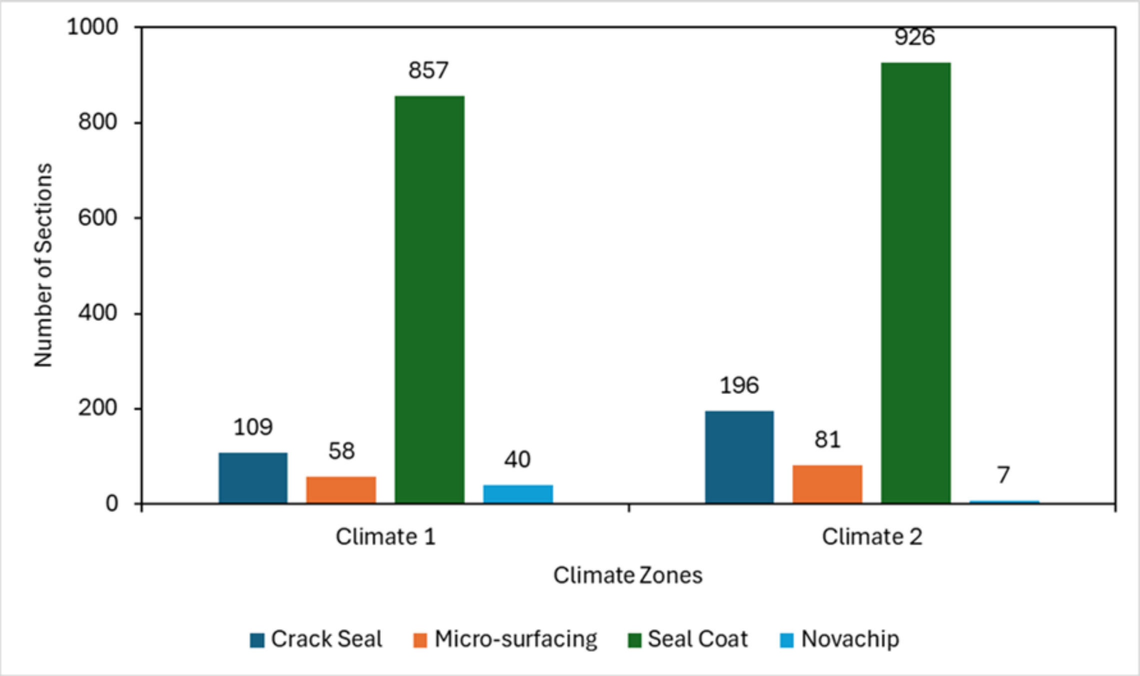


Figure 6. Number of Sections and Treatments in Each Climate Zone.

Figure 7 shows the distribution of the number of sections in different pre-treatment age category. For all the treatment types, majority of the treatments were applied when the pre-treatment age was between 4 and12 years. Seal coat, crack seal, and micro-surfacing had a significant number of sections with pre-treatment age less than 4 years. Only seal coat and crack seal had a significant number of sections with pre-treatment age greater than 12 years.

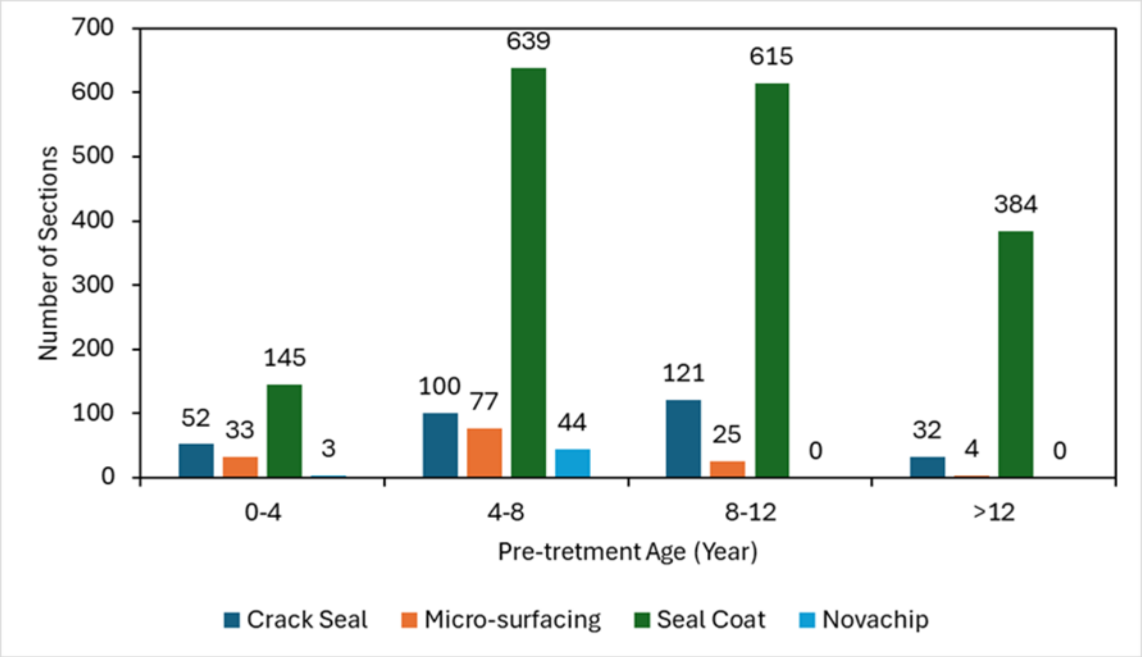


Figure 7. Pre-Treatment Age of Sections

Figure 8 shows the distribution of the number of sections in different pre-treatment OPI category. For all the treatment types, majority of the treatments were laid out when the pre- treatment OPI was less than 70. Only Seal coat had significant number of sections available with pre-treatment OPI less than 70. Majority of the micro-surfacing sections included in this study were applied when pre-treatment OPI was within 80-90, whereas majority of the Novachip sections included in this study were placed when pre-treatment OPI was greater than 90.

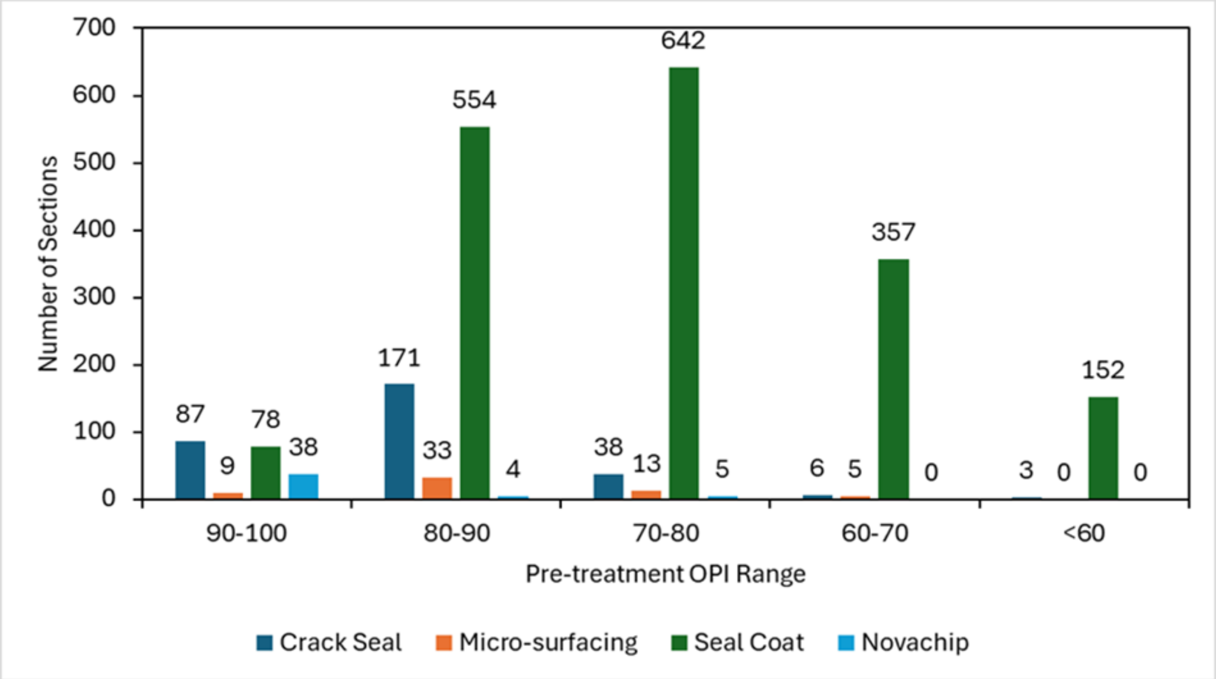


Figure 8. Pre-Treatment OPI of Sections.

4.3.2 Performance Models for Seal Coat

The pre-treatment and post-treatment performance models for seal coat are illustrated through Figure 9 to Figure 13. Figure 9 represents the pre-treatment and post-treatment models for all seal coat sections while Figure 10 through Figure 13. represents the pre-treatment and post- treatment performance models for seal coat sections located in climate zone 1 and climate zone 2, and BPN 3 and BPN 4, respectively. The summary of the performance models along with the life extension calculated from the performance models are also presented in Table 22. The benefit of seal coat on pavement is apparent from the difference between the pre-treatment and post-treatment model shown in Figure 9 through Figure 13. As expected, at any given age, the post-treatment model had higher OPI than that of pre-treatment model. In addition, for all cases post-treatment models had milder slope compared to the corresponding pre-treatment model, which indicates long term benefit of seal coat application by slowing down the rate of deterioration of the pavement section. As shown in Figure 14, application of seal coat extended the service life of the pavement by 4.8 years for the overall network. However, a slight difference in service life extension was observed due to seal coat application between the pavement sections located in climate 1 and climate 2. The results indicated that the life service extension due to seal coat application in climate 2 was 5.7 years compared to a service life extension of 3.9 years in climate 1. As described previously, sections in climate 1 experience lower temperatures and snow due to mountainous geography compared to warmer subtropical climate in climate zone 2. Therefore, the results suggest a higher life service extension due seal coat application associated with warmer climate in climate zone 2. For sections from BPN 3, service life extension due to seal coat application was observed to be 5.8 years, whereas a service life extension of 4.6 years was observed for sections from BPN 4. Despite higher traffic count in BPN 3 compared to BPN 4, a similar trend was observed in previous study (Morian, 2011).

Table 22. Pre- and Post-Treatment Pavement Performance.

	Pre-Treatment		Post-Treatment		Life Extension
	Performance Model	R^2	Performance Model	R^2	(years)
Climate 1	y = -2.632x + 99.531	R^2 = 0.4976	y = -1.9035x + 96.073	R^2 = 0.3444	3.9
Climate 2	y = -1.6544x + 93.501	R^2 = 0.3336	y = -1.2025x + 91.149	R^2 = 0.2228	5.6
Combined	y = -2.1592x + 96.789	R^2 = 0.411	y = -1.5452x + 93.69	R^2 = 0.2725	4.8
BPN 3	y = -2.1143x + 97.795	R^2 = 0.3024	y = -1.5117x + 95.872	R^2 = 0.322	6.5
BPN 4	y = -2.2227x + 96.812	R^2 = 0.4236	y = -1.5962x + 93.727	R^2 = 0.3033	4.6

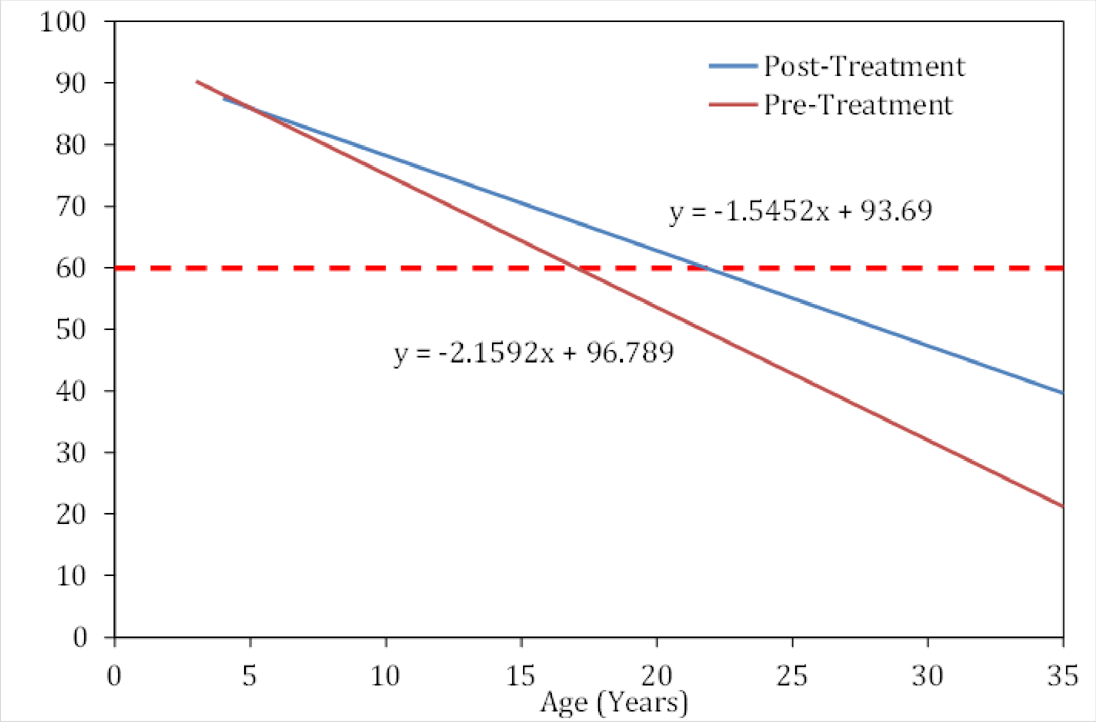


Figure 9. Pre- and Post-Treatment Pavement Performance for all seal coat sections.

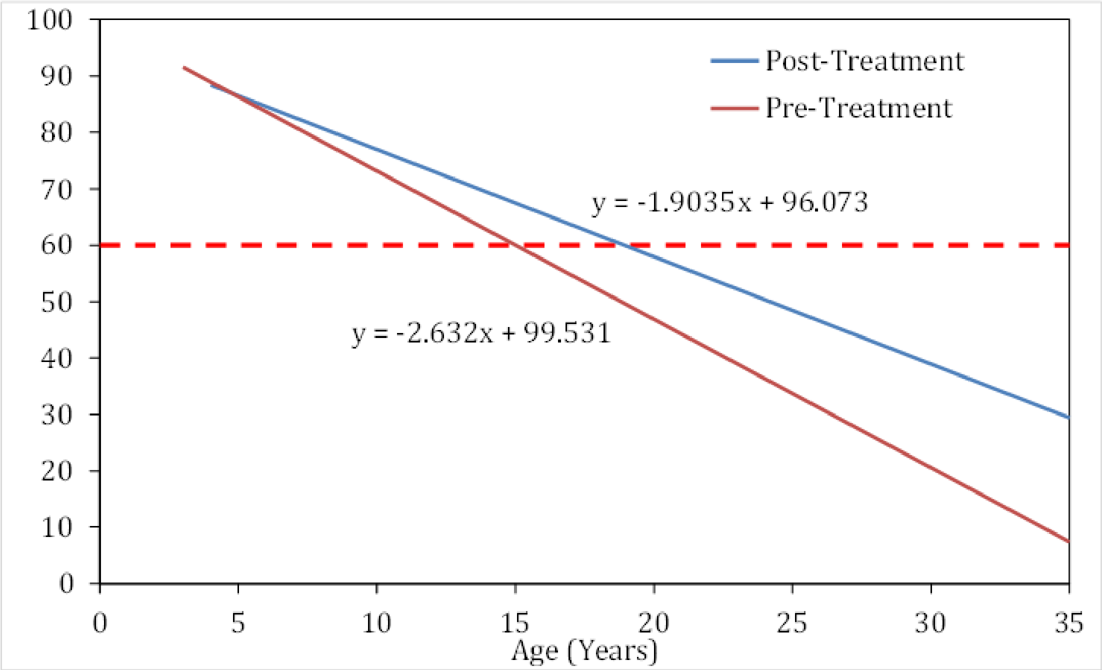


Figure 10. Pre- and Post-Treatment Pavement Performance for seal coat sections in climate 1.

