Iowa Pavement Preservation Guide

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Center for Transportation Research and Education

Iowa State University
Institute for Transportation

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16. Abstract

Pavement preservation is an essential component of highway asset management, enabling transportation agencies to maintain roadway performance and extend pavement service life while efficiently allocating limited maintenance resources. This study was conducted in collaboration with the Iowa Department of Transportation (Iowa DOT) to evaluate the effectiveness and cost-efficiency of commonly used pavement preservation treatments for both flexible and composite pavements.

Historical pavement management data from the Iowa DOT were analyzed to estimate treatment performance based on two key metrics: life extension, representing the additional service life gained from a treatment, and index benefit, representing the cumulative improvement in pavement condition over time. The analysis considered several preservation treatments, including microsurfacing, patching, slurry seal, crack sealing/filling, seal coat, and hot-mix asphalt (HMA) overlay. To enhance the robustness of the evaluation, national pavement performance data from the Long-Term Pavement Performance (LTPP) dataset were also incorporated to supplement and validate the analysis where appropriate. Historical bid tabulation data from Iowa DOT projects were used to estimate representative treatment costs.

The results provide insights into the relative performance of preservation treatments under different pavement conditions and traffic levels and demonstrate how treatment effectiveness varies depending on the timing of application. These findings were combined with cost information to conduct benefit-cost evaluations and to develop decision-support matrices for flexible and composite pavements. This study provides a data-driven framework to support pavement preservation decision-making. The results and tools developed through this research can assist the Iowa DOT in selecting cost-effective treatments and establishing long-term pavement preservation strategies across the state's highway network.

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IOWA PAVEMENT PRESERVATION GUIDE

Final Report
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EXECUTIVE SUMMARY

Pavement preservation is a critical step in maintaining roadway performance and extending pavement service life while efficiently using limited maintenance resources. Selecting the right treatment at the right time requires reliable information on treatment effectiveness, expected performance improvement, and cost. To support pavement preservation decision-making, the Iowa Department of Transportation (Iowa DOT) sponsored this study to evaluate the performance and cost-effectiveness of commonly used pavement preservation treatments using Iowa DOT pavement management data and historical construction cost information. The study's goal was to provide a basis for augmenting the objective view in pavement preservation decision-making.

The research analyzed several preservation treatments commonly used in Iowa, including microsurfacing, patching, slurry seal, crack sealing/filling, seal coat, and hot-mix asphalt (HMA) overlay. Treatment performance was evaluated using two practical performance measures: life extension, representing the additional service life gained from a treatment, and index benefit, representing the cumulative improvement in pavement condition after treatment. The analysis considered both flexible and composite pavements and examined treatment performance under different pavement condition levels.

The study used historical pavement condition and treatment data from the Iowa DOT pavement management system. Data processing and analytical methods were applied to organize treatment records, address data inconsistencies, and estimate treatment effectiveness using observed pavement performance trends. Where appropriate, national pavement performance datasets were reviewed to supplement and support the analysis. In addition, historical bid tabulation data from Iowa DOT projects were analyzed to estimate representative treatment costs per lane-mile. These performance and cost estimates were combined to conduct benefit-cost evaluations for multiple analysis periods.

The results provide several practical insights for pavement preservation planning. Structural treatments such as HMA overlay generally provide the largest improvement in pavement condition and the greatest life extension, although they also involve higher costs. Preventive treatments such as microsurfacing, slurry seal, and crack sealing/filling provide smaller improvements but can be highly cost-effective when applied at appropriate pavement condition levels. The findings also confirm that treatment effectiveness depends strongly on pavement condition at the time of application, highlighting the importance of applying preservation treatments before severe deterioration occurs. Based on the performance and cost analyses, the study developed decision-support matrices that identify cost-effective preservation treatments for different combinations of pavement type, condition, and traffic level. These matrices provide a practical reference that can assist engineers and pavement managers in selecting preservation treatments during project planning and programming.

INTRODUCTION

Summary

In modern society, transportation infrastructure, specifically pavements, plays a key role in the economic health of communities and the mobility of goods and people. Highway infrastructure planners are tasked with addressing mobility, safety, accessibility, and economic development issues for multimodal corridors that have different functional classifications and for networks that stretch for thousands of miles. This work is increasingly challenging due to limited funding coupled with the rapid deterioration of pavement infrastructure over time. Contributing to this deterioration is an increase in urbanization and the pressure it puts on highway facilities (France-Mensah and O’Brien 2018).

When a new pavement is designed, the engineer must specify a design life, which establishes a pavement layer thickness. If the quality of construction and materials is adequate, the pavement is anticipated to remain in an acceptable condition for its design life and perform at a reliability level chosen by the design engineer. On the first day after construction, the pavement’s condition is at its highest level. Over time, deterioration occurs due to traffic and environmental impacts, leading to the need for maintenance, preservation treatments, and rehabilitation. At the time of construction, it is unknown what types of distresses will present themselves first; however, each distress may require different treatments. Engineers are tasked with selecting the best pavement maintenance and preservation techniques for the roadway. These techniques need to be selected based on the pavement distresses that are meant to be prevented (Buss et al. 2019).

There are three main types of treatment categories in the pavement management process: preservation, rehabilitation, and reconstruction. Pavement preservation is a proactive method to maintain existing pavements in a state of good repair. Unlike rehabilitation and reconstruction, pavement preservation focuses on extending pavement service life rather than adding any structural capacity (Chan et al. 2011). It offers numerous benefits, including optimized resource usage to improve safety, mobility, and user satisfaction.

Due to the overwhelming number and variety of preservation treatments and the limited resources available to implement them, preservation programs have been developed for highway agencies in order to improve pavement performance and investment in preservation treatments. An objective of these programs is to implement the right proactive treatments at the right time and to the right projects (the 3R concept) using high-quality materials and construction practices. While engineering judgment is still the most broadly used approach for selecting and prioritizing pavement treatments, many state departments of transportation (DOTs), including the Iowa Department of Transportation (Iowa DOT), spare no effort to develop and improve pavement preservation programs. State DOTs have their own unique systems to select the best treatment option at the right time considering different factors, including distress types and severities, treatment effectiveness, and cost-effectiveness. Cost-effectiveness is calculated based on the ratio of treatment effectiveness to cost and represents the relative efficiency of each treatment option (Goh et al. 2019, Babashamsi et al. 2016).

Pavement preservation decisions should ultimately be made based on the information available about the pavements requiring treatment as well as the pavement preservation options available. This information includes a range of factors, such as the current condition of the pavement, traffic and truck traffic levels, and the types of preservation treatments that are either currently accepted or can be implemented by highway agencies.

A comprehensive pavement preservation guide that defines pavement preservation methods, their application criteria, and their performance is essential for decision-makers to perform cost-effective pavement maintenance and achieve the best pavement performance at the lowest cost.

Overview of Research Phases

Phase I of this research established a deterministic framework for estimating pavement preservation treatment effectiveness using life extension (LE), index benefit (IB), and benefit-cost analysis (BCA). While the Phase I methodology provided a transparent, robustness-oriented approach for evaluating treatment performance based on historical data, the research team identified several limitations that agencies face when relying solely on conventional curve-fitting techniques. Specifically, Phase I identified the following issues:

- Pavement condition and project records contain inconsistencies and unrecorded maintenance and rehabilitation (M&R) events.
- Certain treatment categories are underrepresented in the dataset, resulting in a significant imbalance among categories.
- Data quality varies across time periods and vendors.
- Traditional regression methods are very prone to overfitting to extreme observations (or outliers) in noisy data.
- Model selection based purely on root mean square error (RMSE) was found to yield unrealistic deterioration curves in many cases.

To address these limitations and enhance predictive robustness, Phase II introduces a hybrid data processing and AI-enhanced modeling framework. This phase integrates statistical denoising, engineering-based constraints, convexity enforcement, and transfer learning using national datasets to improve generalization and realism in pavement performance modeling. It should be mentioned that the Phase II work is not meant to replace the deterministic logic developed in Phase I but to strengthen it by incorporating machine learning techniques while maintaining strict engineering interpretability and domain-specific constraints.

Phase II extends the deterministic LE and IB computation engine developed in Phase I by introducing a layered modeling architecture:

1. **Data Quality Enhancement Layer**

    - Statistical denoising
    - Outlier detection

- Monotonicity enforcement

2. **Engineering Realism Layer**
   - Regularization scoring
   - Convexity guard (shape constraints)
   - Out-of-range control

3. **Transfer Learning Layer**
   - Pretraining on the Long-Term Pavement Performance (LTPP) dataset
   - Fine-tuning on Iowa's Pavement Management Information System (PMIS)
   - Hybrid long short-term memory (LSTM) model coupled with gradient boosting models
   - Monotone-constrained gradient boosting models

4. **Treatment-Stratified Machine Learning Modeling**
   - Categorical boosting (CatBoost) pooled modeling
   - Stratification by condition, traffic, family, and climate

5. **Uncertainty Quantification**
   - Bootstrap resampling
   - Confidence bands for LE and IB

The LE and IB calculation logic remains consistent with the models described in Phase I, ensuring continuity in benefit-cost analysis and decision matrices.

PROBLEM STATEMENT

The implementation of pavement preservation techniques has proven beneficial in enhancing pavement performance. In Iowa, there is a growing emphasis on optimizing infrastructure investments, prompting systematic collection of data on pavement performance. This gathered information, along with construction details and standard treatment expenses, offers deeper insights into the impact of preservation methods on the state's roads. The goal of research in this field is to provide clear evidence of these methods' effectiveness in improving ride quality and slowing down pavement wear and tear. Better understanding the performance of pavement preservation treatments can also lead to an overarching shift in asset management toward approaches that cost-effectively delay pavement deterioration through proactively addressing pavement distresses before a substantial decrease in serviceability occurs.

While Iowa has actively used pavement preservation methods as a way to extend pavement service life, improved understanding of these pavement preservation techniques, with a focus on pavement performance over time, is needed. To meet this need, this research compiled construction and performance data, enabling an objective evaluation of the cost-effectiveness of various preservation strategies based on their real-world performance (Buss et al. 2019).

OBJECTIVES

This research aimed to enhance the understanding of pavement preservation effectiveness in Iowa by focusing on two key areas: (1) measuring the effectiveness of pavement preservation techniques using quantitative metrics while considering important factors that influence the performance of these strategies and (2) evaluating the costs and benefits of various pavement preservation techniques (Buss et al. 2019).

The primary objective of Phase I of this research was to enhance the overall understanding of pavement preservation effectiveness within the state of Iowa. This was achieved through a data-driven approach designed to enable objective decision-making:

- **Quantitative effectiveness measurement**: The research aimed to measure the actual performance of preservation treatments using specific quantitative metrics, such as LE and IB. This involved analyzing real-world pavement performance data before and after the implementation of various treatments to quantify their impact.
- **Cost-benefit evaluation**: A key area of focus was to evaluate the economic efficiency of various preservation techniques. This included analyzing historical bid tabulation data to determine average costs and calculating the benefit-cost ratio (BCR) for each treatment.
- **Identification of performance factors**: The research sought to identify and incorporate critical factors that influence how well different strategies perform, including pavement type, existing condition (in terms of pavement condition index [PCI]), traffic volume, and truck traffic.
- **Development of decision-support tools**: A practical objective of Phase I was the creation of a pavement preservation treatment guide toolbox, an ArcGIS-based tool designed to help decision-makers at the Iowa DOT select optimal preservation strategies for specific route segments.
- **Establishment of decision matrices**: The research intended to develop comprehensive decision matrices that link pavement conditions and dominant defects (such as cracking, high International Roughness Index [IRI] values, and rutting) to recommended preservation solutions.

In Phase II, the primary objective was to overcome or minimize the impact of the data limitations identified during Phase I and take one step further toward transitioning the Iowa Pavement Preservation Guide into a dynamic, AI-powered decision-support system. The specific objectives included the following:

- **Implementation of a hybrid data processing framework:** Overcome local data scarcity by integrating a nationwide LTPP dataset (1989–2023) with an Iowa-specific PMIS dataset (1998–2023).
- **Application of transfer learning:** Develop a pretrained neural network based on millions of nationwide data points and fine-tune it using Iowa's specific environmental and material data, ensuring high predictive accuracy even for treatments with limited local history.