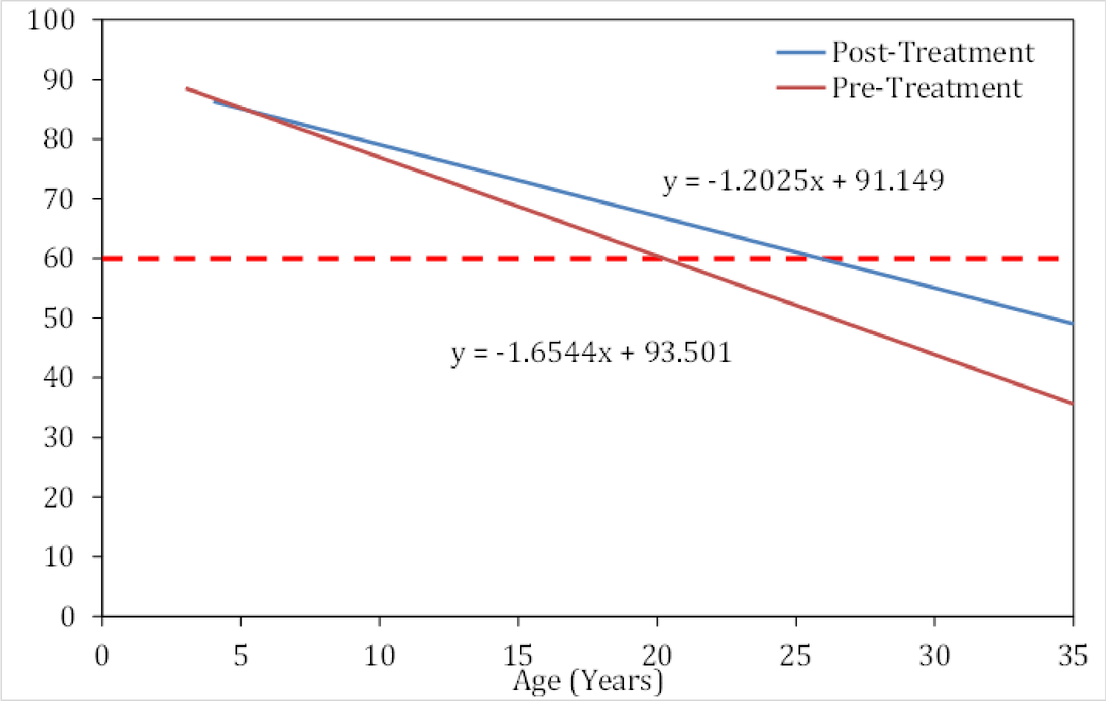


Figure 11. Pre- and Post-Treatment Pavement Performance for seal coat sections in climate 2.

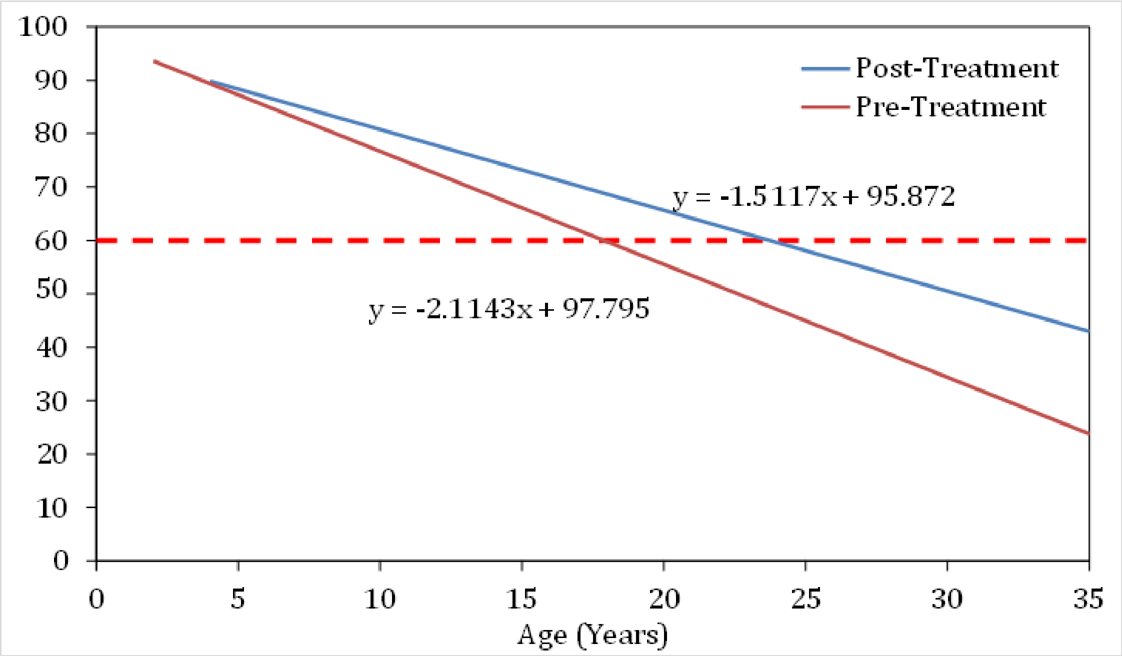


Figure 12. Pre- and Post-Treatment Pavement Performance for seal coat sections in BPN 3.

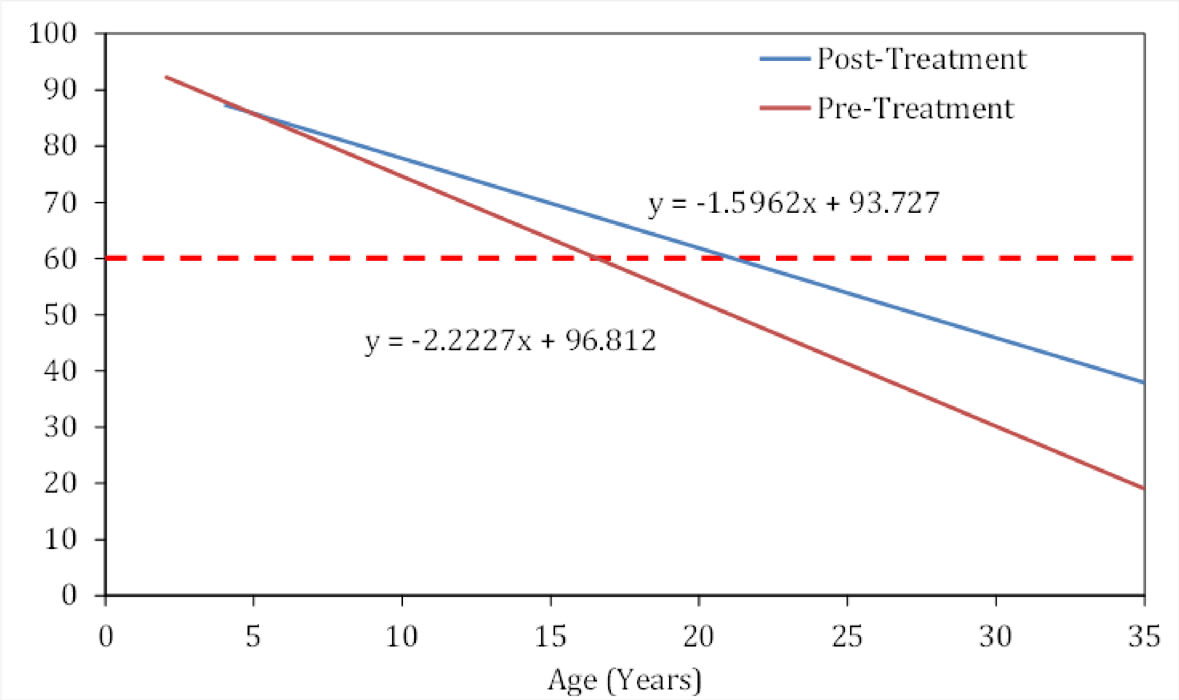


Figure 13. Pre- and Post-Treatment Pavement Performance for seal coat sections in BPN 4.

4.3.3 Performance Models for Crack Seal

Figure 14 through Figure 18 demonstrates the pre-treatment and post-treatment performance models for sections treated with crack seal. As indicated by Figure 14, the overall service life extension was found to be 1.5 years for crack seal for the entire network. Figure 15 and Figure 16 present the pre-treatment and post-treatment performance models. Unlike seal coat, no significant difference between service life extension was observed between the sections located in climate zone 1 and climate zone 2. The life extension in climate zone 1 and climate zone 2 was observed to be 1.67 and 1.21, respectively.

The life service extension for BPN 2 and BPN 3&4 are shown in Figure 17 and Figure 18, respectively. It was observed that service life extension for BPN 2 was 2.9 years as opposed to the service life extension of 1.1 years in BPN 3&4. BPN 2 pavement section consists of national highway systems, whereas BPN 3&4 are non-national highways including rural and urban roads. It is possible that the pavement sections from BPN 2 are composed of durable structures compared to BPN 3&4, which may contribute to the higher service life extension. However, further investigation is required to confirm exact reasons of this higher extension of service life due to crack seal application in BPN 2 compared to BPN 3&4. The summary of the performance models along with the life extension calculated from the performance models are also presented in Table 23.

Table 23. Pre- and Post-Treatment Pavement Performance.

	Pre-Treatment		Post-Treatment		Life Extension
	Performance Model	R^2	Performance Model	R^2	
Climate 1	y = -1.3878x + 98.255	$R^2 = 0.4152$	y = -1.3051x + 98.161	$R^2 = 0.4027$	1.7
Climate 2	y = -1.2651x + 97.848	$R^2 = 0.3019$	y = -1.1959x + 97.232	$R^2 = 0.3276$	1.2
Combined	y = -1.3161x + 98.023	$R^2 = 0.3417$	y = -1.2366x + 97.582	$R^2 = 0.3536$	1.5
BPN 1&2	y = -1.4476x + 98.216	$R^2 = 0.3608$	y = -1.2969x + 98.03	$R^2 = 0.4237$	2.9
BPN 3&4	y = -1.3365x + 97.17	$R^2 = 0.5331$	y = -1.2743x + 96.829	$R^2 = 0.4691$	1.1

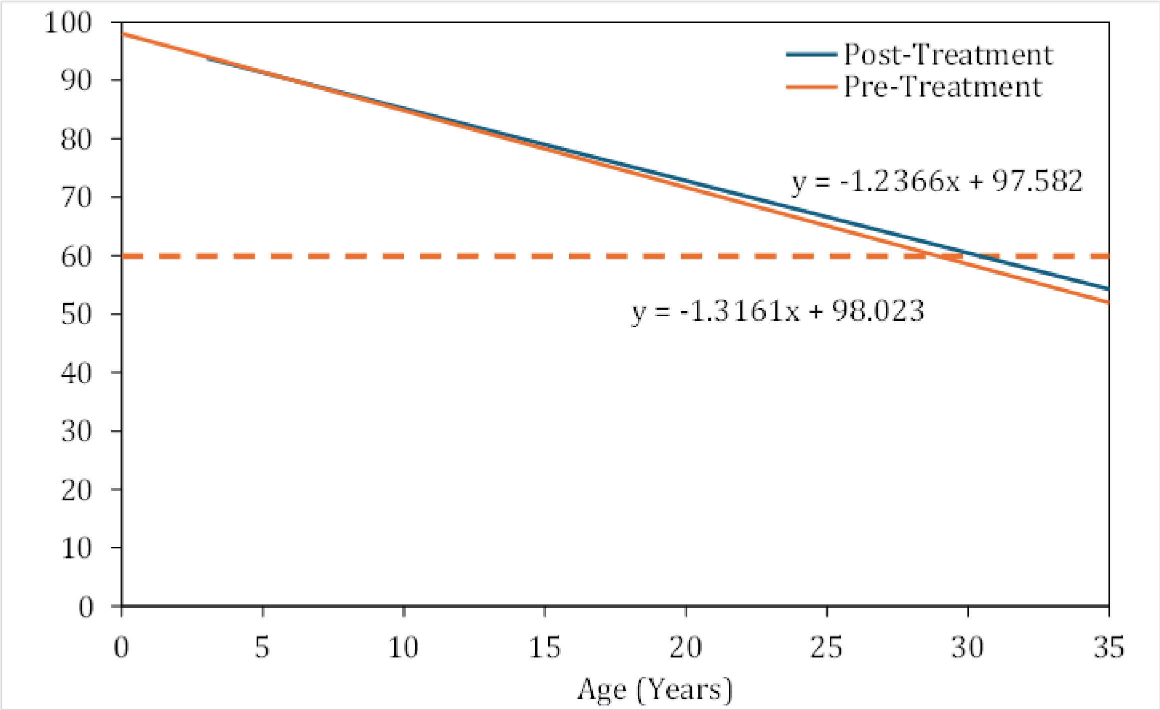


Figure 14. Pre- and Post-Treatment Pavement Performance for all crack seal sections.

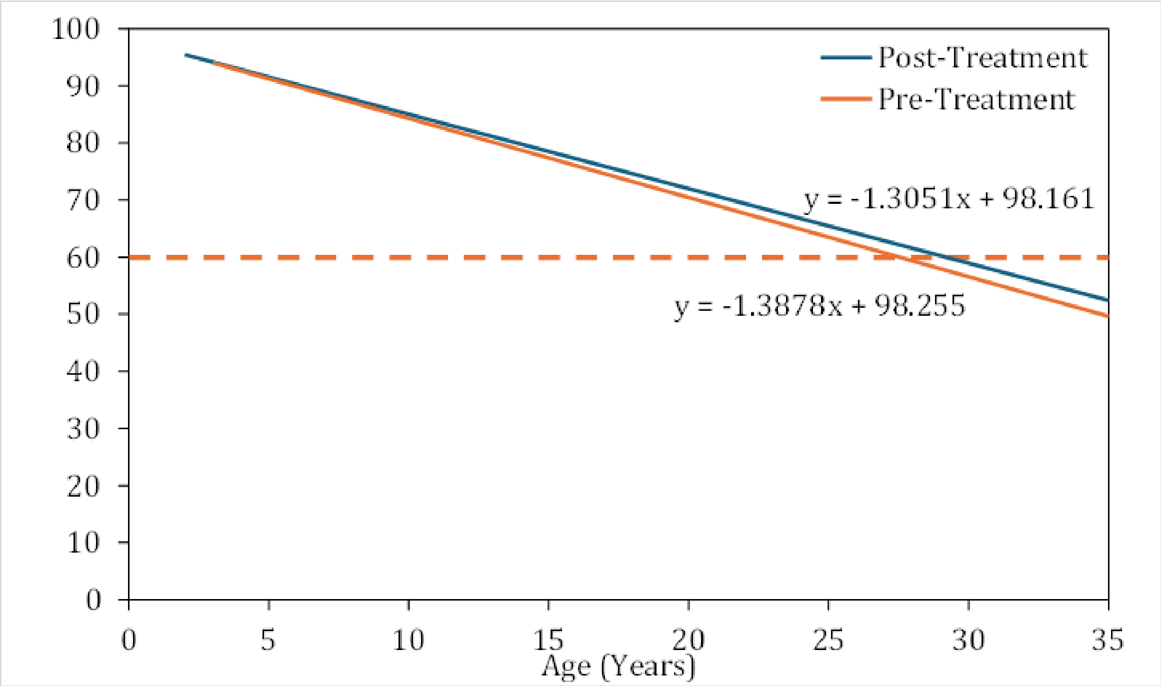


Figure 15. Pre- and Post-Treatment Pavement Performance for all crack seal sections in climate 1.

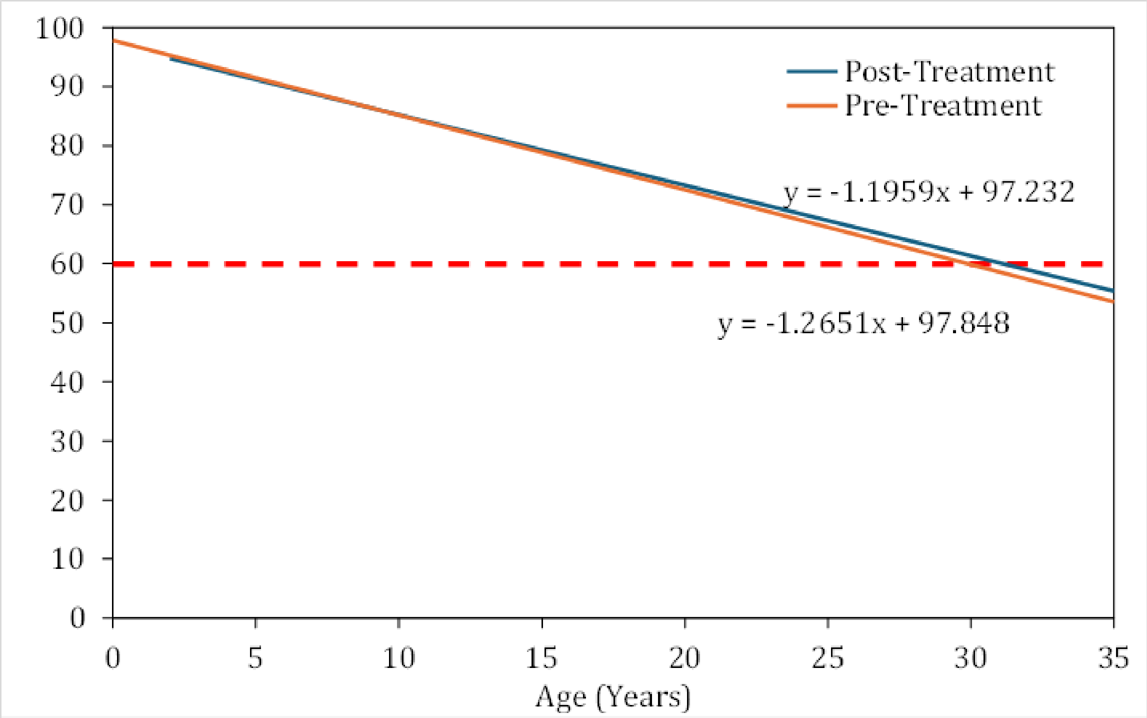


Figure 16. Pre- and Post-Treatment Pavement Performance crack seal sections in climate 2.