- **Enforcement of shape constraints:** Develop a modeling architecture that enforces "hard" engineering constraints (monotonicity and convexity), ensuring that every predicted curve is physically realistic and defensible to pavement engineers.
- **Quantification of uncertainty:** Move beyond point estimates by incorporating bootstrap confidence intervals (CI), allowing decision-makers to see the "reliability range" for predicted life extension and index benefit.
- **Enhanced cost analysis:** Calculate the index benefit-cost ratio using the improved performance predictions.

PAVEMENT CONDITION

The primary step in recommending a pavement preservation treatment is to record and assess the target pavement's condition. To assess pavement condition, highway agencies should identify, measure, and classify the severity/extent of pavement distresses. Underlying causes for distresses should be identified, especially if distresses are occurring prematurely. Typical pavement distress severity levels include low, moderate, and high. Severity is assessed based on the width, depth, area, or shape of the distress, while extent is calculated by measuring the length or the percentage of the pavement segment affected. Threshold values of distress severity and extent are identified based on engineering expertise and judgment. The levels and threshold values of pavement distresses should be part of the distress identification manuals of state DOTs.

The overall pavement condition can be evaluated in terms of one or multiple indicators or indexes of condition or level of service (LOS). Several different indicators have been developed and used to characterize pavement condition. Pavement condition indicators can represent pavement structural condition, such as pavement structural number or distress score; pavement functional condition, such as IRI or ride quality; or both pavement structural and functional conditions, including PCI or pavement condition rating (PCR) (Yamany 2020).

These indicators are not only used to describe pavement condition but also to determine the required pavement maintenance or rehabilitation actions. Some indicators can be determined using simple mathematical formulas and visual inspection, while others may require the use of automated machines and laser scanners. Most agencies depend on visual inspection to assess pavement condition. State DOTs use different pavement condition indices based on their policies and the information collected in their respective pavement management systems. Some DOTs use predeveloped and widely accepted indicators, while others have developed their own. For instance, most DOTs, including but not limited to Iowa and Indiana, use IRI in addition to pavement surface distresses to evaluate pavement condition. Some state DOTs have developed their own indicators; for example, Minnesota has developed and uses surface rating (SR) and pavement quality index (PQI). The Iowa DOT has also created its own condition indexes, such as cracking index and overall PCI.

Table 1 shows the most common pavement condition indicators and some indicators developed specifically for some states. The table shows the difference between these indicators and the state DOTs that use them.

Table 1. Pavement condition indicators

Indicator/ Index	Description	Rating Scale	Calculations	DOTs
Pavement Condition Index (PCI)	Numerical indicator. First developed by the U.S. Army Corps of Engineers. Represents pavement condition based on surface distresses.	0–100 0: failed 100: perfect	Manual inspection; calculated in terms of distress type, severity and extent	Iowa, Wisconsin
Pavement Condition Rating (PCR)	Similar to PCI but considers surface distresses and roughness.	0–100 0: failed 100: perfect	Manual inspection; calculated in terms of distress type, severity, extent and roughness	Ohio, Indiana, Minnesota
Present Serviceability Index (PSI)	Represents pavement capability to serve existing traffic at its existing condition. Developed by AASHO Road Test in 1960. Considers surface distresses and roughness.	-	Manual inspection; calculated in terms of distress type, severity and extent; roughness	Wyoming, Minnesota
Pavement Surface Evaluation and Rating (PASER)	-	1–10	Manual inspection; calculated in terms of distress type, severity and extent; roughness	Missouri
International Roughness Index (IRI)	Amount of vertical movement a standard vehicle would experience when driven down the road. Indicates pavement roughness and ride quality.	0–∞	Automatic inspection; calculated from Profilometer records	Most states*
Ride Quality Index (RQI)	Represents the rating that a typical road user would give to the pavement's smoothness. Newly constructed sections have RQI above 4.0. Pavement service life ends at a terminal RQI value of 2.5.	0–5 0: poor ride quality 5: good ride quality	Calculated based on IRI values	Minnesota, Louisiana, Michigan
Distress Index (DI)	-	-	Manual inspection; calculated in terms of distress type, severity and extent	Michigan
Surface Rating (SR)	Indicator of pavement surface distresses. Newly constructed sections have SR of 4.0. Pavements need reconstruction or rehabilitation at SR equals 2.5.	0–4 0: poor ride quality 4: good ride quality	Automatic inspection; calculated from images based on distress type, severity and extent	Minnesota
Pavement Quality Index (PQI)	Composite index representing RQI and SR. Gives an overall indication of pavement condition. Considers cracks and roughness.	0–4 0: poor ride quality 4: good ride quality	Calculated from RQI and SR as PQI = SQRT(RQI×SR)	Minnesota

Source: Buss et al. 2019
* Iowa, Indiana, Kentucky, Illinois, Maryland, South Carolina, Michigan, Wisconsin, Missouri, Mississippi, Louisiana, Colorado, South Dakota, Connecticut, and California

BACKGROUND AND CONCEPT

Pavement Preservation Treatments

The intended purpose of a pavement preservation program is to maintain or restore the surface characteristics of pavements and to extend the service life of pavements. However, preservation does not generally increase structural value or add capacity to pavements. A pavement preservation program uses preventive maintenance treatments as a means of improving the functional condition of the road network and reducing the overall rate of deterioration of pavement assets. Preventive maintenance treatments are relatively inexpensive in comparison to rehabilitation or reconstruction projects and are an effective means to preserve the investment in the pavement asset.

Several pavement preservation treatments have been developed and used by DOTs across the United States and around the world in order to keep their pavement infrastructure in a state of good repair. These range from localized applications to treatments that are applied to the entire pavement surface. For all preservation treatments, the purpose is to minimize the effects of pavement distress or prevent them from occurring (MnDOT 2020). Some of these preservation treatments have been used and accepted for a while, and their performance is well established. However, other treatments are relatively new, and their performance is still under study. For instance, the use of a thin hot-mix asphalt (HMA) overlay with profile milling is relatively new at the Iowa DOT, and its performance has not been extensively studied (Buss et al. 2019).

Many different pavement preservation techniques and treatments are available. Commonly used preventive maintenance treatments and minor rehabilitation techniques are described in the follow sections.

Crack Treatment

Crack treatment in asphalt pavements involves packing appropriate material into cracks in order to prevent moisture infiltration into the pavement structure. Cracks are categorized as either working cracks or nonworking cracks. Working cracks exhibit seasonal opening and closing movement due to temperature changes. Nonworking cracks have little to no movement (Buss et al. 2019, Tsai et al. 2021).

The two main treatment methods are crack sealing and crack filling:

Crack sealing has the following characteristics:

- Uses sealant materials placed into and above working cracks
- Prevents water and debris intrusion
- Often involves routing and cleaning cracks prior to sealant application

Crack filling has the following characteristics:

- Uses filler materials placed into nonworking cracks
- Primarily reduces water infiltration

The main factor in determining appropriate treatment is properly identifying working versus nonworking cracks. Working cracks are typically transverse thermal and reflective cracks and diagonal cracks with horizontal/vertical movement due to temperature changes. Nonworking cracks are typically longitudinal cracks like longitudinal cold-joint, reflective, and edge cracks that experience minimal movement. Crack sealing is more applicable to working cracks, while crack filling is better suited for nonworking cracks.

Crack sealing and filling treatments are recommended for pavements in relatively good structural condition with only minimal cracking present because they do not improve structural capacity; rather, they only reduce moisture damage to extend service life. However, it should be noted that the crack treatment may increase surface roughness over time as sealed cracks settle under loading into shallow depressions along the crack paths (Buss et al. 2019, Tsai et al. 2021).

Crack sealing and filling offer several advantages in pavement maintenance. These include reducing water infiltration and associated pavement deterioration; mitigating crack damage such as edge spalling; slowing overall deterioration, which manifests as roughness and depressions; offering efficacy across climates/traffic levels; allowing quick reopening after treatment; and providing substantial life-cycle cost savings. Additionally, milling, which is the process of removing the surface layer of asphalt, is not required, streamlining the process. However, it is essential to consider negative impacts associated with this method. Limitations involve potential over-application, which decreases skid resistance; undesirable aesthetics from obscured markings/darkened materials; and increased roughness without improving structural integrity (Buss et al. 2019, Tsai et al. 2021).

Crack sealing and filling is most effective when done in moderately cool temperatures, such as in spring or fall, to ensure that the material remains effective throughout all seasons. It is crucial to adhere to specific guidelines regarding sealant use, particularly ensuring that the ambient and surface temperature is at least 40°F and rising. Application should be avoided in the presence of moisture or impending rain. Additionally, a comprehensive traffic control plan should be implemented and maintained before and during operations, and traffic should only be allowed once the sealant has adequately cured. This process is ideally performed when the pavement is still in good condition, with careful consideration of crack characteristics such as type, width, length, and orientation, which influence the treatment’s timing and the choice of sealant. In cases of reflective cracking, which typically occurs due to movement in underlying concrete slabs, routing may be necessary before sealing to extend the pavement’s life (Buss et al. 2019, Tsai et al. 2021).

Fog Seal

Fog sealing or flush sealing is the process of applying diluted asphalt emulsion directly onto the pavement surface with no aggregate. The treatment does not add structural capacity to the pavement and may result in a negative impact on friction; however, it is effective at sealing the pavement surface and mitigating raveling. The treatment is suitable for both low- and high-volume roads. Before applying fog seals, pavement surfaces should be treated to address rutting, patching, and cracking. Fog seals are not recommended when the pavement is in poor structural condition or exhibiting flushing/bleeding, friction loss, or thermal cracking. The expected service life of fog seals depends on the underlying pavement properties and exposure to sunlight. Fog seals have a fairly short life, from one to two years (Buss et al. 2019).

Scrub Seal

Scrub sealing is the process of spraying a polymer-modified rejuvenating emulsion on the pavement surface. A broom is then dragged across the pavement surface to scrub the emulsified asphalt into the surface cracks. After brooming, a thin layer of uniformly graded, fine aggregate is spread over the emulsified asphalt. Scrub seals are effective in filling narrow cracks, rejuvenating oxidized asphalt, and improving poor friction; however, scrub seals do not add any structural capacity to the pavement. Similar to all preservation treatments, scrub seals are not recommended when the pavement is in poor structural condition. Scrub seals are also a suitable treatment for low to high traffic volumes (i.e., annual average daily traffic [AADT] values of less than 1,500). However, scrub seals are prone to damage from snow plow operations. Additionally, this treatment should not be applied to pavement with rut depths greater than ½ in. (Buss et al. 2019).

This method, which can include scrub sealing (where emulsified asphalt is scrubbed into cracks) and sand sealing (a similar process without the scrubbing), is designed to retard pavement aging and improve ride quality and surface friction. These treatments are suitable for a range of traffic volumes and can be executed rapidly without affecting overhead clearance or adjacent traffic. They do not, however, offer any structural benefits and are not suitable for pavements with stripping or areas that undergo frequent snow plowing operations.

Thin HMA Overlay

A thin HMA overlay treatment involves the application of a thin HMA layer less than or equal to 3 in. to improve ride quality, increase surface friction, and reduce the risk of hydroplaning. Thin HMA overlays are not recommended for pavements that exhibit serious structural failures. According to the National Asphalt Pavement Association (NAPA), thin HMA overlays can increase the structural capacity of pavements when used on well-built surfaces. For Iowa roadways, the technology is relatively new, and performance has not been extensively studied; however, it has been found that the material properties of the overlay are an important component of performance (Buss et al. 2019).

Thin overlays are used to replace only the top, worn-out asphaltic layer; it is assumed that the underlying layer is in good condition. The key criterion for choosing a thin overlay project is that the underlying layers of the target pavement are structurally sound. The following guidelines outline the selection criteria for thin overlay projects (Buss et al. 2019):

1. Thin overlays should be reserved for structurally sound pavements with minor defects, which excludes pavements exhibiting base failures. Additionally, they are suitable for pavements where excessive stone loss or other severe defects have occurred.
2. Various distresses, such as rutting, cracking (longitudinal or transverse cracking, alligator cracking), potholes, raveling, polished aggregate, flushing/bleeding, etc., should be assessed before opting for a thin overlay.
3. Limited rutting (less than ½ in. or 12.70 mm) is acceptable, but rutting greater than ½ in. (12.70 mm) requires milling.
4. Pavements that exhibit cracking, including limited load cracking (Levels 1, 2, and 3) and block cracking (Levels 1 and 2), can be considered for thin overlays. Pavements that exhibit limited load cracking (Levels 3 and 4) may be suitable with combined treatments, such as deep patching or milling.
5. Thin overlay projects are most cost-effective on pavements with minor issues. The benefits diminish if the existing pavement is still in excellent condition.

Since thin overlay treatments are most effective when road conditions are still favorable, it is important to prioritize application of this treatment to roads with moderate to high distress levels before structural deterioration progresses further. In instances where the overlay is very thin, cooling occurs from both the top and bottom, with a cooling time twice as fast as the cooling time of thicker overlays. Therefore, the time available for the contractor to obtain a sufficient density is reduced. For this reason, production temperatures may need to be greater for thin overlays (Buss et al. 2019). Prior to and during thin overlay operations, a comprehensive traffic control plan should be developed and maintained. The pavement can be opened to traffic once the mix has been compacted and the mat has cooled to 60°C (140°F) or the agency's required temperature (Buss et al. 2019).

Thin overlays are most effective on roads with a sound underlying structure but that exhibit wear on the surface layer. It proves ideal for roads showing a moderate level of cracking and minimal rutting (less than ½ in.). Even roads with localized and more severe rutting or cracking can be considered suitable candidates, provided patching repairs are undertaken beforehand. However, it is crucial to avoid using thin overlays on roads with extensive distresses, such as severe rutting or structural damage. The primary objective is to replace only the top damaged layer and not to address deeper underlying structural problems (Buss et al. 2019).

Slurry Seal

Slurry seals are cold-mixed surface treatments that are applied as a protective or preventive maintenance technique to seal small cracks, stop raveling, improve ride quality, and enhance friction properties. A slurry seal mixture consists of emulsified asphalts, dense-graded crushed fine aggregate, mineral filler, or other additives and water. Its suitability across different traffic volumes makes it a versatile treatment option. However, there are some limitations associated with the application of slurry seal as a surface treatment. For example, it is susceptible to damage from snow plowing operations. The Nebraska Department of Transportation also recommends that slurry seal not be applied if wheel path depressions are greater than ½ in. In addition, slurry seal should not be applied when structural deficiencies exist (Buss et al. 2019).

Slurry seal provides a cost-effective way to extend the life of an aged pavement. It works best on pavements where the asphalt has become oxidized but the underlying structure remains sound. Ideal candidates have hairline cracks and minimal rutting less than ¼ in. deep. The small cracks should be sealed to prevent water intrusion before the thin slurry layer is continuously applied over the surface, but the amount of crack sealant should not be excessive. This treatment does not add structural capacity; rather, it simply seals the pavement and improves the ride quality. Additionally, slurry seal cannot fix wide cracks, severe rutting, or subgrade failures, which require more substantial repairs.

A tack coat should be applied immediately prior to the slurry seal. The slurry seal should then be spread over the pavement in a continuous manner (Buss et al. 2019). It is recommended that slurry seal be applied when the ambient temperature is warm. If any moisture is present on pavement surfaces or within cracks, or if rain is expected in the near future, the application of slurry seal is not recommended (Buss et al. 2019). Appropriate traffic control plans must be formulated and implemented before and during the slurry seal operations. The pavement should not be reopened to traffic until the slurry seal has sufficiently cured to withstand potential marring and tearing, which ensures that no water will be pumped to the surface (Buss et al. 2019).

Microsurfacing

Microsurfacing, a specialized form of slurry seal, is a composite blend consisting of polymer-modified emulsified asphalt, mineral aggregate, mineral filler, latex polymer, water, and various additives. This treatment serves to effectively hinder raveling and oxidation while enhancing surface friction, sealing, and the filling of wheel ruts up to 1¼ in. With its rapid curing capability, microsurfacing allows for the swift restoration of traffic within one hour post-application. However, it is important to note that microsurfacing does not augment structural capacity, making it unsuitable for pavements experiencing structural failures (Buss et al. 2019).

Distinguished by the use of polymer-modified asphalt emulsion and applied with specialized machinery, microsurfacing cures through a chemical reaction at a faster rate compared to traditional slurry seals. It can also be applied in thicker layers, making it advantageous for applications requiring quick cure times or thicker coatings, particularly on pavements just beyond the cracking or rutting limits of slurry seals. Although microsurfacing is thicker than slurry seal, it does not contribute to structural capacity and requires special equipment due to its lower liquid binder content and modified binder. Consequently, it is generally more expensive than slurry seal (Buss et al. 2019).

Microsurfacing is recommended for pavements initially considered for slurry seal but exhibiting higher levels of raveling or rutting than recommended for the latter. Ideal candidates include pavements in relatively good condition with asphalt surfaces experiencing raveling, oxidation, or slight rutting. However, it is not recommended for pavements with wide cracks, alligator cracking, or excessive rutting (greater than ½ in.) or those already demonstrating subgrade failure due to moisture (which requires deep patching). The application process involves sealing hairline cracks without excessive use of sealant, milling elevated areas, filling minor ruts using a leveling course, applying a tack coat before placement, and ensuring uniform and continuous microsurfacing (Buss et al. 2019). For optimal results, microsurfacing is recommended in warm temperatures; application should be avoided in the presence of moisture, cracks, rain, or freezing temperatures. Adequate traffic control plans must be developed and maintained before and during microsurfacing operations, with the pavement remaining closed until the treatment has cured sufficiently to withstand potential marring and tearing (Buss et al. 2019).

Patching

HMA patching involves removing areas of severely distressed pavement and replacing the voids with a structurally sufficient HMA mixture. This preservation technique is commonly chosen as a spot treatment to address only the failed areas of pavements. Treatments can include full-depth repairs, partial-depth repairs, or the filling of potholes, depending on the severity of the distresses (Claypool 2016).

Chip Seal (Seal Coat)

Chip seal treatments, also known as seal coats, are nonstructural treatments that involve constructing a single thin surface by spraying a bituminous binding agent and then immediately spreading a uniformly graded aggregate cover over the bituminous surface. This technique is reliable and provides a smoother surface with high friction resistance. Chip seals are used to address small cracks, bleeding, raveling, and loss of surface friction. Chip seals are appropriate for roads with either low or high traffic volumes (i.e., less than 2,000 or greater than 2,000 AADT, respectively) and do not impact adjacent traffic or overhead clearances. While chip seals offer numerous benefits, they have limitations. They are not recommended for areas experiencing frequent heavy vehicle maneuvers, such as turning or braking, due to potential damage (Buss and Claypool 2022, Buss et al. 2019).

Additionally, it should be noted that chip seals are not designed to enhance the structural capacity of pavements. Instead, they serve as a means of preventive maintenance, effectively improving pavement surface conditions and extending service life when applied to pavements with limited or no distress; pavements with severe distresses or extensive deterioration are not suitable for chip seal application. Additionally, chip seals cannot bridge cracks wider than 1/4 in., nor can they properly address ruts deeper than 3/8 in. Chip seals may result in a rough, open texture that generates high noise and that may not be as smooth as the surfaces resulting from asphalt mixtures. In the early stages of service, dislodged stones can cause broken windshields if chip seals are not properly constructed. The use of modified binders and sand seals with chip seals can help alleviate some of these concerns (Buss and Claypool 2022, Buss et al. 2019).

It is required that chip seals be constructed when the temperature is warm. If there is moisture on the pavement surface or if rain or freezing temperatures are imminent, the treatment should not be applied. Relative humidity can affect the amount of time for an asphalt emulsion to cure; therefore, chip seals should be used with caution when the temperature is warm and the relative humidity is high. In addition, high temperatures may also lead to lower viscosity in the binder, causing the chip seal's aggregates to be picked up by the rubber tires of rollers (Buss and Claypool 2022, Buss et al. 2019).

Proper traffic control plans should be developed and maintained before and during chip seal application. The pavement should not be opened to traffic until the bituminous material has cured sufficiently to ensure that the aggregate will not be loosened, dislodged, or whipped off by slow moving traffic. Low-speed traffic may be allowed to travel on a fresh chip seal after the pavement is swept to remove loose aggregate; a pilot vehicle should be used to control the speed. Traffic will continue to compact the chip seal to its full embedment over time (Buss and Claypool 2022, Buss et al. 2019).

Chip seal operations can leave behind excess or loose aggregate stones on the road surface. This unwanted residue could have some negative consequences (Buss and Claypool 2022, Buss et al. 2019):

- Reduction of skid resistance
- Possible windshield damage
- Obscuring of striping
- Dislodgement of stone that would not otherwise be disturbed
- Negative public perception of chip seals

The main causes of loose stone include unsuitable bitumen binders, improper paving temperatures, inadequate rolling and compression, over-application of the aggregate layer, failure to properly sweep after chip seal application, or a combination of these errors. Proper practices can minimize loose stone. These include selecting quality binder and aggregate, paving in appropriate weather, sufficiently setting the chips and ensuring adequate adhesion, applying the optimal stone amount, and thoroughly sweeping to remove excess aggregate. Executed correctly, chip seals provide excellent road friction without leaving behind problematic loose debris (Buss and Claypool 2022, Buss et al. 2019).

Pavement Preservation Decision-Making

State transportation agencies have been developing their own decision-making trees and matrices to help practitioners select the right treatment for the right pavement segment at the right time. These decision trees and matrices are designed to map the available preservation treatments to pavement distress types and severity levels on the basis of engineering practices and treatment effectiveness. Some decision matrices, such as those developed for the Indiana Department of Transportation (INDOT), consider traffic loading as one of the selection criteria for appropriate treatments. Some treatments are not recommended for roads with heavy traffic. INDOT's matrices also account for pavement roughness and friction.

Other decision matrices, such as that developed for the Michigan Department of Transportation, specify the criteria and condition threshold values for which various treatments are feasible or recommended (MDOT 2020). The criteria for treatment selection in Michigan are the minimum remaining service life (RSL) of the pavement section, distress index, ride quality index, IRI, and rutting depth.

Some decision matrices are designed to map pavement distresses to the preservation treatments that are recommended to address the corresponding distresses according to engineering practices and treatment effectiveness. The decision matrices used by the South Dakota Department of Transportation (SDDOT) were developed to identify the treatments that are recommended, feasible, or not recommended for each type of pavement distress (SDDOT 2021). Unlike INDOT's decision matrices, the selection of treatments at SDDOT is based on categorizing distresses according to three severity levels and four extent levels and does not consider traffic loading or ride quality.

Unlike the simple decision matrices developed for INDOT or SDDOT, other decision trees, such as those developed for the Illinois Department of Transportation (IDOT) (IDOT 2010), are more comprehensive, incorporating a greater variety of distress and traffic loading levels and considering the relative costs of treatments. The format of the decision matrices developed for IDOT in 2010 is similar to that of the decision matrices developed for SDDOT. However, IDOT's decision matrices account for more treatment selection criteria, such as five distress levels, three traffic loading levels, the quality of pavement surface friction, and the relative costs of treatments. Decision-makers should first identify the different distresses and the levels of distress exhibited on the pavement surface and then identify the recommended treatments for the pavement section. If more than one treatment is recommended for a pavement section, then the relative cost should be considered to make the final selection decision.