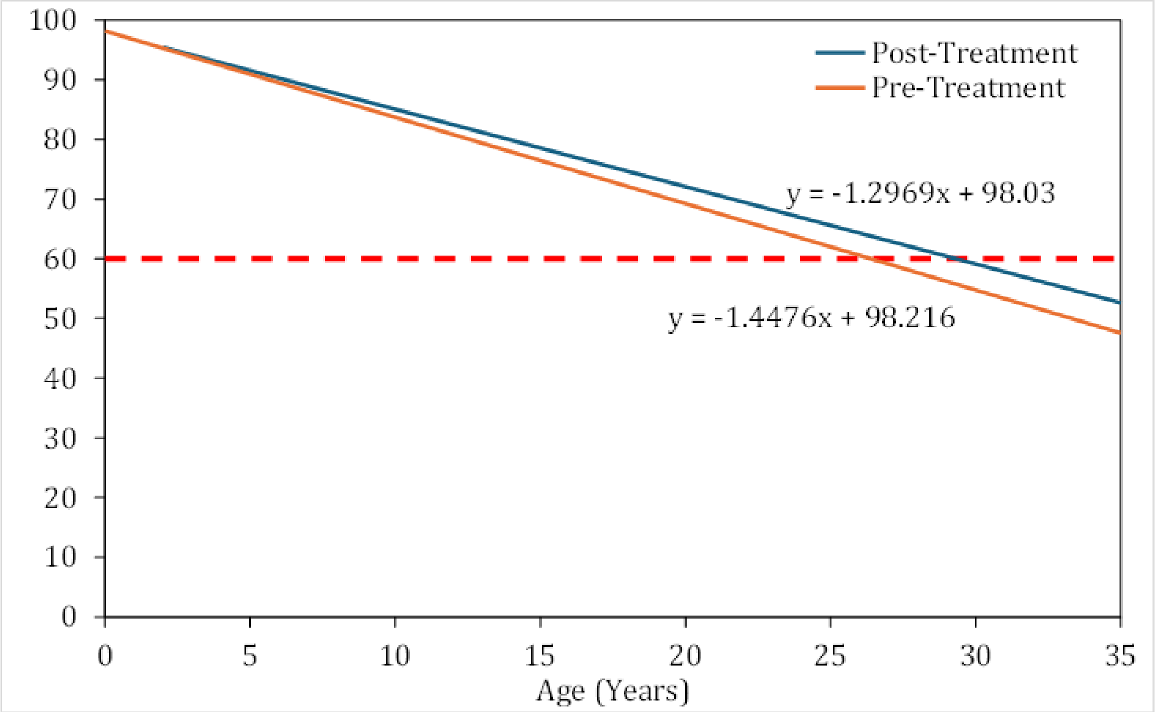


Figure 17. Pre- and Post-Treatment Pavement Performance for all crack seal sections in BPN 1&2.

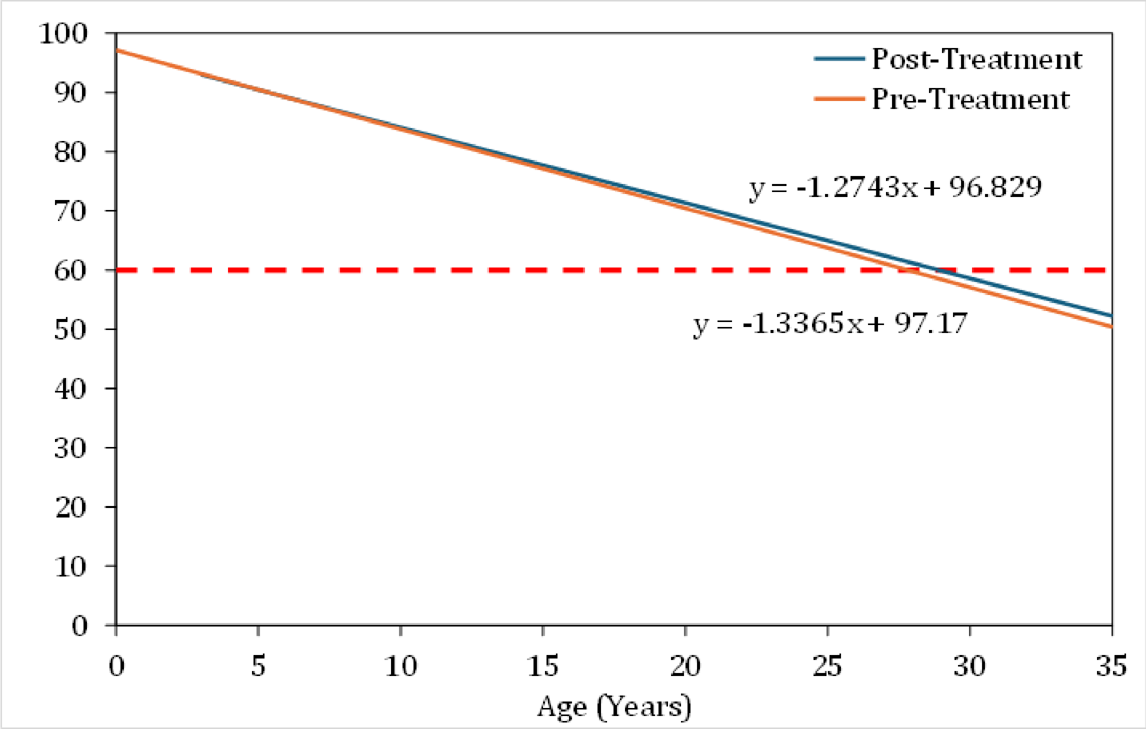


Figure 18. Pre- and Post-Treatment Pavement Performance for all crack seal sections in BPN 3&4.

4.3.4 Performance Models for Micro-Surfacing

Figure 19 through Figure 23 demonstrate the pre-treatment and post-treatment performance models for sections treated with micro-surfacing. As indicated by Figure 19, an overall service life extension of 7.2 years was found due to micro-surfacing application. Like seal coat, higher service life extension was observed in climate zone 2 compared to climate zone 1 (Figure 20 and Figure 21). However, for micro-surfacing the effect of climate zone on service life extension was less pronounced. The life service extension for BPN 2 and BPN 3&4 are shown in Figure 22 and Figure 23, respectively. It was observed that service life extension for BPN 2 was 8.15 years as opposed to the service life extension of 6.45 years in BPN 3&4. The summary of the performance models along with the life extension calculated from the performance models are also presented in Table 24.

Table 24. Pre- and Post-Treatment Pavement Performance.

	Pre-Treatment		Post-Treatment		Life Extension
	Performance Model	R^2	Performance Model	R^2	
Climate 1	y = -1.9355x + 97.032	$R^2 = 0.453$	y = -1.35x + 95.445	$R^2 = 0.4372$	7.1
Climate 2	y = -1.9355x + 97.032	$R^2 = 0.453$	y = -1.2891x + 94.557	$R^2 = 0.2882$	7.7
Combined	y = -2.2472x + 99.122	$R^2 = 0.4422$	y = -1.4861x + 96.604	$R^2 = 0.4206$	7.2
BPN 2	y = -1.9355x + 97.032	$R^2 = 0.453$	y = -1.296x + 95.37	$R^2 = 0.3036$	8.2
BPN 3&4	y = -1.9355x + 97.032	$R^2 = 0.453$	y = -1.4038x + 95.919	$R^2 = 0.4043$	6.5

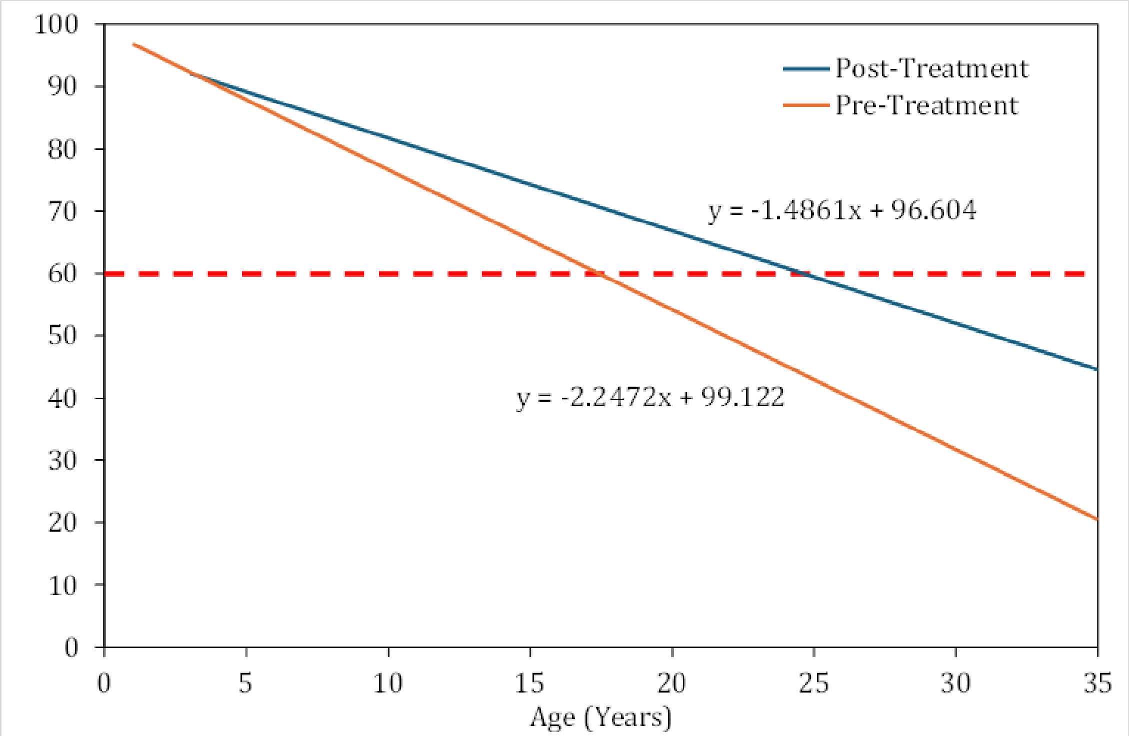


Figure 19. Pre- and Post-Treatment Pavement Performance for all micro-surfacing sections.

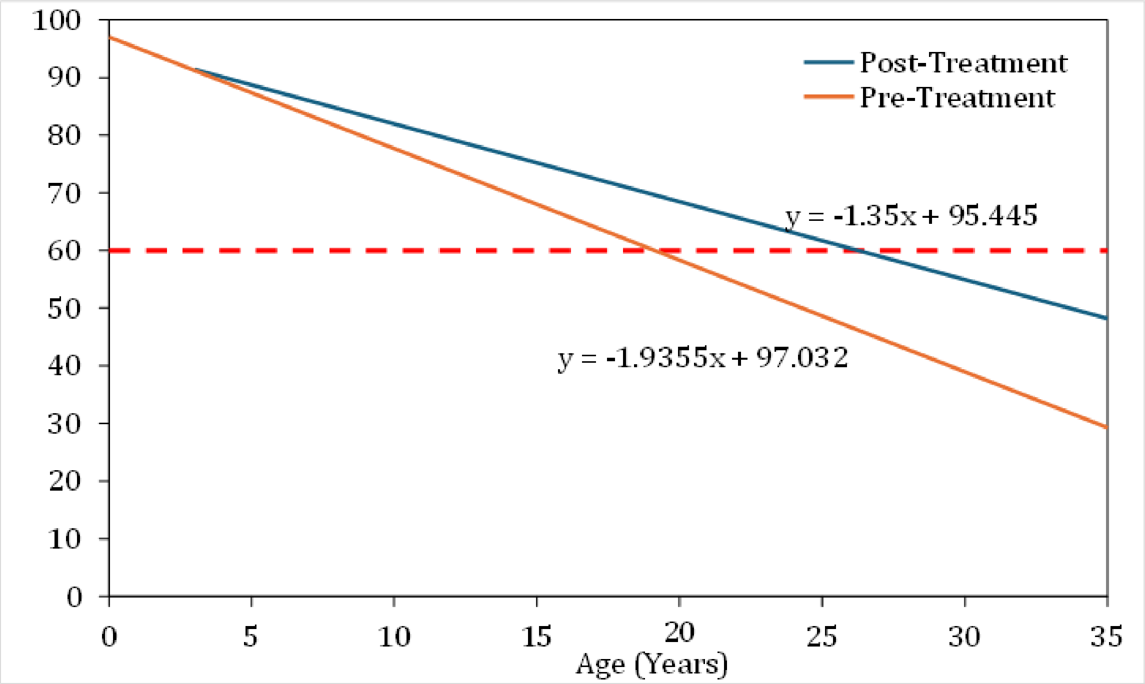


Figure 20. Pre- and Post-Treatment Pavement Performance for all micro-surfacing sections in climate 1.

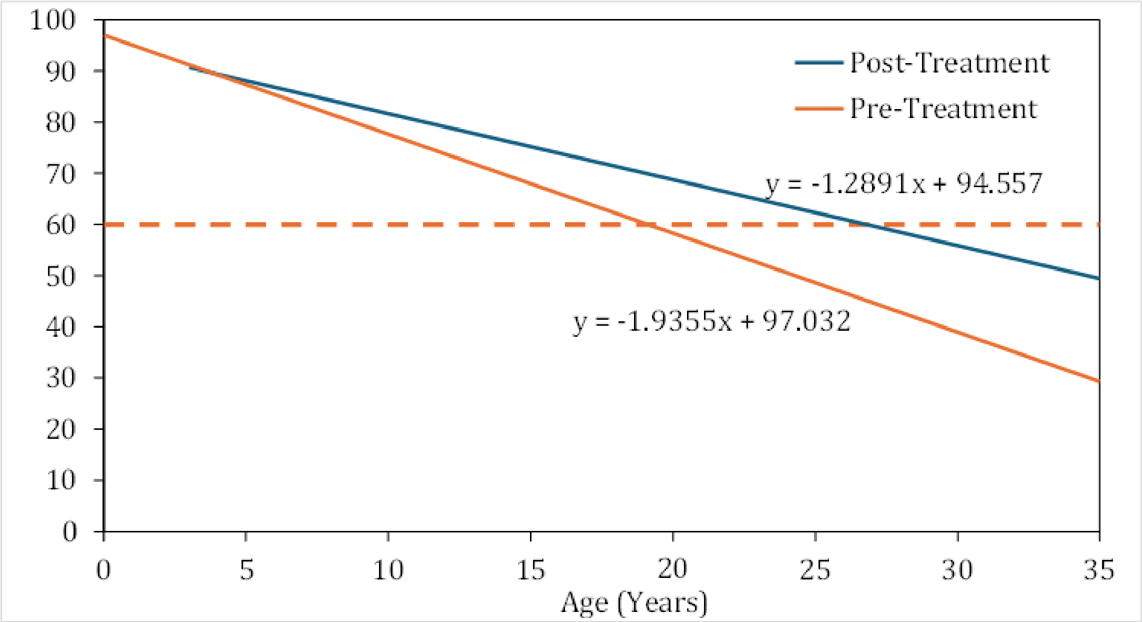


Figure 21. Pre- and Post-Treatment Pavement Performance for all micro-surfacing sections in climate 2.

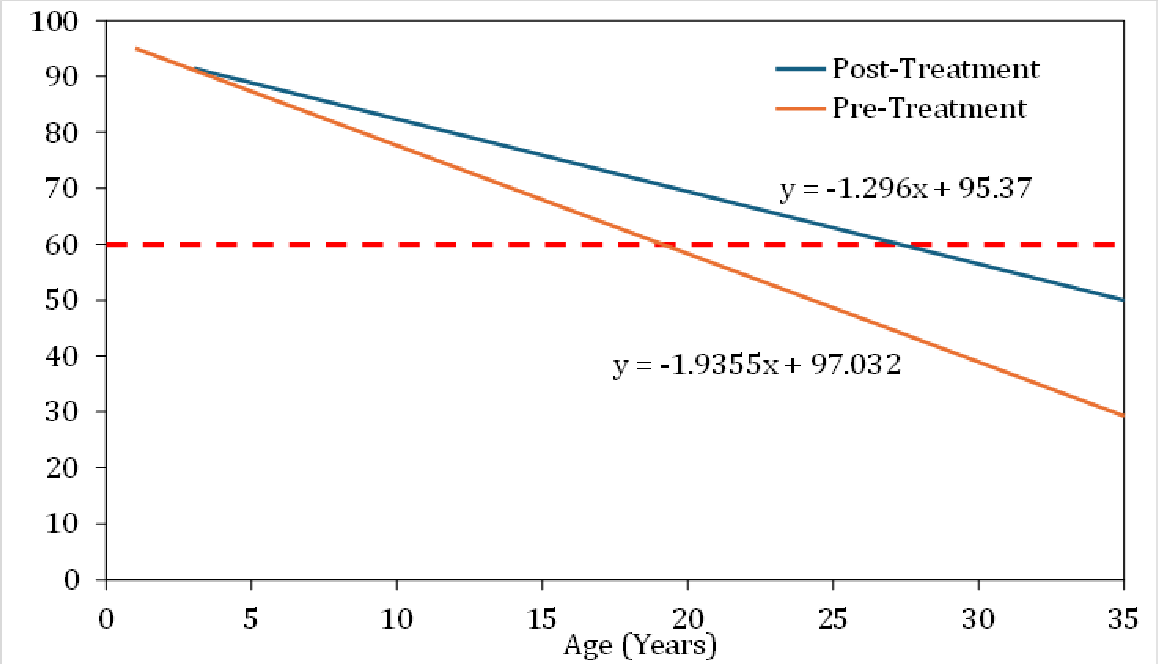


Figure 22. Pre- and Post-Treatment Pavement Performance for all micro-surfacing sections in BPN 2.

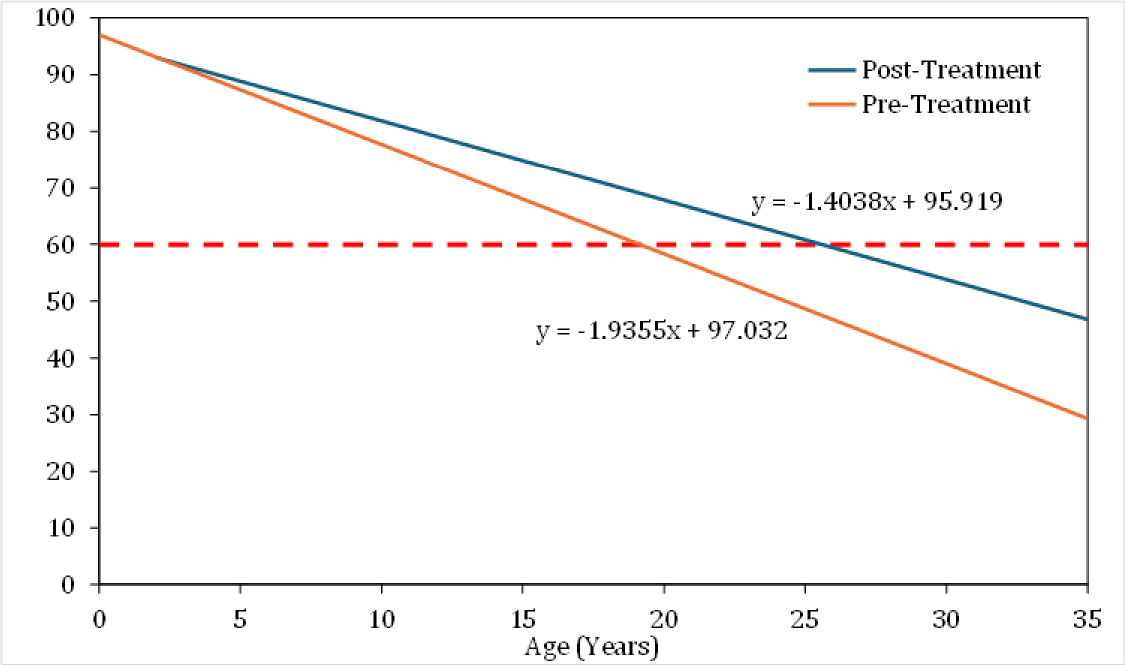


Figure 23. Pre- and Post-Treatment Pavement Performance for all micro-surfacing sections in BPN 3&4.

4.3.5 Performance Model for Novachip

The pre-treatment and post-treatment performance models for sections treated with Novachip are shown in Figure 24. Due to the limitation of the data availability the analysis was confined to the sections from BPN 1 and located in climatic zone 1. As shown in Figure 24, the service life extension due to the application of Novachip was found to be 9 years. Table 25 presents the performance models and life extension for a Novachip. Among all the preservation treatments, the service life extension was maximum Novachip. The outcome of the results is consistent with previous studies where researchers have found higher service life extension for Novachip compared to the other pavement preservation treatment included in this study (Morian, 2011).

Table 25. Pre- and Post-Treatment Pavement Performance.

Pre-Treatment		Post-Treatment		Life Extension
Performance Model	R^2	Performance Model	R^2	
y = -1.198x + 95.314	$R^2 = 0.4979$	y = -1.0541x + 100.58	$R^2 = 0.7162$	9.1

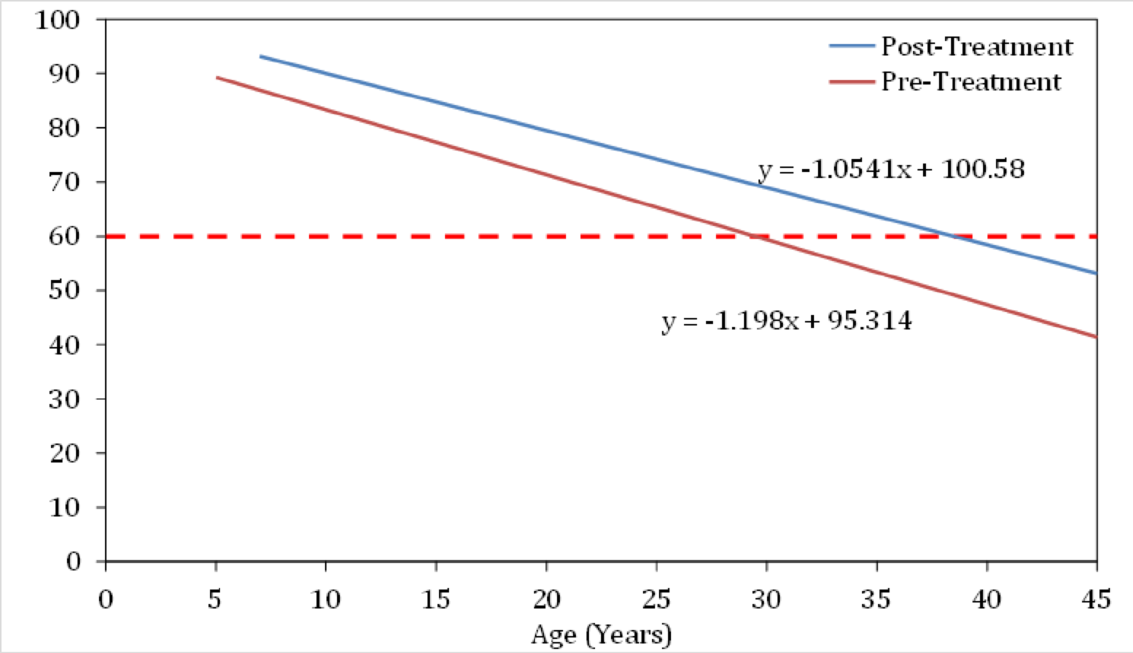


Figure 24. Pre- and Post-Treatment Pavement Performance for Novachip sections (climate 1 and BPN 1).

Numerous studies have reported that the pre-existing condition of the pavement is the single most important factor determining the service life of the treatment (Talha et al., 2022; Wang et al., 2013). Since pavement preservation treatments do not add any structural capacity, the service life of preservation treatments is significantly compromised when the treatments are applied on pavements that may have structural deficiency. On the contrary, optimum service life extension may not be obtained if the treatment is applied when the pavement is in excellent condition.

To further investigate the effect of pre-treatment pavement condition on the service life extension of seal coat and crack seal, the overall datasets for seal coat and crack seal were split based on varying ranges of pre-treatment OPI and the service life extension was calculated based on different pre-treatment condition. The effect of pre-treatment OPI on the service life extension was not evaluated for micro-surfacing and Novachip due to lack the data availability for different pre- treatment OPI ranges.

Figure 25 shows the service life extensions of pavement sections due to seal coat applied at different pre-treatment condition. Figure 25 clearly depicts the service life extension is dependent on the pre-treatment condition of the pavement section. As shown in Figure 26, no service life extension was observed when seal coat was applied when pre-treatment OPI was more than 80.

The service life extension reached its peak (5.8 years) when seal coat was applied at pre-treatment OPI between 70-80. The results suggests that relatively higher service life extension can also be obtained for seal coat if seal coat is applied at pre-treatment OPI between 60-70. However, service life extension significantly reduced when pre-treatment OPI was less than 60. Therefore, the results based on this study indicate that seal coat should be applied when OPI of the pavement is within the range of 70-80 to obtain the optimum service life extension.

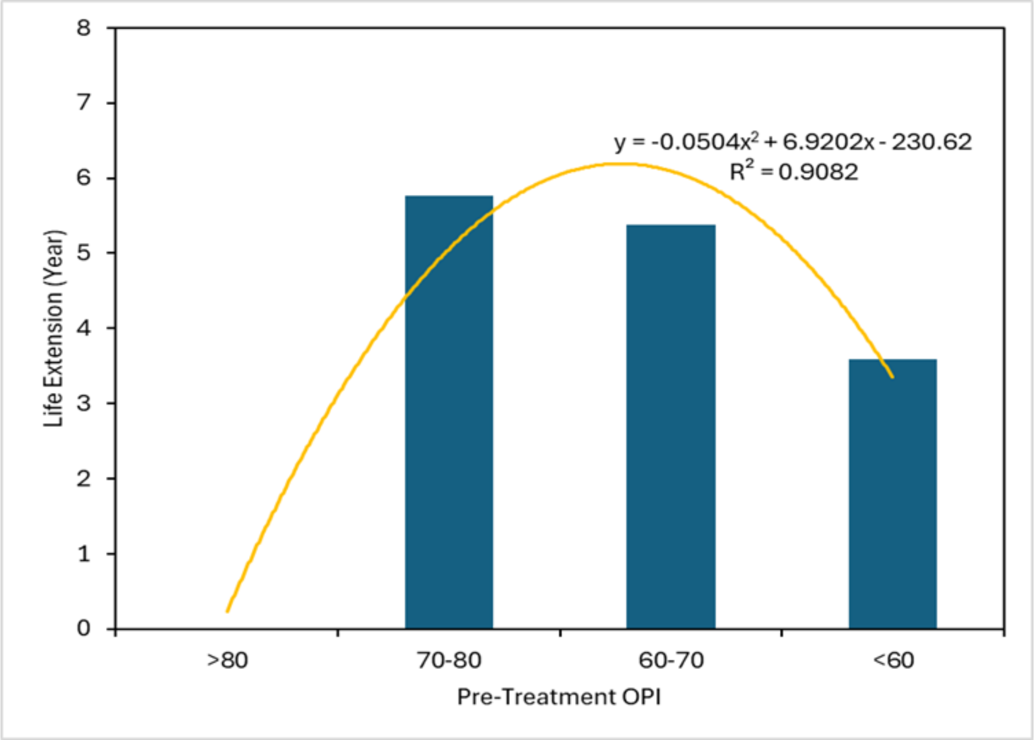


Figure 25. Life Extension of Seal Coat Applied at Different OPI Conditions.

Figure 26 shows the service life extensions of pavement sections due to crack seal applied at different pre-treatment condition. The maximum service life extension of 2.9 years due to crack seal application was observed when crack seal applied pavement OPI was above 90. A satisfactory 2.7 years of service life extension was observed at pre-treatment OPI of 80-90. However, the service life extension decreased when pre-treatment OPI was below 80. Therefore, results from this study suggest that crack seal should be applied to a pavement section when pre-treatment OPI is at least 80 to obtain satisfactory life service extension. It is worth mentioning that the applicability of crack seal also depends on the width of the crack. PennDOT typically recommends crack seal to be applied on cracks with ¼”to 1” in width.

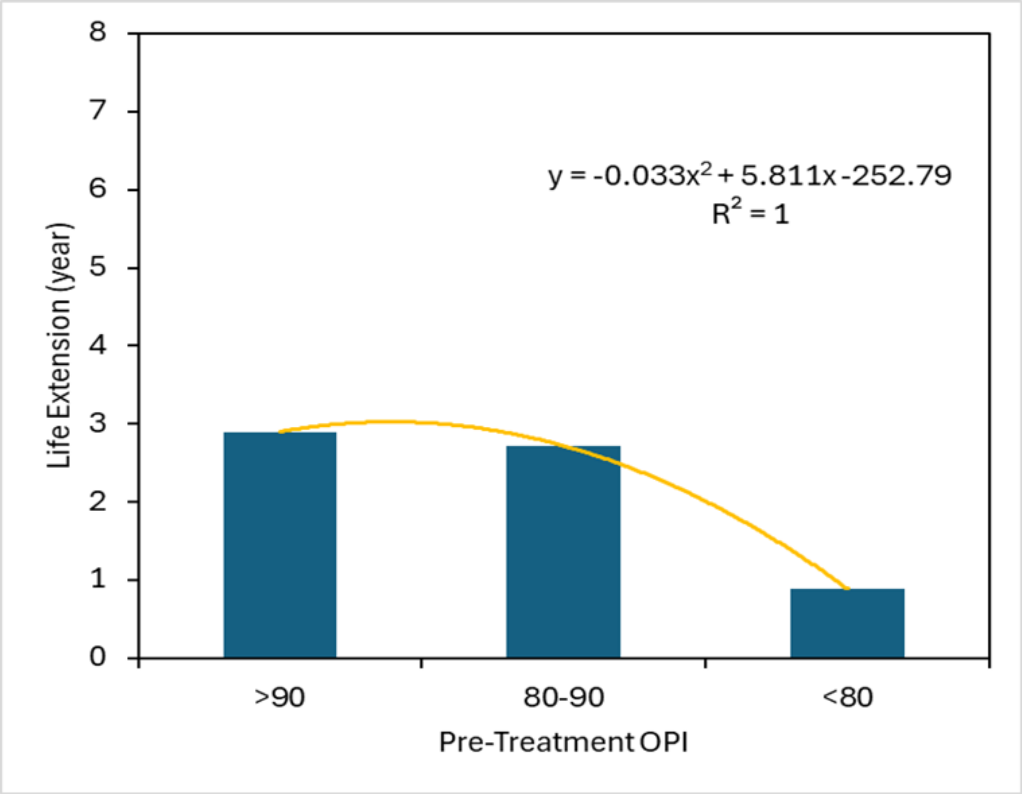


Figure 26. Life Extension of Crack Seal Applied at Different Pre-Treatment Age.

4.3.6 Effect of Pre-Treatment Pavement Age on Service Life Extension

To further investigate the effect of pre-treatment pavement age on the service life extension of seal coat, crack seal, and micro-surfacing, the datasets for these treatments were divided into different pre-treatment age category, including:

a) pre-treatment age < 4 years,
b) pre-treatment age of 5 &6 years,
c) pre-treatment age of 7&8 years,
d) pre-treatment age of 9&10 years, and
e) pre-treatment age >10 years.

The pre-treatment and post-treatment performance model were generated for each dataset to obtain the service life extension of the three treatments, mentioned above, applied at different pre-treatment age. The effect of pre-treatment age of service life extension of Novachip application was not included due to limited data for different pre-treatment age groups.

Figure 27 shows the service life extension of seal coat applied at different pre-treatment age. It is interesting to note that no extension in service life was observed when the seal coat was applied when the pre-treatment age of the pavement sections was less than or equal to 4. The maximum service life extension was observed when seal coat is applied on pavement sections with pre- treatment age between 7 and 8 years. Based on the results of this study, applying seal coat on pavement sections with pre-treatment age greater than 10 years provided the least benefit in terms of service life extension.

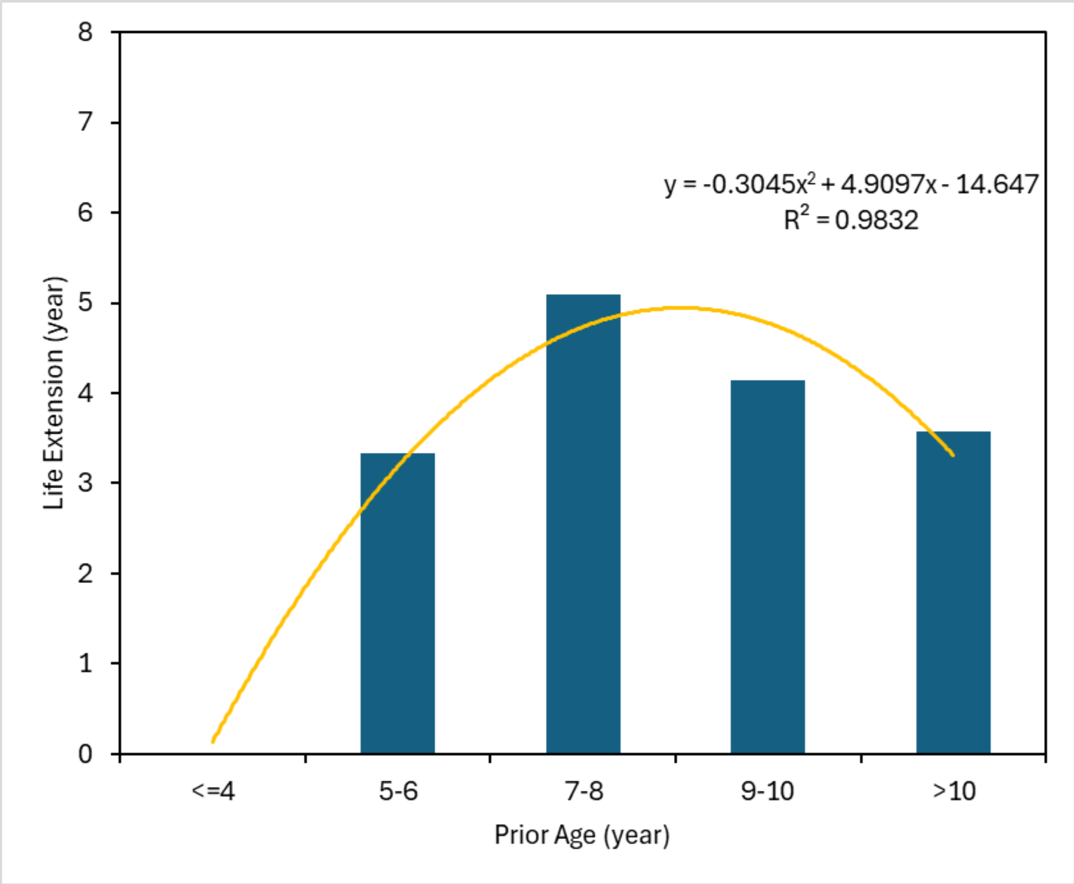


Figure 27. Life Extension of Seal Coat Applied at Different Pre-Treatment Age.