As is evident from the above discussion, decision matrices can become complicated when several selection criteria must be considered. Therefore, some state DOTs, such as the Minnesota Department of Transportation (MnDOT), have developed decision trees to be incorporated into their decision matrices. Decision trees are flow charts that link treatment selection criteria to preservation treatments. The decision tree format simplifies the selection of treatments when numerous criteria must be considered, such as the time of last rehabilitation, pavement age, and past treatments. As such, decision trees can be used with decision matrices to make the final decision regarding treatment selection.

The preservation guide developed for the Maryland Department of Transportation (MDOT [Maryland]) contains 2 comprehensive decision trees and 10 comprehensive decision matrices for asphalt cement concrete (ACC) and portland cement concrete (PCC) pavements (MDSHA 2012). MDOT [Maryland] uses an extended decision tree for ACC pavements based on traffic loading and IRI to identify which decision matrix/table the user or decision-maker should use to find the recommended treatments. The decision tree developed for PCC pavements leads to two decision matrices: one for pavements with less than 25% patching and another for pavements with higher patching levels that require major rehabilitation or reconstruction. The decision matrices/tables do not suggest treatments based on subjective distress levels but on structural cracking index, functional cracking index, skid number, and rutting depth values.

In pavement preservation decision-making, an important component is pavement performance modeling. Previous studies have employed different types of deterioration models, including deterministic, probabilistic, and neural network models (Yamany and Abraham 2021, Abdelaty et al. 2016, Donev and Hoffmann 2020, Moeinizade and Hu 2020). Deterministic models predict an exact pavement condition and do not account for uncertainty and randomness (Amin 2015, Fuentes et al. 2021, Saha et al. 2017, Abaza 2004, Chu and Durango-Cohen 2008, Sakhaeifar et al. 2019, Dadashova et al. 2021). In contrast, probabilistic models such as the Markov transition consider randomness in pavement condition estimation by predicting the future state of a pavement based on its current state. However, the development of transition probability matrices for probabilistic models can be challenging and requires appropriate statistical techniques and a robust methodology (Mandiartha et al. 2010, Pulugurta et al. 2009, Abaza 2015, Hassan et al. 2017, Pérez-Acebo et al. 2018, Pérez-Acebo et al. 2020). Artificial neural network (ANN) models have also been used in pavement performance prediction, but the results are not always straightforward, and the internal workings of the models can be difficult to interpret (García de Soto et al. 2018, Amin and Amador-Jiménez 2017, Plati et al. 2016, Yamany et al. 2019).

Furthermore, several research efforts have been made to address uncertainty in BCA methodologies. Various researchers have used probability theory, simulation techniques, association analysis, and historical cost data to improve life-cycle cost analysis for pavement maintenance and rehabilitation decisions (Salem et al. 2003, Pour and Jeong 2012, Swei et al. 2013).

METHODOLOGY

This chapter describes the development of preservation treatment selection guidelines for the Iowa DOT. It is important to note that this research focused solely on treatments for composite and flexible pavements. Future proposed improvements to the selection guidance described in this report include the incorporation of preservation treatments and a treatment selection process for rigid pavements.

Appropriate preservation treatments for a given pavement section are determined based on a combination of the current pavement condition and the distress types present. In some cases, combinations of preservation strategies might be needed to correct the combination of distresses present on the pavement. The process of selecting the right treatments for preservation includes the following general steps:

- Obtain pavement information
- Assess pavement condition
- Evaluate pavement data to develop a performance model
- Identify feasible preservation treatments
- Analyze the costs and benefits of each type of treatment
- Select a preservation treatment

Evaluate Pavement Data

In order to determine whether a given pavement section is a good candidate for pavement preservation treatments, the following should be considered:

- 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 the pavement 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?

If the answer to the majority of these questions is “no,” then the pavement section is likely to be a good candidate for pavement preservation techniques. When the answer to most of these questions is “yes,” preservation techniques should not be considered. Instead, more investigation is needed to determine other rehabilitation options (MnDOT 2020).

Identifying Feasible Preservation Treatments

The preservation process for a given pavement section is initiated by evaluating the type and severity of the observed pavement distresses and selecting treatment methods based on attributes such as distress levels, ride quality, traffic and truck traffic levels, and relative treatment costs. Each of these characteristics is primarily assessed in terms of a relationship between a single treatment and a single distress. When multiple distresses exist, the treatment to address each distress type should be examined, and the recommended treatments must be used in combination with engineering judgment to make final treatment decisions. It should be noted that regional pricing, availability of qualified contractors, and availability of materials may also play a role in the selection of preservation treatments (MnDOT 2020).

Selecting Preservation Treatments

Of the feasible preservation treatments, the most efficient alternative is the one with the highest benefit to cost ratio that enables pavement performance targets to be achieved. There are several methods to identify the treatment with the most benefit for the associated cost. This analysis is done internally within many pavement management systems. Ideally, the selection of the right treatment at the right time is governed by optimization (maximizing the benefits for a given set of constraints) (MnDOT 2020).

Data Sources

Pavement Management Information System

A PMIS database was developed for the Iowa DOT to help engineers and researchers evaluate the performance of pavements and various preservation treatments. For the present project, the primary data source was the Iowa DOT's PMIS, which contains comprehensive data about road characteristics for all publicly owned roads in Iowa. This dataset includes detailed measurements of distress, traffic information, and pavement history. Roadways in the PMIS are segmented into sections of varying lengths, each having a unique 17-digit identifier known as the origin key; the average length of road sections in this analysis was 4.3 km (2.7 mi), with an approximately 30 km (18.5 mi) range and standard deviation of 2.8. Table 2 presents the PMIS information.

Table 2. PMIS database information

Section	Details
Section Control Information	Primary key Pavement management year Pavement type Construction year Project year Age (number of years since last project) Location
Condition Data	Pavement Condition Index Version 2.3 (PCI_2) Rutting index Rut depth IRI Transverse cracking index Longitudinal cracking index Longitudinal wheel path cracking index Alligator cracking index
Construction History	Project type (Surface type) Surface thickness
Traffic Data	AADT Annual average daily truck traffic (AADTT)
Other Information	-

As can be seen in Table 2, the condition data in the PMIS include PCI; indexed distress metrics such as rutting index, riding index, IRI, and cracking index; and measurements of various distress types such as alligator cracking, transverse cracking, longitudinal cracking, durability cracking, and joint spalling. PCI is obtained from indexed distress metrics using specific formulas for rigid and flexible pavements defined by the Iowa DOT. This study made use of performance data from a total of 7,255 PMIS road segments over the period from 1998 to 2020.

Long-Term Pavement Performance Dataset

The LTPP dataset provided this research with a national source of pavement condition and treatment data and was used as a high-quality knowledge base to augment the Iowa PMIS data and improve the predictive power of the models. The LTPP program is a nationwide pavement research initiative established under the Strategic Highway Research Program (SHRP) and later continued under the Federal Highway Administration (FHWA). The program was designed to systematically collect long-term performance data on in-service pavements across diverse climatic regions, traffic conditions, structural configurations, and material types throughout North America. Because of its breadth, consistency, and controlled experimental design, the LTPP database is widely regarded as one of the most comprehensive and reliable pavement performance datasets available in the world.

The LTPP dataset contains records of pavement performance that span multiple decades, including detailed distress surveys, structural data, materials information, traffic loading, and environmental variables. Data collection began in the late 1980s and continues today, resulting in longitudinal time-series extending over 30 years for many sections. The 1989–2023 period was used in this study. The LTPP dataset differs from the Iowa PMIS dataset in several important ways that make it particularly suitable for transfer learning and model pretraining:

1. **Longitudinal depth:** Many LTPP test sections contain continuous performance records spanning multiple decades. This temporal depth is particularly valuable for training time-series models such as LSTM encoders, which require extended sequences to learn realistic deterioration dynamics.
2. **Geographic and climatic diversity:** LTPP sections are distributed across multiple climatic zones, including wet-freeze, wet-non-freeze, dry-freeze, and dry-non-freeze regions. This diversity enables the modeling framework to learn how temperature, precipitation, freeze–thaw cycles, and environmental exposure influence pavement deterioration. These environmental relationships enhance generalization when transferring knowledge to Iowa's specific climate conditions.
3. **Detailed structural and distress information**: The LTPP database includes PCI and distress components, cracking indices, rutting depth measurements, ride quality indicators, layer thicknesses and structural properties, and traffic loading (AADT and equivalent single axle loads [ESALs]). These features align closely with the predictors used in our performance models and enable effective feature mapping between the LTPP and PMIS datasets.
4. **High measurement consistency:** Unlike agency-level pavement management system databases that may involve multiple vendors and evolving data collection protocols, LTPP data were collected under standardized procedures. This consistency reduces measurement bias and makes this dataset a suitable anchor to be used for fine-tuning the models.

In the data analysis step of this study, the LTPP dataset was not used to directly compute life extension or index benefit values for Iowa projects. Instead, it was used as a knowledge source within a transfer learning framework to enhance prediction of post-treatment pavement performance in the Iowa PMIS dataset. The use of the LTPP dataset occurred in three primary stages:

1. Model Pretraining

Machine learning models, including neural networks and gradient boosting models, were initially trained on LTPP data to learn generalized deterioration relationships between the following:

- Previous PCI and future PCI
- Traffic intensity and degradation rate
- Environmental exposure and performance loss
- Pavement age and distress progression

Pretraining allowed the models to learn broad structural patterns before being exposed to Iowa-specific data.

2. Feature Transfer

The following features were harmonized between the LTPP and PMIS datasets:

- Previous PCI
- Previous cracking index
- Previous rutting index
- Previous riding index
- Pavement age
- Traffic volume (AADT)
- Truck traffic percentage
- Precipitation
- Average temperature
- Freezing index
- Freeze-thaw cycles

By aligning these features, pretrained models could transfer learned parameter relationships to the Iowa dataset with minimal structural modification.

3. Fine-Tuning on Iowa PMIS Data

After pretraining on LTPP data, models were fine-tuned using Iowa PMIS data. This fine-tuning step adjusted model parameters to do the following:

- Reflect Iowa's material specifications
- Capture Iowa-specific construction practices
- Account for local maintenance strategies
- Adapt to state-specific environmental patterns

Selective layer freezing was used in the neural network models to preserve transferable knowledge while allowing later layers to adapt to Iowa conditions. In gradient boosting implementations (e.g., XGBoost), pretrained trees informed initialization and parameter selection before full retraining on PMIS data.

Transfer Learning Type and Scope

Transfer learning was used in this study to improve prediction stability by first training the models on a cleaner and more internally consistent external source, then adapting them to local data. The transfer learning applied here was transductive in nature, in which the prediction task was identical in both the source and target domains (i.e., predicting PCI from condition history and site characteristics), but the data distributions differed due to differences in geographic coverage, climate exposure, traffic regimes, measurement protocols, and maintenance practices between the LTPP and Iowa PMIS datasets.

The models did not change tasks between pretraining and adaptation; rather, they transferred distributional knowledge about how pavements deteriorate across a wide range of conditions and then specialized that knowledge for Iowa, with the LTPP database being the source domain. In other words, pretraining on the LTPP data allowed the models to learn physically plausible deterioration patterns before they were exposed to Iowa data. When the models were subsequently fine-tuned or jointly trained on Iowa PMIS data, the source-domain structure constrained the adaptation, i.e., instead of fitting freely to the noise and inconsistency existing in the local records, the models adjusted the LTPP-learned relationships toward Iowa-specific conditions. This stabilizing property was the main advantage of using transfer learning in this study, especially for treatment categories and time periods where Iowa PMIS data quality was weakest or observation windows were shortest.

Data Preparation for Transfer Learning

Before any model training could begin, both datasets were structured around a common input representation. For each road section and observation year *t*, every model received two categories of input:

- The recent deterioration trajectory through condition indices recorded in prior years, including the flexible cracking index, riding index, rutting index, and the composite PCI. Depending on the method, either only the single most recent prior year (t−1) or the three preceding years (t−1, t−2, t−3) were used.
- Current-year site factors included pavement age, AADT, truck traffic volume, total annual precipitation, mean annual temperature, and freeze index.