The service life extension of crack seal applied at different pre-treatment age is shown in Figure 3.27. As shown by Figure 28, satisfactory levels of service life extensions are observed if the pre- treatment age of the pavement was less than 7 years, with maximum service life extension of 3.3 years when the pre-treatment age was between 5-6 years. After pre-treatment age of 7 years, the life service extensions were significantly reduced. Finally, the service life extension of micro- surfacing applied at different pre-treatment age is shown in Figure 29. As shown by Figure 29, the service life extensions are comparatively higher when the pre-treatment age during the application of micro-surfacing was within the range of 5-8 years, with the maximum service life extension of 7.9 years when the pre-treatment age was 7-8 years.

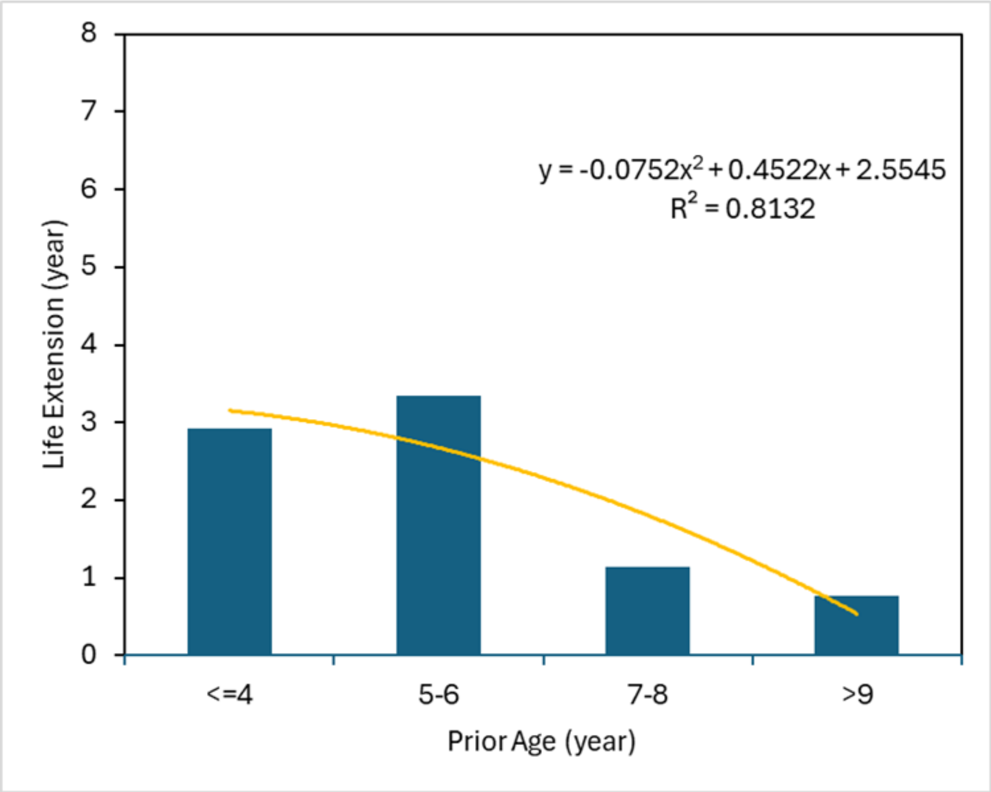


Figure 28. Life Extension of Crack Seal Applied at Different Pre-Treatment Age.

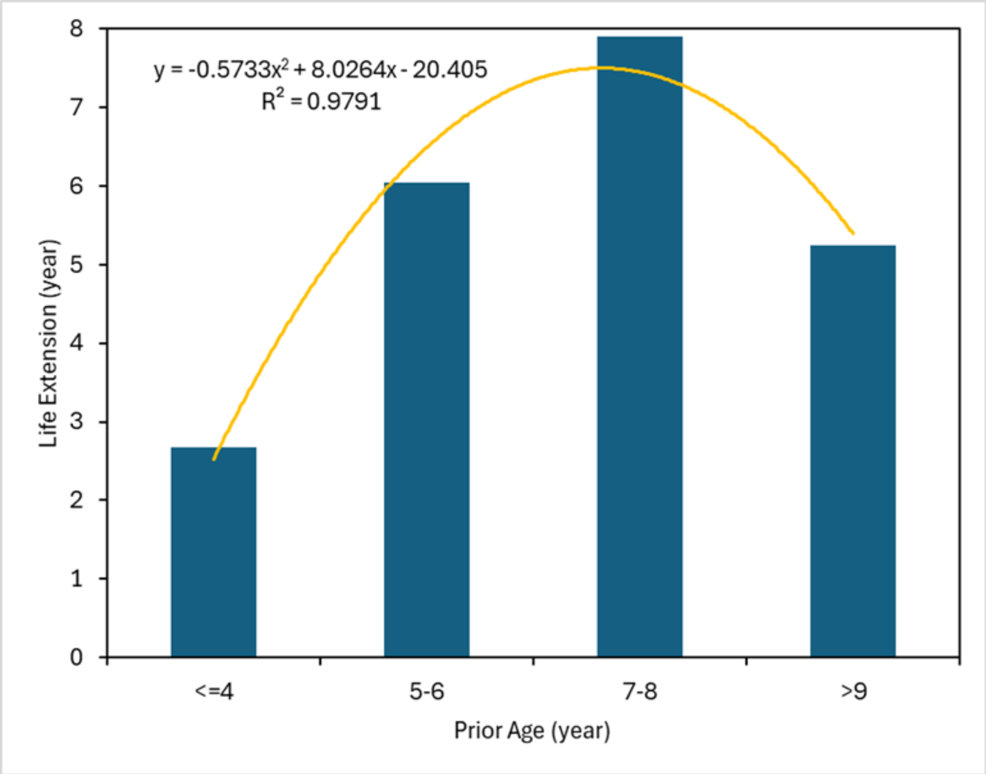


Figure 29. Life Extension of Micro-Surfacing Applied at Different Pre-Treatment Age.

The second order polynomial functions for the life extension at various pre-treatment age and OPI are shown in Figure 3.17 through Figure 3.21 The relationships can be used to obtain the service life extension at any given pre-treatment OPI and pre-treatment age for the selected preventative maintenance treatments. The polynomial equations presented in Figure 3.24 and Figure 3.25 describe the relationship between the service life extension and the pre-treatment OPI for seal coat and crack seal, respectively. The polynomial equations presented in Figure 3.26, Figure 3.27, and Figure 3.28 describe the relationship between the service life extension and the pre-treatment age for seal coat, crack seal, and micro-surfacing, respectively.

5 ROADMAP OF ANALYSIS STEPS

The roadmap of the analysis steps is shown in Figure 30. The first task was to conduct a comprehensive literature review to document the practices related to preventative treatments. In addition, a questionnaire survey was conducted to document the practices of peer states regarding the preventative treatments. The first step in data analysis shown in Tasks 2-4 was to combine the historical performance dataset, pavement layer dataset, and treatment construction dataset. The next step included filtering out sections with multiple treatments and sections constructed before year 2000. The filtered dataset was utilized to develop performance models for the various preventative maintenance treatments based on the key featured identified from the literature search and discussion with the PennDOT research team. Finally, service life extension was calculated as the difference between the service life at OPI of 60 for the pre-, and post-treatment models. Final recommendations were provided based on the results obtained in the analysis phase. Furthermore, a Microsoft ® excel based tool was developed as a part of this study. This tool can be used by PennDOT to make informed decision to select optimal types and timings of treatment.

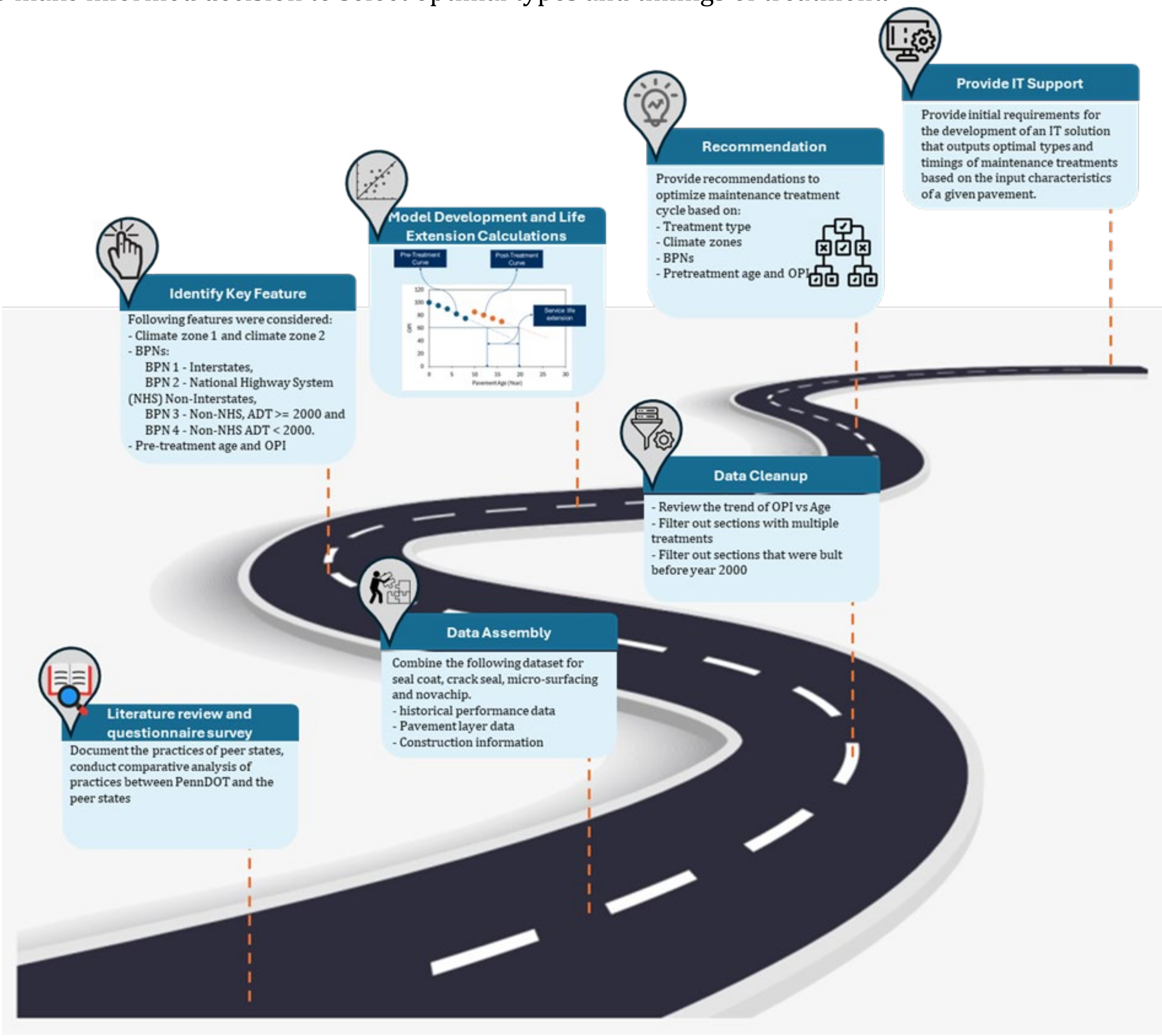


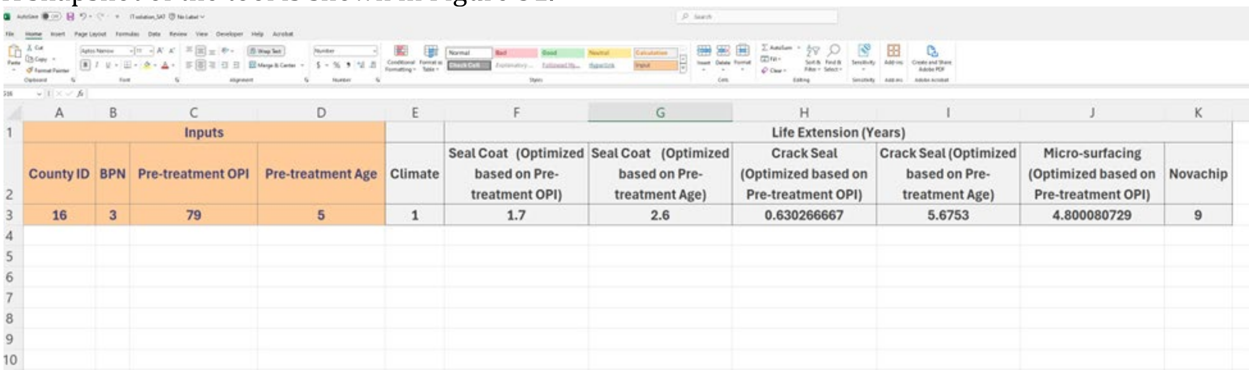
Figure 30. Roadmap of the Analysis.

6 DEVELOPMENT OF INITIAL REQUIREMENTS FOR AN INFORMATION TECHNOLOGY (IT) SOLUTION

ARA developed a Microsoft® Excel based tool to determine the life extension based on pre- treatment OPI and pre-treatment age for the various preventative maintenance treatments. The tool is based on the models developed in this report and will require the following inputs. This tool will allow the user to determine life extension of individual counties based on the maintenance treatments applied.

- County ID
- BPN
- Pre-Treatment OPI
- Pre-Treatment Age

A snapshot of the tool is shown in Figure 31.



Inputs					Life Extension (Years)					
County ID	BPN	Pre-treatment OPI	Pre-treatment Age	Climate	Seal Coat (Optimized based on Pre-treatment OPI)	Seal Coat (Optimized based on Pre-treatment Age)	Crack Seal (Optimized based on Pre-treatment OPI)	Crack Seal (Optimized based on Pre-treatment Age)	Micro-surfacing (Optimized based on Pre-treatment OPI)	Novachip
16	3	79	5	1	1.7	2.6	0.630266667	5.6753	4.800080729	9

Figure 31. A snapshot of the Developed Microsoft Excel Spreadsheet to Calculate Service Life Extension.

In addition, the following section outlines steps required to extract relevant data from the pavement databases, develop performance models and obtain life cycle extension due to application of a preventative treatment. The following steps can be replicated in future to accommodate new data to fine tune existing models or develop models for a new treatment type that were not included in this analysis.

The following PennDOT databases are required for this analysis:

1. Database A: Historical performance data from 2011 to 2021. Required for obtaining the OPI (Overall Pavement Index) data from 2011 to 2021.
2. Database B: Treatment types and the construction date for various treatments.
3. Database C: Pavement layer information and the construction date. Required to identify the latest major rehabilitation date which is used as the starting age for a pavement section.

Each database includes key information (district, county, route number, segment begin, and segment end) that can be used to create a unique identifier for each pavement section. The databases can be combined using the following unique ID format:

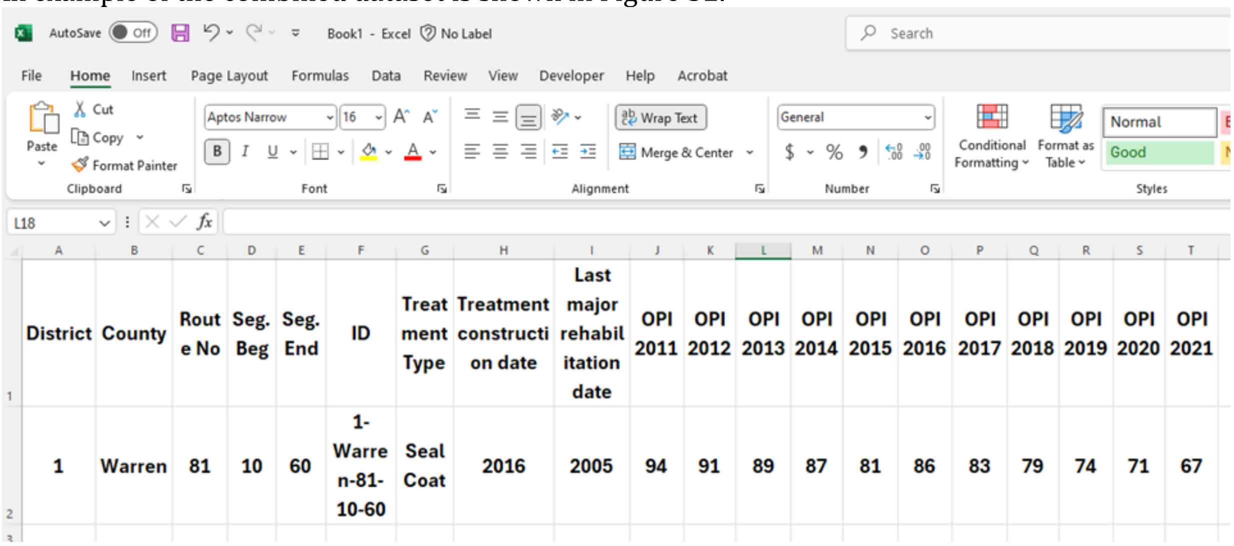
“District-County-Route No-Segment Begin-Segment End”

The combined dataset must include the following attributes:

- District
- County
- Route Number

- Segment Begin
- Segment End
- OPI (2011-2021)
- Treatment Type
- Treatment Construction Date
- Last Major Rehabilitation Date

An example of the combined dataset is shown in Figure 32.



District	County	Route No	Seg. Beg	Seg. End	ID	Treatment Type	Treatment construction date	Last major rehabilitation date	OPI 2011	OPI 2012	OPI 2013	OPI 2014	OPI 2015	OPI 2016	OPI 2017	OPI 2018	OPI 2019	OPI 2020	OPI 2021
1	Warren	81	10	60	1-Warren-81-10-60	Seal Coat	2016	2005	94	91	89	87	81	86	83	79	74	71	67

Figure 32. A Snapshot of the Combined Dataset with the Attributes Required for Performance Models Development.

For the example shown above in Figure 32, a seal coat treatment was applied in 2016. Therefore, OPI data from 2011 to 2015 is used to develop the pre-treatment curve, and OPI data from 2016 to 2021 is used to develop the post-treatment curve. The curves are plotted by age (calculated from the year of the last major rehabilitation) on the x-axis and OPI on the y-axis. For example, if the last major rehabilitation was in 2005, the pavement age in 2011 would be 6 years. Once the age is calculated, the age vs. OPI data is plotted for both pre- and post-treatment periods.

The performance model is developed for both pre- and post-treatment conditions by fitting linear regression lines to the age vs. OPI data. Once the performance models are established, the service life corresponding to an OPI of 60 (as per Morian, 2011) is calculated for both pre-treatment and post-treatment models. This process is illustrated in Figure 33.

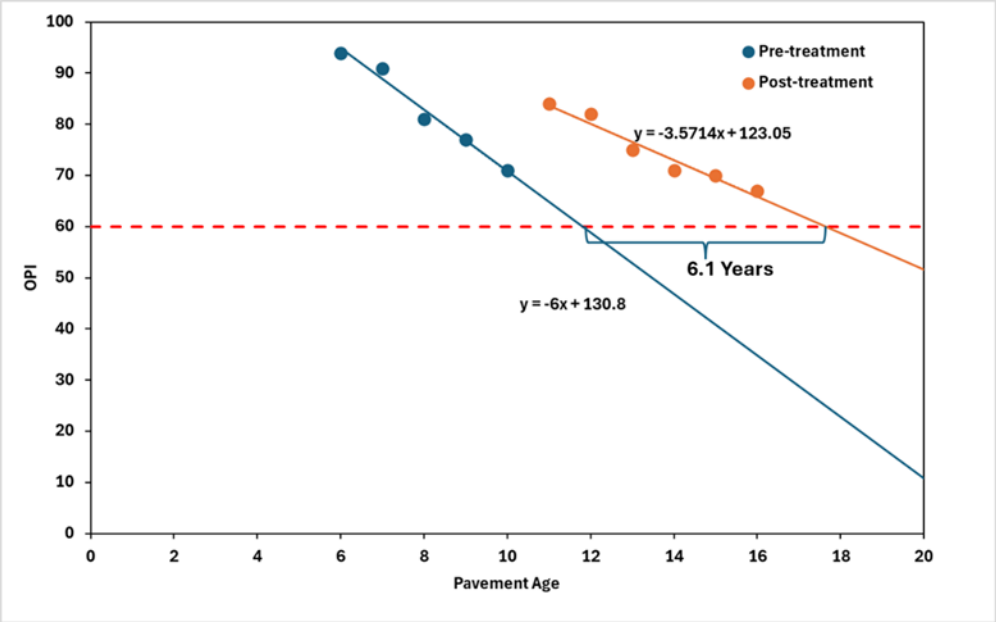


Figure 33. Life Service Extension Calculation.

To ensure the validity of the performance models, the following filtering criteria were applied:

- The performance curves were developed based on the performance data from 2011 to 2021.
- Typically, OPI decreases with age as the pavement deteriorates unless a treatment is applied. In cases where OPI increased with age without any work done, the data was eliminated from analysis.
- A section was included for analysis only if the considered treatment was the first applied treatment after any major rehabilitation. For example, if two pavement sections were constructed in year 2000, one received micro-surfacing in year 2013 and the other micro-surfacing in years 2005 and 2013, only the first section was considered for analysis to eliminate any bias due to previously applied treatments, sections that had received treatment/treatments between the construction year and 2011, was not included in the analysis.
- Only the sections that were reconstructed or rehabilitated on or after 2000 were included in the database.
- The pavement surface age was calculated from the year of last major rehabilitation. If a subsequent treatment was applied, data after the application of the treatment was not included in the analysis.

7 CONCLUSIONS AND RECOMMENDATIONS

The goal of this study was to estimate the optimum maintenance cycle for the preservative treatments commonly used in Pennsylvania. The maintenance cycle was determined based on the life service extension due to application of these treatments. To this end, the analysis was conducted on seal coat, crack seal, micro-surfacing, and Novachip. Life service extension for the considered treatments was determined with respect to different climate zones and BPNs. In addition, service life extension of these treatments was determined based on different pre- treatment OPI and age to determine the most suitable time of application to achieve the optimal service life extension from these preservative treatments.

The life service extension analysis indicated that the overall estimated service life of seal coat, crack seal, micro-surfacing was 4.6 years, 1.5 years, 7.2 years, and 9.0 years, respectively. The service life for seal coat varied significantly based on different the climate zones. The service life extension for seal coat in warmer region (climate zone 2) was found to be 5.6 years as opposed to service life extension of 3.9 years in colder region (climate zone 1). The service life extensions for crack seal in climate zone 1 and climate zone 2 were found to be 1.6 years and 1.2 years, respectively. Finally, the service life extensions for micro-surfacing in climate zone 1 and climate zone 2 were found to be 7.1 years and 7.7 years, respectively. Service life extension analysis based BPNs indicated that in general, lower BPN yielded higher service life extension for all preservation treatment. The service life extension for seal coat was found to be 5.8 years and 4.6 years for BPN 3 and BPN 4, respectively. Crack seal had service life extension of 2.9 years in BPN 2, whereas service life extension of 1.1 years for crack seal was observed in BPN 3 and BPN 4. For micro-surfacing, service life extension was observed to be 8.1 years in BPN 2, as opposed to life extension of 6.5 years in BPN 3 and BPN 4.

The results indicated that the optimal timing for various pavement treatments to achieve the highest possible service life extension varies based on the pavement's condition and age. For seal coat application, the optimal service life extension was obtained when the pre-treatment OPI is between 70-80 or when the pavement is 7-8 years old. Crack sealing is most effective when the pre- treatment OPI is greater than 90 or the pavement is less than 6 years old. Lastly, micro-surfacing achieves the highest service life extension when applied to pavements that are 7-8 years old.

Based on the obtained results, following recommendations are proposed to further optimize the maintenance treatment cycle:

- Life service extensions seem to vary based on climatic zones and BPNs for certain treatment, including seal coat and micro-surfacing. Therefore, climatic zones and BPNs are important factors to consider while selecting the maintenance cycle.
- In addition to service life extensions, life cycle cost should also be considered while selecting the most suitable treatment from a batch of similar treatment (i.e., micro- surfacing, Novachip, and seal coat). Conducting life cycle cost analysis was beyond the scope of this study. Nonetheless, it is recommended to conduct further research on life cycle cost the considered treatment.
- Apart from the pre-treatment OPI and pre-treatment age, other factors, such as pavement structural condition, crack width, and type of pavement deficiencies can be considered for selecting the optimal treatment type.

APPENDIX A: REQUIREMENTS FOR SEAL COAT, CRACK SEAL, MICROPAVING, MICRO-SURFACING, MASTICS AND REJUVENATORS FOR SPECIFIC DOTS.

Agency	Seal Coat							
	Emulsion		Aggregate	Traffic restriction	Alternative treatment	Treating seal coat with fog seal	Weather Requirement	Suitability
MnDOT	CRS-2P		Use fine aggregate following the gradation table.	AADT<10000.	Micro-surfacing, Thin lift overlay and UTBWC.	A fog seal (CSS-1h) is recommended on all applications to reduce long term aggregate loss and potential vehicle damage. Fog seal can be placed as soon as one day after the seal coat.	Seal coats are placed from May 15 to August 10 in the northern part of the state and May 15 to August 31 in the southern portion of the state. Seal coats are placed during day light hours when the pavement and air temperatures are 60°F and rising and free of foggy conditions. Not recommended on surfaces with standing water.	Pavement distresses including low severity longitudinal, transverse, and block cracking, raveling/weathering (loose material must be removed), friction loss, and moisture infiltration. Not Suitable for: crack seal/fill candidate, rutting >0.5 inch, any load related distress.
WisDOT	NA		Follows fine aggregate gradation.	NA	NA	NA	NA	NA
PennDOT	Application of emulsion followed by coarse aggregate	RS-2P, CRS-2P, HFRS-2P,RS-2,CRS-2,HFRS-2 (use non polymer modified emulsion on municipal projects and State projects approved by the District Executive in writing)	Follows fine aggregate gradation.	1,000 ADT	NA	Emulsion for fog seal: CSS-1h, SS-1h, SS-1hPM, and CSS-1hPM emulsion must be diluted with 1 part emulsion to 1 part water Use a Cationic Emulsified Asphalt material CSS-1h when a Cationic Emulsified	Apply emulsified asphalt when the air, surface, and aggregate temperatures are above 60F. Not recommended if rain is imminent or freezing temperatures are expected within 24 hours after application.	NA

Agency	Seal Coat							
	Emulsion		Aggregate	Traffic restriction	Alternative treatment	Treating seal coat with fog seal	Weather Requirement	Suitability
	Application of emulsion followed by asphalt precoated aggregate	Precoating asphalt materials: MC-30, MC-70, SS-1h, CSS-1h, PG 64S-22, PF 58S-28 Asphalt material: RS-2, CRS-2, PG 46S-40 (on shoulders only) Precoating with 0.4 to 1% residual binder with cutback / emulsion. Precoating with 0.6% to 1.2% residual binder with asphalt cement.	Follows fine aggregate gradation.	NA	NA	Asphalt was used for the Asphalt Seal Coat. Use an Anionic Emulsified Asphalt material SS-1h when an Anionic Emulsified Asphalt was used for the Asphalt Seal Coat	NA	NA
	Asphalt seal coat with RAP	RS-2P, CRS-2P,HFRS-2P, RS-2, CRS-2, HFRS-2	Follows RAP gradation.	Requires District Executive approval for routes with ADT > 1000. Not recommended if ADT > 5000.			Application recommended when roadway surface Temperature is below 120F.	NA

MnDOT						WisDOT		PennDOT		
Sieve No	FA-1	FA-2	FA-2 1/2	FA-3	FA-3 1/2	Sieve No	% Passing	seal coat with coarse aggregate coated or uncoated		seal coat with RAP
	% Passing	% Passing	% Passing	% Passing	% Passing			Sieve No	% Passing	
1/2"	-	-	-	-	100	1/2"	100	1/2"	100	100
3/8"	-	-	100	100	90-100	4	0-60	3/8"	90-100	85-100
1/4"	100	100	0-80	0-70	0-70	16	0-5	1/4"	0-70	
4	0-100	0-100	0-50	0-25	0-25			4	0-25	0-30
8	-	0-40	0-12	0-5	0-5			8	0-5	0-15
16	0-30	0-10	0-5	-	-			16		0-10
50	0-15	0-5	-	-	-			50		
100	0-5	-	-	-	-			100		
200	0-1	0-1	0-1	0-1	0-1			200	0-1	0-1

Agency	Crack Seal/Fill					
	Material Type Crack Seal	Material Type Crack Fill (if different from crack seal)	Routing requirement	Weather Requirement	Time before application of other treatment	Suitability
MnDOT	Thermosetting and thermoplastic materials are both used for crack sealing. Following are the crack seal/fill types: Hot-Poured, Crumb-Rubber Type Crack Sealer Hot-Poured, Elastic Type Joint and Crack Sealer Hot-Poured, Extra Low Modulus, Elastic Type Joint and Crack Sealer	NA	3/4"x3/4" routing for crack seal project dealing working cracks.	Placement should occur during moderate, dry weather conditions. Application during Spring and Fall weather, when cracks are at a moderate width, allows the filler material to expand and contract. Application should be avoided when roadbed moisture exists	NA	**Crack Fill is suitable for candidate that meets the following requirement:** Age since Last Rehab > 5 but ≤ 8 and Moderate Transverse Cracking ≤ 50% and No High Severity Longitudinal Cracking and No High Severity Transverse Cracking and Low Severity Transverse Cracking ≥ 13% and Total Transverse Cracking < 40% and Last Maintenance Activity not a Crack Seal/Crack fill **Rout and Crack Seal is not suitable for the following:** Age since Last Rehab > 2 but ≤ 5 and Moderate Severity Transverse Cracking ≤ 4% and Low Severity Transverse Cracking ≥ 13% and Total Transverse Cracking < 40% and Last Maintenance Activity not a Crack Seal/Crack Fill Both crack seal and fill are suitable for only non-structural cracking and Rutting measured > 10% of mile section and > 0.5 inches

Agency	Crack Seal/Fill					
	Material Type Crack Seal	**Material Type Crack Fill (if different from crack seal)**	**Routing requirement**	**Weather Requirement**	**Time before application of other treatment**	**Suitability**
Michigan DOT	Hot-Poured, Extra Low-Modulus, Joint and Crack Sealer.	Alternate 1: Provide a field-blended liquid mixture with the following characteristics and proportions: a. Performance graded asphalt binder PG 64-22 south of M-46 and PG 58-28 north of M-46; b. Asphalt rubber product selected from the Qualified Product List, 5 % by weight; and c. Polyester fibers, 5 percent by weight. Alternate 2 : An asphalt rubber product (must be selected from the Qualified Product List).	All primary transverse cracks in the traveled lanes should be sealed by the Saw/Rout and Seal Method. All other cracks in the traveled lanes and the shoulder areas can be filled by the Overband Crack Fill Method.	Place material at air temperatures between 45 °F and 85 °F. Do not place material if moisture is present in the crack.	NA	**Suitable for:** cracks that are 1 ¼" wide or less (For wider cracks, the use of mastic is recommended) Crack density <100-200 ft for 100 ft long and 12 ft wide section **Not suitable for:** transverse crack that has excessive secondary crack

Agency	Crack Seal/Fill					
	Material Type Crack Seal	Material Type Crack Fill (if different from crack seal)	Routing requirement	Weather Requirement	Time before application of other treatment	Suitability
Ohio DOT	OhioDOT have four different kinds of sealers as options: Type I- hot applied joint sealer conforming to ASTM D 6690, Type II Type II- PG 64-22+Polyester Fiber minimum 5% (recycled fibers not allowed) Type III - PG 64-22 +polypropylene Fiber minimum 7% (recycled fibers not allowed) Type IV - Preapproved modified binder + Polyester Fiber minimum 2% (recycled fibers not allowed)	NA	Routing/sawing should be considered only when pavements are not expected to be treated for several years and where cracks are newly formed.	Do not seal cracks if the surface is visibly damp or the temperature is below 45 F (7 C).	All types of crack sealing should be aged at least a full 12 months prior to any type of asphalt overlay to prevent tearing of the overlay during the rolling process.	**Suitable for:** Seal only cracks that are wide enough to permit entry of sealant. Seal tightly closed cracks (less than 1/4-inch (6 mm) wide) only if they show signs of raveling or spalling. For pavement sections with PCR 65-80. **Not Suitable for:** Crack sealing is not an acceptable treatment for cracks wider than one inch (25 mm) pavements that require more than 5000 pounds of crack seal material per lane mile Do not seal cracks greater than 1-inch (25 mm) wide, and do not seal spalls or cavities greater than 4 inches (100 mm) wide, unless otherwise directed. Type I and Type IV materials are not appropriate for pavements that will be microsurfaced within 2 years Type II material should be specified for preparing pavements just prior to microsurfacing or chip sealing
PennDOT	Asphalt rubberized sealing compound following ASTM D5078. Rubberized Joint Sealing Material. ASTM D6690-Type I. Asphalt wearing course 4.75 mm following section 413.2 (PennDOT pub 408).	NA	If required, rout cracks to create a reservoir 1/2 inch deep.	NA	NA	Suitable for crack widths within 0.25 to 1 inch. Cracks wider than 1 inch must be filled with asphalt wearing course 4.75 mm.