The prediction target was PCI at year t. Only values from years strictly before *t* were used as historical inputs, preventing any leakage of future condition information into the features.

On the LTPP side, only flexible and composite pavement sections with construction years after 1990 were retained, consistent with the pavement types present in the Iowa network. Sections with fewer than two consecutive annual observations, documented structural failures, or experimental treatments without an Iowa analog were excluded. Climate variables were derived from the MERRA module in the LTPP database and matched to each section’s geographic location using the same procedure applied to Iowa PMIS sections, ensuring comparability.

Cost Data for Life-Cycle Cost Analysis

The necessary project details and cost information were obtained from historical bid tabulations provided by the Iowa DOT for the period from 2015 to 2023. The bid data were accessed through the Iowa DOT contracts portal and Bid Express subscription service. In the Bid Express portal, bids were ranked based on their total value, and a detailed cost breakdown was provided, specifying the quantity and cost of each construction item. Based on the analysis of bid items and project quantities, an eight-year average cost was determined for each preservation treatment type. For seal coat treatments, cost data were obtained from the MnDOT Bid Express subscription service.

Data Quality Challenges

The Iowa PMIS dataset (1998–2020) and associated bid tabulation data represent a valuable longitudinal database for pavement preservation analysis. However, extensive exploratory analysis revealed several structural challenges. Extensive effort was made in this project to mitigate or reduce the impacts of data quality issues on the reliability and overall performance of the models.

Changes in the PMIS Dataset over Time

Data collection and input for the PMIS are outsourced to selected vendors and are typically carried out on an annual basis. However, the use of different vendors in different years introduced considerable variability in the data, posing a significant challenge during the data analysis for this study. The data therefore needed to be cleaned (Buss and Claypool 2022, Buss et al. 2019).

The inconsistencies within the dataset extend beyond this issue. The Iowa DOT transitioned from the metric system to the imperial system of measurement in 2013. To ensure uniformity across the dataset, it was necessary to convert all non-index-based data collected prior to 2013 into the imperial system, whether the data were measured in length or area. However, the 2010 PMIS data were found to be already consistent with the post-2012 datasets in terms of unit measurements.

For IRI specifically, the records from 1998 to 2009 and for the years 2011 and 2012 were recalibrated from meters per kilometer to inches per mile. Rutting data for these same periods were also converted from millimeters to inches. Furthermore, an array of cracking data files were converted to conform to the imperial system.

Additionally, following a study in 2014 (Bektas et al. 2014), the Iowa DOT revised its PCI calculations, introducing an updated version known as PCI_2. Consequently, the PMIS data prior to 2014 were updated in the present study based on the new calculation formula, which incorporates an equation that weights cracking, ride quality, and rutting, as shown in equations (1) and (2):

For rigid pavements:

$$PCI = 0.4 \times (\text{Cracking Ind.}) + 0.4 \times (\text{Riding Ind.}) + 0.2 \times (\text{Faulting Ind.}) \qquad (1)$$

For flexible and composite pavements:

$$PCI = 0.4 \times (\text{Cracking Ind.}) + 0.4 \times (\text{Riding Ind.}) + 0.2 \times (\text{Rutting Ind.}) \quad (2)$$

where the cracking index is a scale that weights the impact of various types of observed cracking, furthered calculated in equation (3). These weights are determined based on expert opinion at the Iowa DOT.

$$\text{Cracking Ind.} = 0.2 \times (\text{TCI}) + 0.1 \times (\text{LCI}) + 0.3 \times (\text{LWPCI}) + 0.4 \times (\text{ACI}) \quad (3)$$

where TCI is the transverse cracking index, LCI is the longitudinal cracking index, LWPCI is the longitudinal wheel path cracking index, and ACI is the alligator cracking index. All indices presented are also on a 0 to 100 scale, where 100 represents a pavement with no cracking/distress (Hosseini et al. 2020).

The Iowa DOT evaluates pavement conditions by considering different levels of distress severity: low, medium, and high. For a systematic and quantifiable approach to calculate the cracking index, these severity levels are represented by coefficients: “1” for low severity, “1.5” for medium severity, and “2” for high severity. This numerical system helps in standardizing the evaluation process by converting all severity levels into low severity.

Furthermore, the Iowa DOT employs a scoring system where a maximum threshold value corresponds to a 100-point deduction. This means that when a particular type of cracking in a pavement reaches its threshold value, it is deemed severe enough to significantly impact the pavement’s condition and warrants a considerable deduction in its overall index. Table 3, which outlines the threshold values for different types of cracking in both flexible and composite pavements, illustrates this system.

Table 3. Threshold values for the cracking sub-indices

Sub-Index	SI System	Pavement Type: Composite	Composite (Built on Old Jointed PCC)	Composite (Built on Continuously Reinforced PCC)	Flexible	Imperial System	Pavement Type: Composite	Composite (Built on Old Jointed PCC)	Composite (Built on Continuously Reinforced PCC)	Flexible
TC	$\frac{count}{Km}$	500	500	500	300	$\frac{count}{mile}$	805	805	805	483
LC	$\frac{m}{Km}$	500	500	500	500	$\frac{ft}{mile}$	2640	2640	2640	2640
LCW	$\frac{m}{Km}$	500	-	-	500	$\frac{ft}{mile}$	2640	-	-	2640
AC	$\frac{m^2}{Km}$	360	-	-	360	$\frac{ft^2}{mile}$	6236.208	-	-	6236.208

When the extent of cracking in a pavement exceeds these thresholds, a cracking sub-index of "0" is assigned to that specific type of crack. This "0" sub-index signifies a severe level of distress, suggesting the need for potentially extensive repair or maintenance. Conversely, when no cracking is present, the sub-index is marked as "100." Values between zero and the established threshold are interpolated to calculate the index. By implementing these precise thresholds, the Iowa DOT can more effectively monitor pavement conditions and accordingly prioritize maintenance and repair efforts.

Riding index is a scaled parameter ranging from 0 to 100 that is calculated using the IRI based on the formula given by the Iowa DOT as follows. IRI values below 0.5 m/km (31.68 in./mi) are scored 100, meaning perfect ride quality, while values above 4.0 m/km (253.44 in./mi) are assigned a score of 0, meaning dysfunctional pavement. Intermediate values between 0.5 and 4 m/km are calculated using linear interpolation.

The rutting index, used in this study, is a tool for assessing the depth of wheel path ruts in pavements. For PCC pavements, however, the faulting index is used instead of the rutting index. A threshold value of 12 mm (0.473 in.) as set to 0 on a rutting index scale of 100. Rutting index is calculated using equation (4):

$$Rutting\ Index = 100 - [(\frac{Rut(mm)}{12(mm)}\ or\ \frac{Rut\ (inch)}{0.47244(inch)}) \times 100] \quad (4)$$

Generally, the PCI assigns a numerical value ranging from 0 to 100 to describe a pavement's condition at the time of evaluation, with 100 indicating the best possible condition. All indices used in calculating the PCI follow a 0 to 100 scale, where a score of 100 represents the optimal condition for each specific index. The Iowa DOT uses these PCI values to classify the condition of the Interstate highway system. A PCI score between 76 and 100 is classified as "good," a score between 51 and 75 is classified as "fair," and a score between 0 and 50 indicates that the pavement is in "poor" condition (Hosseini et al. 2020).

Inconsistent Project Records

Preservation project years recorded in the PMIS do not always match the actual construction records obtained from electronic plans and proposals. In some cases, deterioration trends suggest that a treatment occurred that was not recorded, while in other cases, recorded project years do not correspond to observable performance improvements (or a condition reset). Two main causes behind these observations were as follows:

- **Outliers and Measurement Noise:** The dataset contains abrupt PCI jumps (more than 5 points without a documented M&R event), single-year spikes, minor monotonicity violations, and vendor-related measurement discrepancies. Without correction, these anomalies significantly distort regression-based curve fitting. They stem from variations in data quality caused by periodic changes in data collection vendors and sensor technologies over the 25-year period covered by the PMIS.

- **Unrecorded M&R Events:** There were many cases where PCI improved without a corresponding record of maintenance in the PMIS, leading to inaccurate deterioration curves. Investigation into the root causes of these jumps, through digging into Iowa DOT data and seeking input from Iowa DOT engineers, showed that such cases cannot always be attributed to outliers or errors. It turned out that there are a considerable number of unrecorded M&R work instances in the data.

Skewed Treatment Distribution

The dataset exhibits a strong skew toward HMA overlays, while treatments such as microsurfacing, slurry seal, and seal coat have substantially fewer reliable records. This imbalance caused data scarcity in certain categories and reduced the reliability of treatment-specific deterministic curve fits. Many treatment categories lacked sufficient local records for robust independent modeling, while others (like HMA overlays) were heavily overrepresented.

Limited Sequence Depth

Many segments have short time sequences, limiting the effectiveness of purely data-driven time-series models without augmentation.

Analysis

Overview

The main research question at this stage was how to develop pavement performance models despite the existing data challenges. This project approached this issue at two levels: (1) by adopting suitable data treatment methods and (2) by incorporating measures within the model development process to mitigate or reduce the impact of data shortcomings. The two phases of this research differed in their data treatment and modeling approaches. Phase I intentionally relied on more straightforward, deterministic methods to investigate the feasibility of data-driven decision-making in pavement preservation using only the available data with minimal intervention. The purpose of beginning with a simpler framework was to establish transparency, interpretability, and methodological baseline performance before introducing more complex techniques. It allowed the research team to understand the structure, limitations, and behavior of the PMIS dataset under conventional curve-fitting and life-extension calculations and to assess whether meaningful preservation metrics (LE, IB, and BCR) could be extracted without advanced data manipulation.

After identifying the limitations of purely deterministic modeling, the second phase incorporated systematic denoising, engineering constraints, convexity enforcement, and transfer learning to improve robustness and generalization. Phase I addressed data challenges primarily through deterministic curve fitting and structured segmentation of pre- and post-treatment performance, relying on robust regression options (e.g., isotonic and Theil-Sen) and geometric constraints to reduce the impact of obvious anomalies while preserving interpretability. However, model selection was largely driven by goodness of fit (e.g., RMSE), and data inconsistencies were handled implicitly rather than systematically. In contrast, Phase II introduced a layered data-quality and modeling framework that explicitly targeted noise, imbalance, and domain limitations. It applied statistical denoising (median absolute deviation [MAD], interquartile range [IQR], residual filtering), heuristic spike detection, realism penalties, and convexity guards to enforce physically plausible deterioration. Additionally, Phase II mitigated sparse or skewed treatment data by incorporating transfer learning from the LTPP dataset and using machine learning models with engineering constraints, thereby improving generalization, robustness, and predictive stability under real-world data imperfections.

Measures to Overcome Data Challenges

Developing reliable pavement performance models required careful attention to data quality, data consistency, and the structural integrity of the historical records. Given the known limitations of the Iowa PMIS dataset, a structured data treatment strategy was implemented. This strategy evolved across the two research phases. As discussed above, Phase I emphasized minimal intervention and transparency to assess feasibility under realistic agency data conditions, while Phase II adopted more in-model measures (such as constraint enforcement) to improve robustness and generalization. The following sections list the major data treatment measures taken in this work under both phases.

Data Compilation and Alignment

In both phases, raw PMIS records were compiled and aligned with (1) M&R records, (2) Iowa DOT bid tabulation cost data, and (3) project letting information. Segment histories were chronologically ordered and split into pre-treatment and post-treatment performance sequences. This segmentation was fundamental for computing LE and IB. In Phase I, this alignment was conducted using available recorded project years without systematic correction for potential unrecorded treatments. In Phase II, this same segmentation step was retained but supplemented with additional validation against performance resets and anomaly detection to flag potentially unrecorded interventions.

Basic Data Cleaning and Filtering

Primarily done under Phase I, the following essential preprocessing steps were undertaken to ensure computational feasibility while maintaining minimal alteration of raw data:

- Removal of duplicate records
- Correction of obvious data entry errors
- Exclusion of records with missing critical variables (e.g., PCI or treatment year)
- Bounding of PCI values within realistic limits (0–100)

The intention in Phase I was to preserve the integrity of the original dataset and avoid excessive manipulation that could mask inherent structural issues. No formal statistical denoising or automated outlier detection procedures were applied at this stage beyond basic sanity checks.

Robust Regression Options

To reduce sensitivity to extreme values during deterioration curve fitting, Phase I incorporated robust regression options (e.g., isotonic regression and Theil-Sen estimators) alongside conventional parametric models. These techniques provided limited resistance to outliers but did not explicitly remove anomalous observations from the dataset. In Phase II, robust regression was retained but repositioned as part of a broader denoising and realism-enforcement pipeline rather than as the sole defense against noisy data.

Statistical Denoising and Outlier Detection

Given the limitations observed in Phase I, Phase II introduced a structured statistical denoising framework prior to model fitting. These procedures systematically reduced the influence of measurement noise, vendor inconsistencies, and unrecorded anomalies before curve fitting. The following techniques were applied:

- **Delta-based outlier detection:** Year-to-year PCI changes were analyzed using MAD, IQR, and Z-score thresholds to identify abnormal jumps. Observations exceeding robust statistical thresholds were flagged as potential anomalies.
- **Residual-based filtering:** Observations deviating significantly from robust baseline fits (isotonic or Theil-Sen) were flagged and removed.
- **Heuristic filters:** Some additional filters derived from the team’s assessment of the data over the two phases and experience working with these datasets, as well as input from Iowa DOT experts, were applied, primarily to enhance the stability of the subsequent curve fitting:
  - PCI increases greater than 5 points without recorded M&R were removed.
  - Isolated single-year spikes were filtered.
  - Minor monotonicity violations were corrected within tolerance.

Engineering Realism Constraints

Phase II introduced additional data treatment at the model selection stage by embedding engineering logic into the modeling process. These measures, which did not modify raw data directly but constrained how treated data could influence model selection, included the following:

- Penalizing near-zero slopes when observed data indicated deterioration
- Penalizing upward-trending curves without M&R
- Rejecting PCI predictions outside acceptable bounds (PCI < –1 or PCI > 101)
- Preventing post-treatment “healing jumps” above the last observed PCI

Convexity Guard and Shape Enforcement

To prevent unrealistic curvature (e.g., pavements strengthening over time), Phase II implemented a convexity guard that rejected concave-up deterioration shapes. Only monotone-decreasing, physically plausible deterioration curves were retained. This layer functioned as a structural data treatment mechanism at the model level, ensuring that cleaned data did not still produce implausible long-term extrapolations.

Treatment Stratification and Data Pooling

Because Phase I revealed an imbalance in treatment representation (particularly the dominance of HMA overlays), Phase II implemented stratified modeling approaches:

- Grouping by treatment type
- Categorizing by initial PCI ranges
- Segmenting by pavement family
- Incorporating traffic class and climate zone

For sparse categories, pooled machine learning models (e.g., CatBoost) were trained across strata to improve generalization. This approach mitigated instability caused by limited observations in certain treatment groups.

Transfer Learning Data Harmonization

To augment the Iowa PMIS data, Phase II incorporated the LTPP dataset through transfer learning. This required harmonization of the following:

- Condition indicators (PCI and sub-indices)
- Traffic variables
- Environmental variables (temperature, precipitation, freeze–thaw metrics)
- Age and performance progression features

Feature normalization and consistent scaling were applied to ensure compatibility between the LTPP and PMIS datasets while minimizing domain shift effects.

Bootstrap Resampling for Uncertainty Assessment

Phase II introduced bootstrap resampling at the segment level to evaluate the stability of LE and IB estimates. This did not modify underlying data but provided statistical insight into sensitivity and robustness under sampling variability.

Performance Modeling

Phase I Model Development

The effectiveness of preservation treatments was assessed by analyzing pavement performance before and after the implementation of each treatment. This analysis involved considering condition indices and the rate of pavement deterioration, which allowed the pavement life extension resulting from the preservation projects to be quantified. As noted above, there are some irregularities in the data used for this analysis. Besides the issues resulting from changes in units or calculation methods, some of the data in the PMIS have been compromised over the past 20 years. This damage has occurred through events such as mistakes in data entry, use of false 0s or perfect 100s in place of blank cell values, combination/deletion of original smart keys, failure to record data, and other potential errors. Although these irregularities exist within the data, potential outliers were not removed from the data primarily because outliers could not be reliably distinguished from unrecorded maintenance effects and the possible adverse effects of some treatments on performance metrics. Instead, robust regression models, such as a random sample consensus (RANSAC) algorithm, were employed to effectively handle these irregularities.

After addressing data quality, the next step was to model the performance of each treatment in order to measure its effectiveness. By applying the life extension calculation to all segments that received a specific treatment, the expected capability of each treatment method to extend pavement life could be determined.

Moreover, analyzing life extension data against pavement and road characteristics, such as the underlying pavement condition, truck traffic, pavement type, and traffic volume, provided insights into when and where the treatments are best implemented.

In the analysis, two deterioration curves were considered: pre-preservation and post-preservation. These deterioration curves were modeled using regression analysis and were represented by the functions that best fit the pavement condition data. The pre-preservation curve specifically modeled the pavement’s deterioration starting from either the beginning of data collection in 1998 or from the last pavement treatment, which could be pinpointed by a significant increase in overall PCI, up to the year just before the preservation treatment was applied. The post-preservation curve focused on the pavement’s deterioration from the time of the preservation treatment until either the next pavement treatment, identified by a significant increase in overall PCI, or the latest year of data collection, which was 2020.

Subsequently, the service life extension provided by each treatment in terms of each condition indicator was determined by solving the post-preservation deterioration curve function using the latest pre-preservation index value. Figure 1 provides a visualization of the improvement in PCI and the corresponding pavement service life extension resulting from a pavement preservation treatment for a hypothetical segment. Deterioration curves were created for each road segment using each condition data attribute, i.e., PCI and distresses, separately. The extrapolation of the pre-preservation performance curve beyond its year range, which ends at the next treatment year, is referred to as the do-nothing curve or do-nothing scenario. This scenario considers the case if the preservation treatment had not been implemented and the pavement had been allowed to deteriorate without intervention.

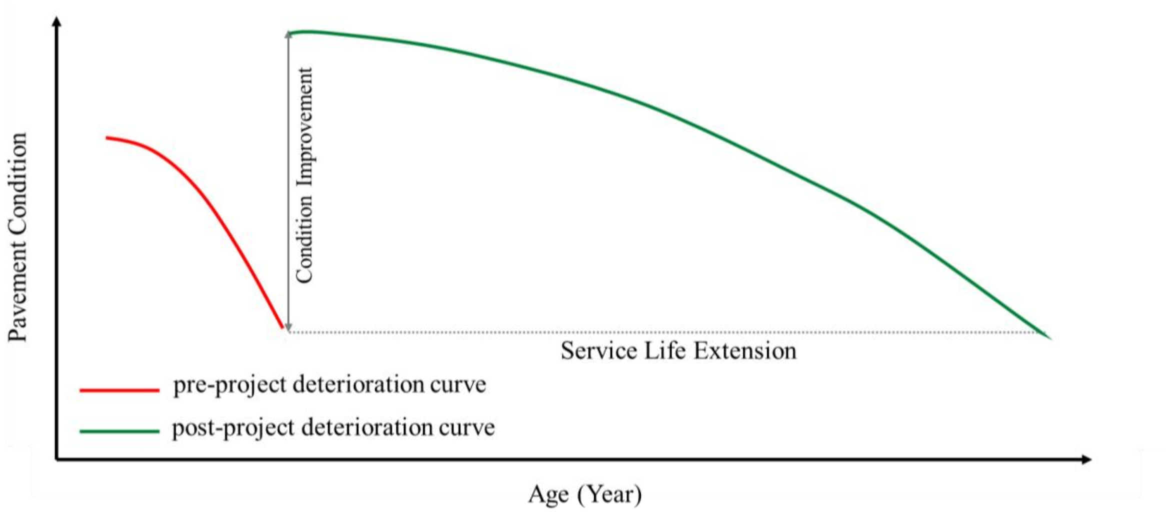


Figure 1. Immediate condition improvement and life extension for a hypothetical segment

When a treatment provided no service life extension for a given condition indicator, that is, when the observed performance deterioration curve was lower than the do-nothing deterioration curve, the service life extension for that treatment and condition indicator was recorded as a zero value. At the other end of this spectrum, the service life extension for a given treatment and condition indicator may have been too large. This could occur if the observed performance deterioration curve had zero slope or nearly zero slope, resulting in a situation where the predicted deterioration would never fall to its value at relative year zero.

To assess a treatment's effectiveness in terms of a specific condition indicator, index benefits were defined as the area between the pre-project deterioration curve (representing the do-nothing scenario) and the post-project deterioration curve over the range of the extended service life, obtained by extrapolating the pre-project deterioration curve over the extended service life. Figure 2 demonstrates the index benefit area for a hypothetical segment, which can be calculated by equation (5), where *n* is the analysis period, and $f(Deterioration\ Curve)$ and $f(Do\ Nothing\ Curve)$ best describe the actual performance when the pavement is preserved or not preserved, respectively.

$$Index\ Benefit = \int_0^n f(Deterioration\ Curve)d_n - \int_0^n f(Do\ Nothing\ Curve)\ d_n \quad (5)$$

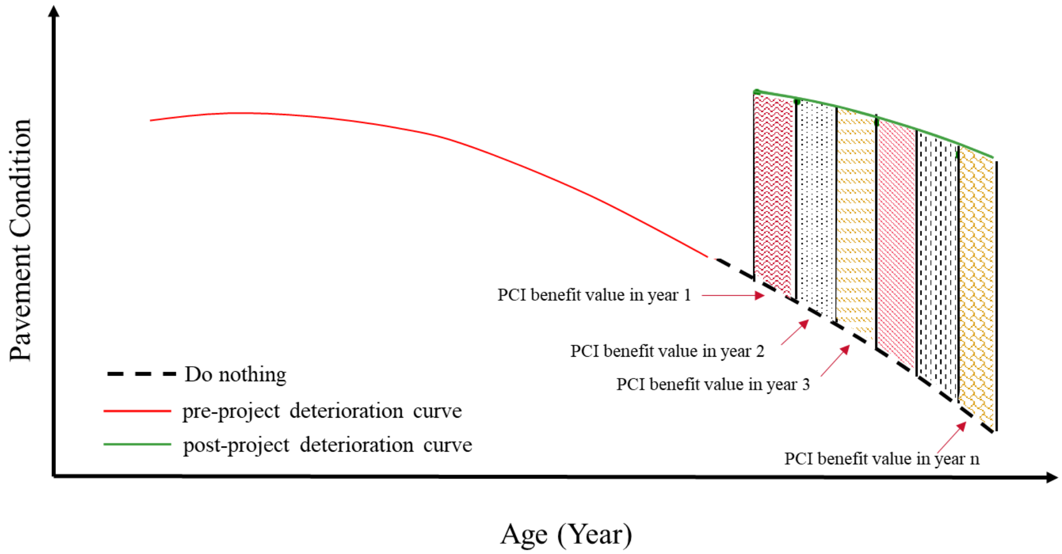


Figure 2. Index benefit concept for a hypothetical segment

Phase II Model Development

Phase II performance modeling was designed to produce treatment effectiveness estimates that remain defensible under the real-world distresses documented in the PMIS dataset while still preserving the interpretability and decision-support logic established in Phase I. Conceptually, both phases shared the same evaluation framework: treatment effectiveness was inferred by comparing pre-treatment and post-treatment performance trajectories, then computing LE and IB from those trajectories. What changed in Phase II was how the deterioration trajectories were modeled and validated. Instead of relying primarily on best-fit regression with limited robustness safeguards, a modeling approach was adopted in Phase II that (1) generated candidate performance models, (2) selected among them using both statistical fit and engineering realism, and (3) strengthened predictive capability in data-sparse categories through transfer learning and pooled machine learning. The result was a modeling workflow that yielded the same core outputs as Phase I (LE, IB, and downstream BCR) but provided stronger guarantees that the underlying curves were physically plausible and stable across imperfect data contexts.