New York DOT	ASTM D3405 from Approved List	NA	Consider a rout and seal treatment if the remaining life of the pavement may exceed 5 years. Routing of the full-width transverse cracks in HMA pavements is recommended because thermal movement is greatest with this type of crack.	Dry weather is required for sealant to cure properly. Air and pavement temperature should be in the middle of the annual temperature range Air temperature must be > 5°C above the dew point. Spring and fall application is preferred.	NA	**Suitable for:** Average spacing no closer than 6 m between cracks. Less than 25% of the crack's length has secondary cracking. **Not suitable for:** Routing and sealing is not preferred for pavement with remaining service life < 5 years.
Illinois DOT	Hot-poured joint sealer shall be according to ASTM D 6690, Type II.	NA	Primary transverse and longitudinal working cracks shall be routed, cleaned, and sealed. Cracks shall be routed following the crack as nearly as possible, approximately 3/4 in. (20 mm) wide by 3/4 in. (20 mm) deep, and as close to a 1:1 ratio as possible.	Placement recommended when air temperature in the shade is 40 °F (5 °C) or greater.	NA	NA

Agency	Crack Seal/Fill					
	Material Type Crack Seal	Material Type Crack Fill (if different from crack seal)	Routing requirement	Weather Requirement	Time before application of other treatment	Suitability
						specified for preparing pavements just prior to microsurfacing or chip sealing
PennDOT	Asphalt rubberized sealing compound following ASTM D5078. Rubberized Joint Sealing Material. ASTM D6690-Type I. Asphalt wearing course 4.75 mm following section 413.2 (PennDOT pub 408).	NA	If required, rout cracks to create a reservoir 1/2 inch deep.	NA	NA	Suitable for crack widths within 0.25 to 1 inch. Cracks wider than 1 inch must be filled with asphalt wearing course 4.75 mm.
New York DOT	ASTM D3405 from Approved List	NA	Consider a rout and seal treatment if the remaining life of the pavement may exceed 5 years. Routing of the full-width transverse cracks in HMA pavements is recommended because thermal movement is greatest with this type of crack.	Dry weather is required for sealant to cure properly. Air and pavement temperature should be in the middle of the annual temperature range Air temperature must be > 5°C above the dew point. Spring and fall application is preferred.	NA	**Suitable for:** Average spacing no closer than 6 m between cracks. Less than 25% of the crack's length has secondary cracking. **Not suitable for:** Routing and sealing is not preferred for pavement with remaining service life < 5 years.
Illinois DOT	Hot-poured joint sealer shall be according to ASTM D 6690, Type II.	NA	Primary transverse and longitudinal working cracks shall be routed, cleaned, and sealed. Cracks shall be routed following the crack as nearly as possible, approximately 3/4 in. (20 mm) wide by 3/4 in. (20 mm) deep, and as close to a 1:1 ratio as possible.	Placement recommended when air temperature in the shade is 40 °F (5 °C) or greater.	NA	NA

Agency	Micropaving										
	Type	Asphalt binder	Aggregate	Tack coat application	Lift thickness	Traffic volume restriction	Suitability	Special surface preparation requirement	Weather limitation	Use of RAP	Alternatively used for
MnDOT	Ultrathin Bonded Wearing Course	PG 58V-34 (4.8-6 %)	Follow aggregate gradation	Polymer Modified Emulsion Membrane	0.4 in. to 0.8 in.	No restriction	Not Suitable for: Sections where structural failures exist (e.g., significant fatigue cracking, deep rutting) or if there is high- severity thermal cracking. In general, UTBWC is not recommended when there is extensive pavement deterioration or little remaining life	NA	NA	RAP is used	Seal coat, micro surface, thinlays and thin-lift overlay.
	ThinLays	NA	NA	NA	5/8 inch to 1 inch	No restriction	Suitable for: Pavement Conditions pavements that are dry looking, porous/permeable, raveled, have extensive cracking too fine for crack sealing, minor rutting (< ¼ "), no structural (fatigue or rutting) damage and will have sufficient remaining structural capacity to last the expected life of the - Little or no load related distresses less than 20' of alligator cracking in 500' section -less than 100' high severity longitudinal cracking in 500' section - less than 10' high severity transverse cracks in 500' section (crack spacing of 50' or more) - less than 100' of multiple cracking in a 500' section -RQI greater than the 2.0	NA	NA	NA	UTBWC Slurry Seal Microsurfacing
Michigan DOT	Dense graded aggregates with 25 mm, 19 mm, 9.5 mm mixes	Asphalt binder meeting PG standards for various temperature (PG 46- 82).	Follow aggregate gradation.	SS-1h, CSS-1H	1.5 inch (2 inch for special circumstances).	No restriction.	**Suitable for:** - pavement with good base condition. The visible surface distress should be minor and may include raveling, longitudinal and transverse cracks and small amounts of block cracking. Low associated distress may be present. -The pavement should only have some minor base failures and depressions **Not suitable for:** - severely distressed composite pavement, severely raveled or rutted HMA pavement, pavement with a weak base, or a HMA surface that is debonding. In addition, a pavement with excessive amounts of crack sealing may not be a good candidate for a - non-structural HMA overlay	The preparation work should be limited to the repair of minor base failures and depressions, filling of voids in the pavement surface, removal of any patched area with poor adhesion or a very high asphalt content that may bleed up through the new HMA surface, and correction of severely tented joints.	NA	NA	NA
PennDOT	6.3 mm dense graded mix.	PG 64E-22 (WMA or modified binders needs to be approved).	Follow aggregate gradation.	NA	NA	NA	NA	Repair potholes and gouges greater than 1 inch in depth. Fill and seal all pavement cracks or joints that exceed 1/8 inches in width.	Do not place asphalt paving mixtures when surfaces are wet, when the air or surface	NA	NA

Agency	Micropaving									
	Type	Asphalt binder	Aggregate	Tack coat application	Lift thickness	Traffic volume restriction	Suitability	Special surface preparation requirement	Weather limitation	Use of RAP	Alternatively used for
									temperature is 50F or lower.		
Ohio DOT	Two types of mixes are used. Type A for less than 1500 trucks per day. Type B for greater than 1500 trucks per day and sections where higher friction is required.	PG 76-2M or PG64-22 modified with 5.0 ±0.3 percent by weight Styrene Butadiene Rubber (SBR) solids and meeting the requirements of PG 76-22. Minium binder content 6.4% for Type B and 8.5% asphalt binder for Type A	Follow gradation for Type A and Type B aggregate.	NA	NA	No restriction	**Suitable for:** for pavement with PCI within 65 and 80 **Not suitable for:** pavements with excessive, cracking, potholes, rutting, or debonding	Localized wheel track cracking or edge cracking should be repaired full depth. Potholes must be repaired full depth. Areas that exhibit debonding must be patched. All existing patches must be in good repair prior to placing a fine graded polymer asphalt concrete overlay.	Do not place the asphalt concrete when the surface of the existing pavement is less than 60 °F (15 °C) or the air temperature is less than 60 °F (15 °C).	Maximum 10 percent in type B. No RAP in type A	NA
New York DOT	A 6.3 mm polymer-modified	Polymer-Modified PG Binder	NA	Rapid setting asphalt emulsion as a tack coat.	NA	No restriction	Suitable for Low-severity cracking. Infrequent corrugations, settlements, heaves, slippage cracks, or raveling.	Perform all required crack sealing. 2. Remove all thermoplastic and preformed pavement markings. 3. Abrade all epoxy and polyester markings to remove the glass beads and roughen the surface.	Minimum temperature is 10°C.	NA	NA

Agency	Micropaving										
	Type	Asphalt binder	Aggregate	Tack coat application	Lift thickness	Traffic volume restriction	Suitability	Special surface preparation requirement	Weather limitation	Use of RAP	Alternatively used for
New York DOT	Paver Placed Surface Treatment. Paver placed surface treatment consists of a warm polymer-modified asphalt emulsion coat followed immediately with a thin hot mix asphalt (HMA) wearing course. Three different	NA	NA	NA	The HMA overlay is placed in 1 lift, having a final thickness of 1 to 1.5 times the diameter of the coarsest aggregate. 12 mm for type A and 20 mm for Type B and C.	Type A is applied in urban and suburban applications with light truck traffic. Type B is applied moderate to heavy traffic and truck traffic on highways with moderate speeds. Type C is recommended for high speed, high traffic applications, and for applications with moderate rutting.	Suitable for: Low severity cracking, or raveling. Infrequent corrugations, settlements, heaves or slippage cracks. Medium severity rutting.	Perform all required crack sealing. 2. Remove all thermoplastic and preformed pavement markings. 3. Abrade all epoxy and polyester markings to remove the glass beads and roughen the surface.	NA	NA	NA
	gradations are applied, including Type A (6.3mm), Type B (9.5 mm), and Type C (12.5 mm)										
Illinois DOT	Dense-graded, open-graded, and stone matrix mixes. (4.75mm, 9.5 mm, SMA 9.5)	NA	Follow aggregate gradation.	NA	IL-4.75 (19 mm), IL-9.5 (31 mm), SAM-12.5 (51 mm), IL-19 (56 mm).	No restriction	**Suitable for:** Low-severity cracking; raveling/weathering friction loss; roughness; low-severity bleeding; low-severity block cracking Thin overlays may also be used to correct rutting **Not suitable for:** Thin HMA overlays are not recommended where there are structural failures (e.g., fatigue cracking), extensive pavement deterioration, or if there is high-severity thermal cracking.	NA	NA	NA	NA

MnDOT				
	A	B	C	D
Sieve No	% Passing	% Passing	% Passing	% Passing
1 "	-	-	100	-
3/4 "	-	100	85-100	-
1/2 "	100	85-100	45-90	-
3/8 "	85-100	35-90	-	100
4	60-90	30-80	30-75	65-95
8	45-70	25-65	25-60	45-80
200	2-7	2-7	2-7	3-8

MDOT			
	21 AA & 21A	22A	23A & 23 AA
Sieve No	% Passing	% Passing	% Passing
1 "	85-100	100	100
3/4 "	-	90-100	90-100
1/2 "	50-75	-	-
3/8 "	-	60-85	60-85
4	-	-	-
8	20-45	25-60	25-60

PennDOT	
Sieve No	% Passing
3/8"	100 Min
1/4"	90-100
4	0-85
8	37-55
50	8-25
200	3-10

ODOT		
	A	B
Sieve No	% Passing	% Passing
1/2"	-	100
3/8"	100	95-100
4	95-100	85-95
8	90-100	53-63
16	80-100	37-47
30	60-90	25-35
50	30-65	9-19
100	10-30	-
200	3-10	3-8

Agency	Micro-Surfacing							
	Emulsion	**Mineral filler**	**Job Mix Formula**	**Tack coat**	**Traffic restriction**	**Alternative treatment**	**Weather Requirement**	**Suitability**
MnDOT	CQS-1hP (for rut filling) CQS-1P (non-rut filling)	Portland Cement, Type-I, Hydrated lime	Asphalt binder content: 5.5 to 10.5 %. Mineral filler: 0.25 to 3.0 % by dry weight of aggregate.	Apply fog seal (CSS-1h) to concrete surfaces and bituminous surfaces if required by the Engineer before the first course of micro-surfacing. Application rate (dilute emulsion) 0.05 to 0.10 gsy.	Applicable for any traffic level	Seal coat, thin lift overlay and Ultra-Thin Bonded Wear Course.	Apply when air and pavement surface temperatures are at least 50°F and rising. Do not place micro-surfacing during rain, or if the forecast indicates a temperature below 32°F within 48 hours of the planned micro-surfacing. Work recommended prior to September 15th.	Suitable for: Micro surfacing does not add structural capacity but will provide protection against surface distresses like low severity cracking, raveling/weathering (loose material must be removed), minor roughness, friction loss, and moisture infiltration. Micro surfacing will also temporarily seal cracks (if severity is low) and can serve as a rut-filler Not Suitable for: Sever crack and load related distress.

Agency	Micro-Surfacing							
	Emulsion	Mineral filler	Job Mix Formula	Tack coat	Traffic restriction	Alternative treatment	Weather Requirement	Suitability
Michigan DOT	CSS-1hM, CSS-1mM	Portland Cement, Type-I	Asphalt binder content: 7.0 to 8.5%, dry weight for 2FA aggregate and 6.5 to 8.0%, dry weight, 3FA aggregate. Mineral Filler: 0.25 to 3.0%, dry weight aggregate.	Apply bond coat on concrete surfaces. Mix bond coat with one part emulsion to two parts water. Apply the bond coat at a rate from 0.035 gallons per square yard to 0.070 gallons per square yard,	Applicable for any traffic level	NA	Apply when air and pavement surface temperatures are at least 45°F and rising. Do not place micro-surfacing during rain, or if the forecast indicates a temperature below 32°F within 48 hours of the planned micro-surfacing. Work recommended prior to September 15th.	Suitable for slight cracking, rutting, minor surface irregularities, flushed or polished surface and/or moderate raveling. Not Suitable for: A standard micro-surfacing formulation should not be used on a pavement with moderate to heavy surface cracks. Not good for reflective crack

Agency	Micro-Surfacing							
	Emulsion	Mineral filler	Job Mix Formula	Tack coat	Traffic restriction	Alternative treatment	Weather Requirement	Suitability
Ohio DOT	CSS-1hM	Portland Cement, Type-I/Type III	Asphalt binder: 7.0 to 8.5% of residual asphalt by dry weight of Aggregate for leveling and surface courses and 6.5 to 8.0 % for rut fill courses Mineral Filler: 0.3 percent to 2.5 percent mineral filler by dry weight of Aggregate.	Apply a tack coat to the existing pavement surface CSS-1H OR CSS-1HM at a rate of 0.06 to 0.12 gsy.	Applicable to any traffic level. However, double course is recommended in ADT >10000.	NA	Apply the mixture only when it is not raining, pavement has no standing water, and the existing pavement surface and atmospheric temperature is a minimum of 45 F and rising and there is no forecast of an atmospheric temperature below 32 F within 24 hours from the time the mixture is applied. Between September 30 and May 1, do not apply the mixture if the existing pavement surface temperature is less than 50 F.	NA

Agency	Micro-Surfacing							
	Emulsion	**Mineral filler**	**Job Mix Formula**	**Tack coat**	**Traffic restriction**	**Alternative treatment**	**Weather Requirement**	**Suitability**
PennDOT	CQS-1hPM (a latex based modifier)	NA	Asphalt residue: 6-8.5 % of aggregate for Type A, 5.5-7.5% for Type B and Type RF Mineral Filler: 1% to 2%± 0.5%	Apply tack coat if existing surface is not asphalt concrete (Anionic or Cationic Emulsified Asphalt) at uniform asphalt residual rates of 0.04 to 0.07 gsy.	Type A - ADT < 20,000 (if used for reprofiling, rut filling and surface course) Type B - ADT < 20,000 (if used for wearing course) For interstate double application of Type A is recommended	NA	Apply when entire surface is in a condition to allow satisfactory penetration and adhesion and the atmospheric temperature is 50F minimum during the entire placement Do not apply mixture if rain is imminent or if freezing temperatures are expected within 24 hours after application. s. Do not apply from September 16 to April 30 in Districts 1-0, 2-0, 3-0, 4-0, 10-0, and 5-0	Suitable for: Type A - seal cracks, rut filling (rut < 0.5 inches) Type B - seal crack, rut filling (rut within 0.5 to 1.25 inches Type RF - filling rut up to 2 inches providing skid resistance Not suitable for: Any distresses related to base failure It is recommended that a double application be used unless the road surface is in excellent condition.

Agency	Micro-Surfacing							
	Emulsion	Mineral filler	Job Mix Formula	Tack coat	Traffic restriction	Alternative treatment	Weather Requirement	Suitability
							(Monroe, Carbon, and Schuylkill Counties only) and from October 1 to April 30 in Districts 6-0, 8-0, 9-0, 11-0, 12-0, and 5-0 (Berks, Lehigh, and Northampton Counties only).	
New York DOT	CQS-1h	Portland Cement, Type-I (ASTM D242)	Asphalt binder: 5.5 - 10.5% of the dry weight of aggregate Mineral Filler: 0 percent to 2.5 % mineral filler by dry weight of Aggregate.	Apply tack coat or dampen the surface with water if directed by the engineer.	Applicable for any traffic. Type III is recommended for high traffic.	NA	Do not place micro-surfacing in the rain, fog, or if the air temperature is expected to fall below freezing within 24 hours after application. Application shall not occur unless pavement and ambient temperatures are above 50ºF and rising. Application shall not occur unless September.	Suitable for: Low severity cracking and raveling. 2. Infrequent corrugations, settlements, heaves, and slippage cracks. 3. Wheel path rutting up to 25 mm

Agency	Micro-Surfacing							
	Emulsion	Mineral filler	Job Mix Formula	Tack coat	Traffic restriction	Alternative treatment	Weather Requirement	Suitability
Illinois DOT	CQS-1hP / CSS-1h (Latex Modified)	Portland Cement, Type-I/Type III	Asphalt binder: 7.0 - 10.5% of the dry weight of aggregate Mineral Filler: 0.3 % to 2.5 percent mineral filler by dry weight of Aggregate.	A tack coat shall be applied uniformly at a rate that will provide a residual rate of 0.025 lb/sq ft (0.122 kg/sq m) for HMA surfaces and/or 0.05 lb/sq ft (0.244 kg/sq m) for concrete surfaces.	NA	NA	Do not place when freezing temperatures are expected. Micro-surfacing should be placed between May 1 and October 15 and when the temperature is at least 50 °F (10°C) and rising and the forecast for the next 24 hours is above 40 °F (5°C).	Suitable for: Low-severity cracking; raveling/weathering (loose material must be removed); low- to medium-severity bleeding; minor roughness; friction loss; and moisture infiltration. Adds limited structural capacity. Temporarily seals fatigue cracks (if severity is low) and can serve as a rut-filler (if the existing ruts are stable). A scratch coat of the micro surfacing can be used for light profile repairs. Not suitable for: Micro-surfacing is not recommended when the pavement contains structural failures (e.g., significant fatigue cracking), high-severity thermal cracking, or extensive pavement deterioration. This treatment can also accelerate the development of stripping in susceptible AC pavements.