The unit of analysis in Phase II remained the pavement "segment history" centered around a preservation action. For each segment, the goal was to estimate two counterfactual performance trajectories:

- **Do-nothing trajectory (pre-treatment continuation):** The expected deterioration path if the preservation action had not been applied.
- **Post-treatment trajectory:** The observed (and modeled) deterioration path after the preservation action.

These two trajectories were the minimum modeling artifacts needed to compute the effectiveness metrics. The modeling approach assumed that the quality of LE and IB depends primarily on whether these trajectories are (1) stable under noise and (2) consistent with engineering behavior. The overall modeling strategy involved two main components:

1. **Curve Modeling and Selection Logic**: Performance trajectories were modeled using a "candidate-and-select" philosophy. Rather than forcing a single functional form, multiple candidate curve families were fit to the segment's condition time-series (for PCI and, where applicable, other indices). Candidate families included common parametric decay forms (including exponential, Weibull, logistic, Gompertz, linear, and power) as well as robust nonparametric options (including isotonic and Theil-Sen). This candidate set was intentionally redundant: different segments exhibit different deterioration shapes due to structure, traffic, climate, and measurement quality. Under this approach, candidate curves were evaluated first for statistical compatibility with the observed sequence and then screened/penalized for unrealistic behaviors that are known to occur when noisy pavement management system data drive purely statistical fitting. Examples of such behaviors include near-flat slopes when deterioration is expected, upward trends without a recorded intervention, predicted values outside plausible bounds, or post-treatment "healing" that contradicts observed limits. The shape enforcement mechanism (as explained before) helped mitigate one of the critical issues faced in Phase I, where a small number of anomalous points could produce curve shapes that look statistically acceptable while creating unrealistic extrapolations. Since LE and IB depend on extrapolating curves beyond the observed window, such occurrences could have serious impacts on the final results.
2. **Transfer Learning and Pooled Modeling for Data Sparsity**: A critical modeling limitation that surfaced in Phase I was an imbalance in the application of preservation treatments, in that some categories (e.g., HMA overlays) that are commonly used by the Iowa DOT have disproportionately higher representation in the data. At this step, we treated this problem as a modeling issue (i.e., not only a data issue) and used transfer learning to address it or at least reduce its impact on the analysis results. To this end, the LTPP dataset was used as a knowledge source to learn generalized deterioration relationships and then adapt those relationships to Iowa conditions. In practical terms, the transfer learning step was used to improve the stability of predicted post-treatment trajectories for categories where Iowa-only fitting becomes unreliable due to sparse samples or short sequences. Several transfer learning strategies were tried (e.g., sequence-learning models and hybrid models), and the final modeling choice was made so as to obtain a balance between predictive accuracy and engineering constraints. The selected approach was then used to generate post-treatment condition predictions (or curve parameters) that are consistent with known deterioration mechanics. An additional measure taken at this step was treatment-level pooling through stratified machine learning (e.g., pooled models within condition, traffic, and climate strata). The key purpose of pooling was not to average away local behavior but to ensure that underrepresented treatments do not yield unstable or extreme effectiveness estimates simply because the local sample is small or noisy.

The LE and IB predictions in this phase were performed using the same conceptual definitions as those used in Phase I, with some minor additional measures. The modeling approach adopted from the previous phase accounted for two practical realities: (1) intersections may not occur within a reasonable horizon due to limited observation windows or near-flat fitted behavior, and (2) excessive extrapolation amplifies uncertainty and can generate implausible LE values. To enhance the prevention of unrealistic results, we further standardized how edge cases were handled. Once the do-nothing trajectory and post-treatment trajectory were established for a segment, the model searched for the time at which the post-treatment trajectory returned to the terminal pre-treatment condition (the decision condition). This intersection time defined the service-life regain for that segment. For this reason, Phase II used a bounded service window (engineering horizon) for intersection search and integration when the data did not support long extrapolations.

Six transfer learning configurations were developed and evaluated. These differed in terms of model architecture, the mechanism by which LTPP knowledge was adapted to Iowa conditions, and the length of the historical condition sequence used as input. Each model was evaluated on Iowa PMIS records where observed PCI values were available, using RMSE, mean absolute error (MAE), and the coefficient of determination (R^2). Coverage, defined as the number of sections receiving valid predictions, was tracked separately as a practical criterion determining what share of the Iowa network benefitted from the transfer learning predictions. The following lists the models developed and assessed:

1. **Neural Network Fine-Tuning (NN-FT)**: A multilayer perceptron (MLP) was pretrained on LTPP data using the three-year condition history and current-year site features. An MLP is a feedforward neural network in which inputs pass through successive layers of weighted linear transformations, each followed by a nonlinear activation function, before producing a prediction. After pretraining, the first hidden layer was frozen to preserve general feature representations learned from the richer LTPP data, and the remaining layers were retrained on Iowa PMIS data at a reduced learning rate to ensure gradual adaptation rather than abrupt departure from the source-domain structure. NN-FT produced an R^2 of 0.667 and an RMSE of 9.20 PCI points on 16,023 sections. The MLP proved more sensitive to the distributional gap between the LTPP and Iowa PMIS data than the tree-based methods: with a smaller local training sample, its larger number of adjustable parameters increased the risk that fine-tuning would drift too far from the LTPP-derived structure.
2. **XGBoost Fine-Tuning with Three-Year History (XGB-FT)**: XGBoost builds an ensemble of decision trees sequentially, each correcting the errors of its predecessors. A key property of transfer learning is its support for incremental training: an existing forest can be extended by appending new trees starting from the pretrained ensemble rather than from scratch, making it the tree-model equivalent of the neural network fine-tuning strategy described above. A full XGBoost model was first trained on LTPP data using the three-year condition history and current-year site features for each section. The pretrained forest then served as the starting point for a second phase of tree growth on Iowa PMIS data, with a lower learning rate and stronger regularization. Monotone constraints were enforced throughout, requiring that age, cumulative traffic loading, and freeze-thaw cycle counts can only decrease predicted PCI, embedding engineering knowledge about the direction of deterioration directly into the model. XGB-FT achieved an R^2 of 0.803 and an RMSE of 7.07 PCI points on 16,023 sections.
3. **XGBoost Fine-Tuning with One-Year Lag (XGB-FT-1Y)**: This method followed the same transfer learning strategy as XGB-FT, with one modification: the historical input was reduced to the single immediately preceding year's observation ($t-1$) rather than the three-year window used by XGB-FT. The motivation was to ensure statewide coverage. A three-

year requirement means that a section must have at least three consecutive prior observations uninterrupted by a major rehabilitation event; many Iowa PMIS sections cannot satisfy this due to shorter records or project breaks. Reducing the required historical input to one prior year expanded the eligible sections from 16,023 to 21,361, an increase of approximately 33%. XGB-FT-1Y achieved an R^2 of 0.759 and an RMSE of 8.13 PCI points, a moderate but acceptable reduction relative to the three-year method. The result confirmed that the single most recent prior-year PCI observation, combined with current-year site factors, carried the majority of the predictive signal available in a three-year window.

As illustrated in Figure 3, the three methods described above (NN-FT, XGB-FT, and XGB-FT-1Y) share the same two-stage transfer learning strategy. In the first stage, a model is pretrained on LTPP source data, producing a source model whose parameters encode generalized deterioration relationships (orange layers). In the second stage, knowledge is transferred by initializing the target model with these pretrained parameters. The target model is then fine-tuned on Iowa PMIS data: the lower layers remain frozen to preserve the LTPP-learned structure, while the upper layers are retrained to adapt to Iowa-specific conditions (green layers). The methods differ only in terms of model type (MLP versus XGBoost ensemble) and in the length of the historical input window provided during both stages.

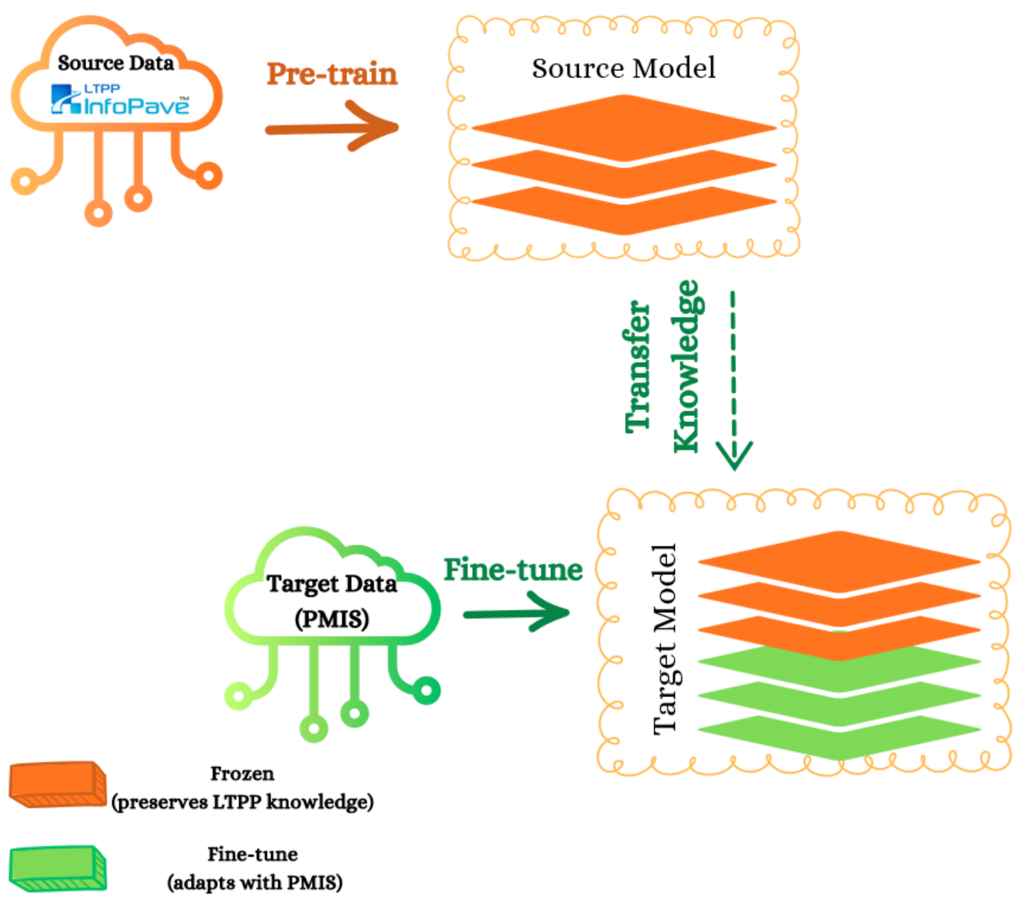


Figure 3.Workflow of two-stage transfer learning strategy used by NN-FT, XGB-FT, and XGB-FT-1Y