	MnDOT			MDOT		ODOT		PennDOT			NYDOT		IDOT	
	Type 1	Type 2	Type 3	2FA	3FA	Type A	Type B	Type A	Type B	Type RF	2 MS	3 MS	FA 23	FA 24
Sieve No	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing
3/8"	100	100	100			100	100	100	95-100	90-100	100	10	100	100
4	100	90-100	70-90	90-100	70-90	85-100	90-100	85-100	65-85	55-75	90-100	70-90	70-90	90-100
8	85-100	65-90	45-70	65-90	45-70	50-80	65-90	50-75	46-65	40-55	65-90	45-70	44-70	64-90
16	72-92	45-70	28-50	45-70	28-50	46-65	45-70	40-65	28-45	24-40	45-70	28-50	28-50	44-70
30	50-75	30-50	19-34	30-50	19-34	25-45	30-50	25-45	19-34	19-34	35-50	19-34	18-32	25-45

	MnDOT			MDOT		ODOT		PennDOT			NYDOT		IDOT	
Sieve No	Type 1	Type 2	Type 3	2FA	3FA	Type A	Type B	Type A	Type B	Type RF	2 MS	3 MS	FA 23	FA 24
	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing
50	35-55	18-30	12-25	18-30	12-25	12-25	18-30	12-25	10-23	10-20	18-30	12-25	11-25	19-25
100	15-35	10-21	7-18	10-21	7-18	-	10-21	-	-	-	10-22	7-20	6-18	9-21
200	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15	5-15

Agency	Mastics		
	Suitability	**Surface Preparation**	**Traffic Consideration**
MnDOT	Pothole at longitudinal joint less than 3 in. wide and 2 in. deep. Mastic is typically used to level cracks fill minor voids such as pothole	Application requires the surface to be cleaned of loose debris and vegetation with an air compressor and dried with a heat lance. A conditioner or primer is applied (if recommend) to the void before applying the mastic.	NA
Michigan DOT	When the width of the crack or separation at the longitudinal joint becomes wider than 1 ¼" Shallow spall repair		No restriction on traffic.

Agency	Rejuvenators			
	Materials	**Traffic restriction**	**Suitability**	**Weather Requirement**
MnDOT	Asphalt based: CMS -1PF, REGENX, ReJuvaSEAL Maltene based: Reclamite bio based: Delta Mist, BioRestor, RePlay.	Low volume road (ADT < 2500) or parking lot, or high-volume roads with low traffic speed	Applicable for low-severity transverse cracking, low-severity longitudinal cracking, and low-severity raveling/weathering	Rejuvenators must be applied only when the surface is dry. Surface treatment shall not be applied when the temperature is less than 40˚ in the shade. When applying emulsions, the temperature of the surface shall be a minimum of 59˚F, and no more than 140˚F.

7.1 References

ODOT pavement design manual 2022 (Pavement Design Manual | Ohio Department of Transportation)

Michigan Department of Transportation (MDOT). 2010. "Capital Preventative Maintenance." Michigan Department of Transportation, Lansing, MI (Capital Preventive Maintenance Guidelines (michigan.gov))

MNDOT PAVEMENT PRESERVATION MANUAL, 2020. (MnDOT_Pavement_Preservation_Manual.pdf (state.mn.us))

COMPREHENSIVE PAVEMENT DESIGN MANUAL, NYDOT, 2005 (Chapter 10 (ny.gov))

Bureau of Local Roads and Streets Manual, Chapter 45. Local Agency Pavement Preservation, Illinois Department of Transportation, Springfield, Illinois, January 2012.(Microsoft Word - Document2 (illinois.gov))

Commonwealth Of Pennsylvania Department of Transportation Publication 408/2020 SPECIFICATIONS (408_2020_6.pdf (state.pa.us))

APPENDIX B: QUESTIONNAIRE RESPONSES

PennDOT RFQ #220720 (Maintenance Preservation Solution Matrix) Questionnaire

The Pennsylvania Department of Transportation (PennDOT) is interested in determining the best pavement maintenance strategies for optimizing maintenance cycles to maximize pavement performance and extend service life. One of the key objectives of this task is to review the standard practice adopted by peer agencies in implementing different traditional and non-traditional pavement treatments. To this end, ARA has prepared a questionnaire to develop an understanding of typical and innovative maintenance treatments utilized by state agencies, and availability of pavement management system data pertaining to the maintenance treatments.

Agency: Michigan Department of Transportation

Tyler Hunt

Primary Contact(s):

HuntT2@michigan.gov

Address:

Email:

Telephone:

1. Has your agency implemented any of the following treatments on a pavement section in the last 10 years?
   a. Micro-paving Yes ☐ No ■
   b. Micro-surfacing

      Yes ■ No ☐
   c. Mastics for patching and crack/joint sealing Yes ■ No ☐
   d. Sealcoating on arterials, expressways, or other similar higher-volume routes.

      Yes ■ No ☐

2. Apart from the treatments mentioned above, has your agency implemented other non- tradition/innovative treatments?

   Yes ■ No ☐

   If the answer to question 2 is 'yes', please provide additional information.

Yes, in the last few years we have tried Void Reducing Asphalt membrane (VRAM), microsurfacing with fibers and softer pen. binder, scrub seals.

3. For each pavement section treated with any of the treatments mentioned above, can the DOT provide the following asset management data?

   a. Overall Performance Index (OPI)
      Yes ☐ No ■
   b. International Roughness Index (IRI)
      Yes ■ No ☐
   c. Asphalt material Type Yes ■ No ☐
   d. Wearing surface Age
      Yes ■ No ☐
   e. Existing completed maintenance activities, including interval, frequencies and seal coat, cracking, joint sealing, and patching activities.
      Yes ☐ No ■
   f. Average Daily Traffic (ADT) and truck percentage Yes ■ No ☐
   g. Business Plan Network (BPN) and functional classification
      Yes ■ No ☐
   h. Lowest Life Cycle Cost (LLCC) treatment options Yes ■ No ☐

4. Have you conducted any research/case studies on the optimal timing of application for the treatments mentioned above?

   Yes ■ No ☐

   If the answer to question 4, is 'yes', please provide additional information.

yes, we did research back in 2013 on the value of preventive maintenance at MDOT that would answer many questions you have

5. Are you willing to participate in a short phone call or virtual meeting to discuss about any of the treatment mentioned above?

Yes ▣ No ☐

Please send your responses to:

Lax Premkumar, P.E. (MI)|Group Leader and Senior Engineer
Transportation Infrastructure Division
Applied Research Associates, Inc.
3605 Hartzdale Drive - Camp Hill, PA
17011 T-717-975-3550 F-717-975-3557
lpremkumar@ara.com

PennDOT RFQ #220720 (Maintenance Preservation Solution Matrix) Questionnaire

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Agency: Minnesota DOT

Primary Contact(s): Joel Ulring, Pavement Preservation Engineer

Address: 1400 Gervais Ave., Maplewood, MN 55109

Email: joel.ulring@state.mn.us

Telephone: (651)366-5432

1. Has your agency implemented any of the following treatments on a pavement section in the last 10 years?
   a. Micro-paving
      Yes ■ No ☐
   b. Micro-surfacing
      Yes ■ No ☐
   c. Mastics for patching and crack/joint sealing Yes ■ No ☐
   d. Sealcoating on arterials, expressways, or other similar higher-volume routes.
      Yes ■ No ☐

2. Apart from the treatments mentioned above, has your agency implemented other non- tradition/innovative treatments?

   Yes ■ No ☐

If the answer to question 2 is 'yes', please provide additional information.

Scrub Seal - Developed a special provision and awarded two contracts in 2023

Slurry Seal - Developed a special provision and have awarded three contracts in past two years.

Spray-Applied Rejuvenator Seal - Currently developing a special provision with plans to let a project in 2024.

3. For each pavement section treated with any of the treatments mentioned above, can the DOT provide the following asset management data?

   a. Overall Performance Index (OPI)
      Yes ■ No ☐
   b. International Roughness Index (IRI)
      Yes ■ No ☐
   c. Asphalt material
      Type Yes ■ No ☐
   d. Wearing surface Age
      Yes ■ No ☐
   e. Existing completed maintenance activities, including interval, frequencies and seal coat, cracking, joint sealing, and patching activities.
      Yes ■ No ☐
   f. Average Daily Traffic (ADT) and truck
      percentage Yes ■ No ☐
   g. Business Plan Network (BPN) and functional classification
      Yes ■ No ☐
   h. Lowest Life Cycle Cost (LLCC) treatment
      options Yes ■ No ☐

4. Have you conducted any research/case studies on the optimal timing of application for the treatments mentioned above?

   Yes ■ No ☐

   If the answer to question 4, is 'yes', please provide additional information.

Currently just initiated a research project to wrap up a 10-year study on chip sealing.

5. Are you willing to participate in a short phone call or virtual meeting to discuss about any of the treatment mentioned above?

Yes ■ No ☐

Please send your responses to:

Lax Premkumar, P.E. (MI)|Group Leader and Senior Engineer
Transportation Infrastructure Division
Applied Research Associates, Inc.
3605 Hartzdale Drive - Camp Hill, PA
17011 T-717-975-3550 F-717-975-3557
lpremkumar@ara.com

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Agency: New York Department Of Transportation

Primary Contact(s): Brendan Rock

Address: 50 Wolf Rd Albany NY 12205

Email: brendan.rock@dot.ny.gov

Telephone: 518-457-7834

1. Has your agency implemented any of the following treatments on a pavement section in the last 10 years?
   a. Micro-paving
      Yes ■ No ☐
   b. Micro-surfacing
      Yes ■ No ☐
   c. Mastics for patching and crack/joint sealing Yes ■ No ☐
   d. Sealcoating on arterials, expressways, or other similar higher-volume routes.
      Yes ☐ No ■

2. Apart from the treatments mentioned above, has your agency implemented other non- tradition/innovative treatments?

   Yes ■ No ☐

   If the answer to question 2 is 'yes', please provide additional information.

   Heater Scarification, joint and crack seal

____

____

3. For each pavement section treated with any of the treatments mentioned above, can the DOT provide the following asset management data?

   a. Overall Performance Index (OPI)
      Yes ☐ No ■
   b. International Roughness Index (IRI)
      Yes ☐ No ■
   c. Asphalt material
      Type Yes ☐ No ■
   d. Wearing surface Age
      Yes ☐ No ■
   e. Existing completed maintenance activities, including interval, frequencies and seal coat, cracking, joint sealing, and patching activities.
      Yes ☐ No
   f. Average Daily Traffic (ADT) and truck
      percentage Yes ■ No ☐
   g. Business Plan Network (BPN) and functional classification
      Yes ☐ No
   h. Lowest Life Cycle Cost (LLCC) treatment
      options Yes ☐ No

4. Have you conducted any research/case studies on the optimal timing of application for the treatments mentioned above?

   Yes ☐ No ■

   If the answer to question 4, is 'yes', please provide additional information.

____

____

____

5. Are you willing to participate in a short phone call or virtual meeting to discuss about any of the treatment mentioned above?

Yes ☐ No ■

Please send your responses to:

Lax Premkumar, P.E. (MI)|Group Leader and Senior Engineer
Transportation Infrastructure Division
Applied Research Associates, Inc.
3605 Hartzdale Drive - Camp Hill, PA
17011 T-717-975-3550 F-717-975-3557
lpremkumar@ara.com

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The Pennsylvania Department of Transportation (PennDOT) is interested in determining the best pavement maintenance strategies for optimizing maintenance cycles to maximize pavement performance and extend service life. One of the key objectives of this task is to review the standard practice adopted by peer agencies in implementing different traditional and non-traditional pavement treatments. To this end, ARA has prepared a questionnaire to develop an understanding of typical and innovative maintenance treatments utilized by state agencies, and availability of pavement management system data pertaining to the maintenance treatments.

Agency: Ohio DOT

Primary Contact(s): Patrick Bierl

Address: 1980 W. Broad St. Mail Stop 5200, Columbus, OH 43223

Email: patrick.bierl@dot.ohio.gov

Telephone: 614-995-5995

1. Has your agency implemented any of the following treatments on a pavement section in the last 10 years?
   a. Micro-paving
      Yes ☐ No ☐
   b. Micro-surfacing
      Yes ■ No ☐
   c. Mastics for patching and crack/joint sealing Yes ■ No ☐
   d. Sealcoating on arterials, expressways, or other similar higher-volume routes.
      Yes ☐ No ☐

2. Apart from the treatments mentioned above, has your agency implemented other non- tradition/innovative treatments?

   Yes ■ No ☐

If the answer to question 2 is 'yes', please provide additional information.

Fine graded polymer asphalt concrete (typically 0.75 to 1" thick), Chip Seal,

In addition to traditional concrete repairs for concrete - Dowel bar retrofit, longitudinal cross stitching, RRCM

1. For each pavement section treated with any of the treatments mentioned above, can the DOT provide the following asset management data?

   a. Overall Performance Index (OPI) Yes ☐ No ☐
   b. International Roughness Index (IRI) Yes ☐ No ☐
   c. Asphalt material Type Yes ☐ No ☐
   d. Wearing surface Age Yes ☐ No ☐
   e. Existing completed maintenance activities, including interval, frequencies and seal coat, cracking, joint sealing, and patching activities. Yes ☐ No ☐
   f. Average Daily Traffic (ADT) and truck percentage Yes ☐ No ☐
   g. Business Plan Network (BPN) and functional classification Yes ☐ No ■
   h. Lowest Life Cycle Cost (LLCC) treatment options Yes ☐ No ☐

2. Have you conducted any research/case studies on the optimal timing of application for the treatments mentioned above?

   Yes ■ No ☐

   If the answer to question 4, is 'yes', please provide additional information.

Link for Chip Seal and Microsurfacing: https://worldcat.org/arcviewer/3/OHI/2010/12/02/H1291321356543/viewer/file1.pdf

1. Are you willing to participate in a short phone call or virtual meeting to discuss about any of the treatment mentioned above?

Yes ■ No ☐

Please send your responses to:

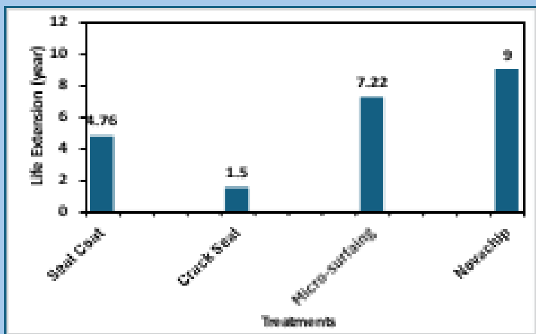
Lax Premkumar, P.E. (MI)|Group Leader and Senior Engineer
Transportation Infrastructure Division
Applied Research Associates, Inc.
3605 Hartzdale Drive - Camp Hill, PA
17011 T-717-975-3550 F-717-975-3557
lpremkumar@ara.com

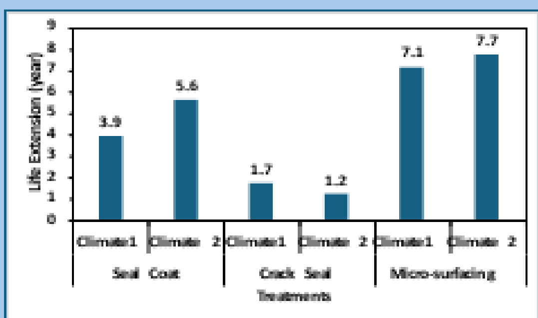
APPENDIX C: IMPLEMENTATION GUIDE

Objective

A data driven decision making process to select optimal types and timing of preventative maintenance treatment

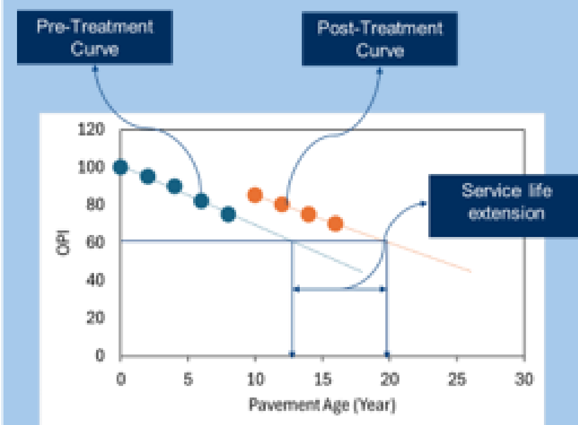
Highlights





Measure of Effectiveness

- Develop pre-, and post-treatment performance models with at least 10 years of performance data
- The service life extension of the preventative maintenance treatment was calculated as the difference between the service life at OPI of 60 for the pre-, and post-treatment models.



Roadmap of the analysis

Literature review and questionnaire survey:
Document the practices of peer states, conduct comparative analysis of practices between PennDOT and the peer states

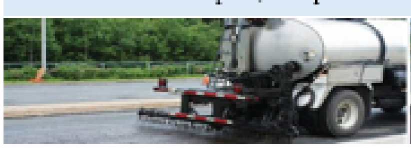
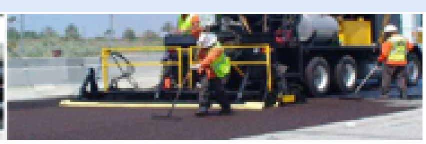
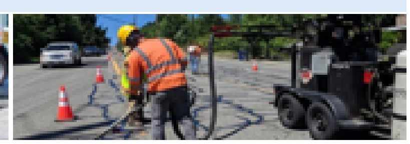
Data Engineering:

- Data Assembly: Combine the historical performance dataset, pavement layer dataset, and treatment construction dataset
- Data Cleanup: Filter out sections with multiple treatments
- Identify Key Feature:
  - Climate zone 1 and climate zone 2
  - BPNs: BPN 1, BPN 2, BPN 3, and BPN 4
  - Pre-treatment age and OPI

Model Development and Service Life Extension Analysis:
Calculate as the difference between the service life at OPI of 60 for the pre-, and post-treatment models.

Implementation Plan:

- ✓ Following actions are recommended to optimize the selection of treatment types and timings:
- ✓ Consider Climate zone, BPN, pre-treatment OPI and pre-treatment age while selecting the types and timing of the considered treatment
- ✓ Use the Microsoft ® excel based tool that was developed as a part of this study based on the obtained results. This tool will enable the user to make informed decision to select optimal types and timings of treatment
- ✓ Conduct life cycle cost analysis to in selecting the most optimal treatment types.

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