4. **XGBoost Joint Training (XGB-Joint)**: Rather than training sequentially, this method pooled LTPP and Iowa PMIS observations into a single combined training set so that the model learned from both domains simultaneously. Because LTPP sections span a wide range of environments, not all are equally informative for Iowa conditions. Each LTPP observation was therefore assigned a sample weight based on its feature-space similarity to the Iowa PMIS training data, measured using a radial basis function (RBF) kernel: sections whose characteristics resembled Iowa conditions received a higher weight, while dissimilar sections were down-weighted. This instance-weighting mechanism adjusted the contribution of source-domain data without modifying the model architecture. The same monotone constraints as those used for XGB-FT were applied. XGB-Joint achieved an R^2 of 0.815 and an RMSE of 6.84 PCI points on 16,023 sections.
5. **Hybrid Architecture with LSTM Encoder and XGBoost Fine-Tuning (Hybrid-A)**: This method separated the temporal and tabular components into two specialized model components. An LSTM network was pretrained on LTPP data to process the three-year condition history for each section. LSTM is a recurrent neural network whose neurons are controlled by three gates: a forget gate that determines which information from the prior state to discard, an input gate that regulates what new information to incorporate, and an output gate that controls what is passed forward. This gating mechanism allows the LSTM network to selectively retain information over long sequences, resolving the gradient vanishing problem that limits simpler recurrent networks and, in this case, enabling it to capture long-range temporal dependencies in pavement deterioration. After processing the condition history, the LSTM produced a compact embedding vector encoding the learned deterioration trajectory. These embedding vectors were combined with current-year site features and passed to an XGBoost model fine-tuned on Iowa PMIS data using the same incremental approach as that used for XGB-FT. The LSTM encoder was not retrained during the Iowa adaptation phase, so its temporal representations remained grounded in the full LTPP experience. Hybrid-A achieved the highest accuracy of all five methods: an R^2 of 0.836 and an RMSE of 6.44 PCI points on 16,023 sections.
6. **LSTM with Progressive Unfreezing (LSTM-PU)**: This method followed the same pretraining strategy as the other LSTM-based variant: the network was first trained on LTPP data using the three-year condition history for each section and then adapted to Iowa PMIS data. The distinguishing feature was how the adaptation proceeds. Rather than unfreezing all layers at once, layers are released sequentially from the output layer toward the input layer across successive training stages, as illustrated in Figure 4. In Stage 1, only the final output layer adapts to Iowa conditions while all earlier layers remain frozen. In Stage 2, the next layer is released, and so on until all layers are fine-tuned in the final stage. The logic is that the early layers encode the most general temporal representations of deterioration and benefit from remaining fixed longer, while the later task-specific layers can absorb Iowa-specific patterns first. Despite the theoretical appeal of this graduated adaptation, LSTM-PU achieved an R^2 of 0.41 on the Iowa PMIS dataset, a value substantially below those of the XGBoost-based methods. Along with the other LSTM variant, it was not carried forward into the final analysis.

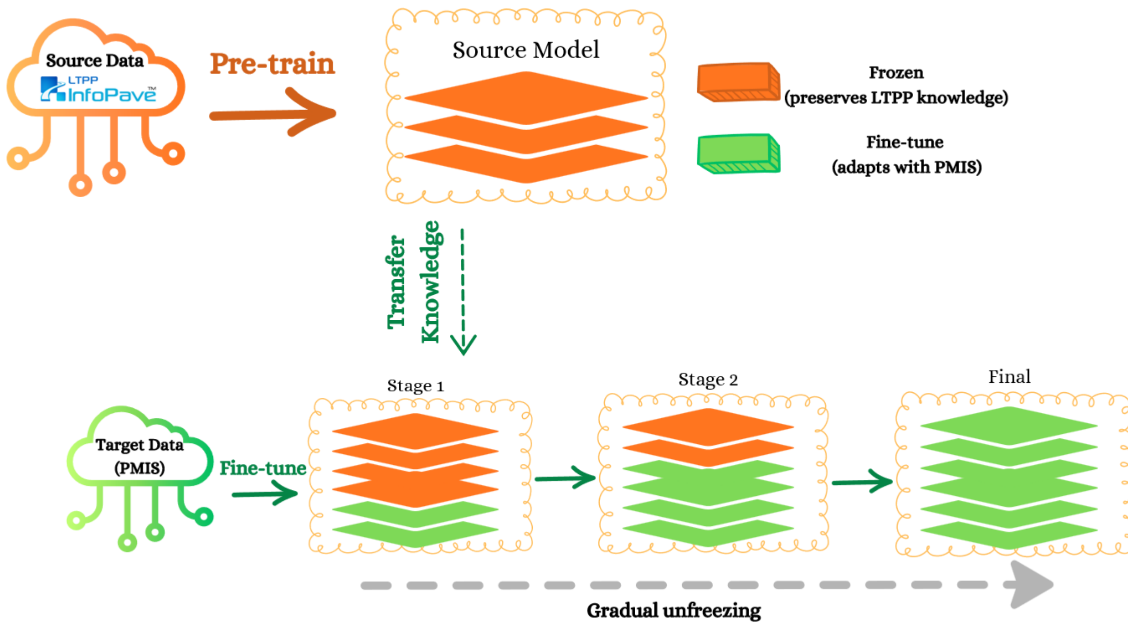


Figure 4. LSTM progressive unfreezing strategy

Hybrid-A produced the highest prediction accuracy, followed closely by XGB-Joint and XGB-FT. All three XGBoost-based methods substantially outperformed NN-FT. This is consistent with a known limitation of neural network fine-tuning when the target-domain sample is small relative to the source: a larger number of adjustable parameters heightens sensitivity to the distributional gap, and, in this case, the adaptation risked drifting from the LTPP-derived structure. XGBoost's incremental tree growth mechanism proved more resistant to this effect under Iowa PMIS data conditions.

XGB-FT-1Y was selected as the transfer learning model for generating the full Iowa PMIS prediction set used in subsequent analyses. The primary reason was network coverage. While its R^2 of 0.759 was a moderate step back from the three-year methods, the expansion from 16,023 to 21,361 eligible sections was consequential for a statewide analysis. Excluding more than 5,000 sections would have introduced geographic and functional class gaps that would have systematically biased network-level condition summaries and the treatment effectiveness estimates that followed. An R^2 of 0.759 remained strong for a network-level pavement condition prediction task. The result also confirmed a practically useful property: the most recent prior-year PCI observation combined with current-year site factors carried most of the predictive signal in a three-year window. The marginal accuracy gain from a longer history did not justify the loss in statewide coverage for this application.

The predictions generated by the selected model were applied to the full Iowa PMIS network to produce post-treatment PCI trajectories for all segments with at least one prior observation available. These predicted trajectories served as inputs to the life extension and index benefit computations described in the following sections, providing stable post-treatment deterioration curves for treatment categories where Iowa-only curve fitting was unreliable due to sparse or short post-treatment records.

Cost-Benefit Analysis

A comprehensive comparative analysis was conducted on the cost of each preservation treatment. The necessary project details and cost information were obtained from historical bid tabulations provided by the Iowa DOT for the period from 2015 to 2022. However, thin HMA overlay projects have been conducted since 2017 to 2023; accordingly, the calculated cost for those projects represents the average cost within that timeframe. It is also important to note that seal coat cost data specific to Iowa were unavailable in Bid Express. To calculate the cost for seal coat, we relied on information from MnDOT. Minnesota, being a neighboring state with similar weather and location conditions to Iowa, provided relevant data for estimating seal coat costs. Therefore, the seal coat cost data used in this analysis were derived from MnDOT.

Access to bid data was facilitated through the Iowa DOT contracts portal and the Bid Express subscription service. In the Bid Express portal, bids were ranked based on their total value, and a detailed cost breakdown was provided that specified the quantity and cost of each construction item.

Among the feasible preservation treatments for a given pavement section, the best treatment is the one that can offer the optimal benefit-cost ratio while aligning with the project's objectives. Various methods exist to identify the treatment that provides the most benefit for the associated cost. BCA is an important tool used in asset management to prioritize and evaluate different treatment alternatives based on their cost-effectiveness. This method considers various economic indicators such as BCR, net present value (NPV), and equivalent uniform annual costs (EUAC). NPV and EUAC work together to combine cost streams into a cohesive economic value that represents an asset's life-cycle cost by incorporating several factors, as illustrated in Figure 5.

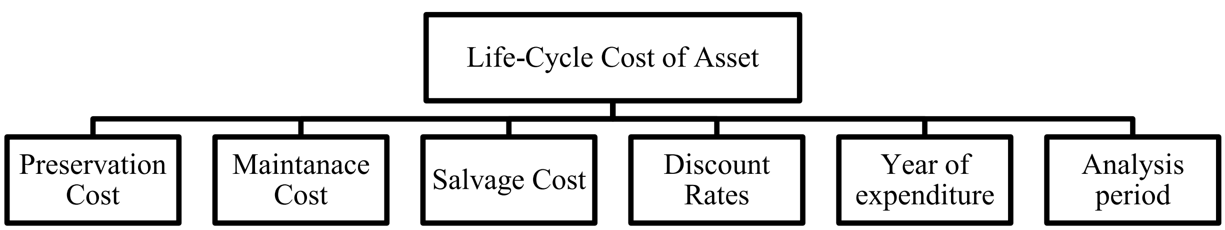


Figure 5. Important factors in benefit-cost analysis

NPV, a.k.a. net present worth (NPW), represents the discounted monetary value of the expected net benefits. It provides a fair basis for comparing different strategies. Equation (6) is considered a popular economic computation for calculating NPV for the lifespan of a pavement section (Wang et al. 2013):

$$NPV = \sum_{0}^{n_k} Preservation\ Cost \left[\frac{1}{(1+i)^{n_k}}\right] + \sum_{0}^{n_k} Maintanance\ Cost \left[\frac{1}{(1+i)^{n_k}}\right] - Salvage\ value \times \left[\frac{1}{(1+i)^{n_k}}\right] \quad (6)$$

where n_k is the year of expenditure and i is the real discount rate according to the Office of Management and Budget (OMB) Circular published by the U.S. government (1.5% to 2%). The analysis periods in this case were 10, 15, 20 and 30 years. Maintenance costs were capped at $2,500 annually and calculated using equation (7) based on a five-year sliding scale. The salvage value was calculated using equation (8), which considers the remaining service life and preservation cost:

$$Maintanance\ cost = \begin{cases} \frac{year}{5} \times 2500 & if\ year \leq 5 \\ 2500 & if\ year > 5 \end{cases}, \tag{7}$$

$$Salvage\ value = \frac{remaining\ service\ life\ after\ analysis\ period}{Total\ amount\ of\ service\ life} \times Perservation\ Cost \tag{8}$$

A schematic example of life-cycle cost analysis and calculation of the remaining service life is illustrated in Figure 6.

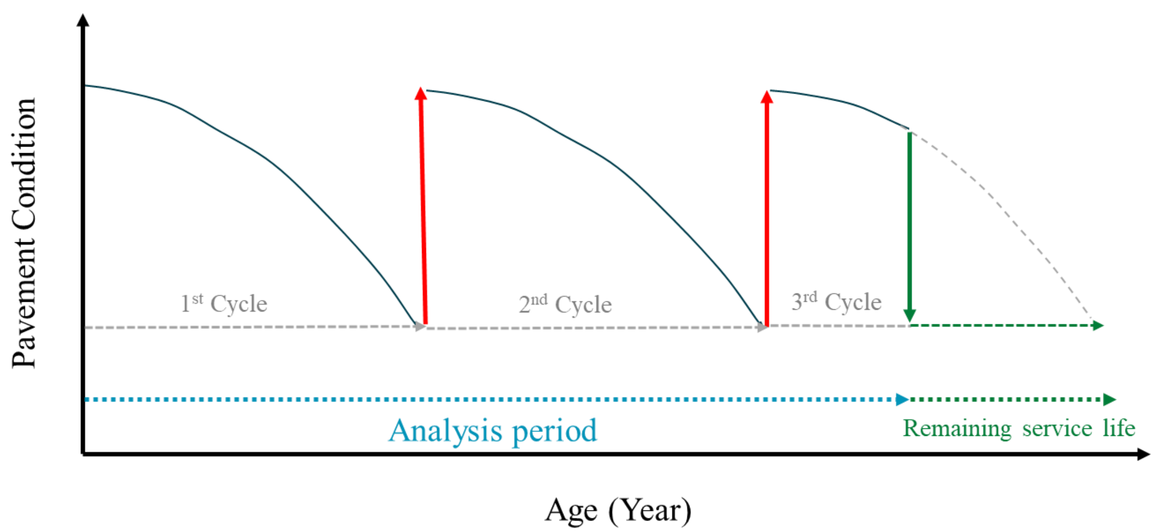


Figure 6. Schematic example of life-cycle cost analysis

Finally, life-cycle cost is represented by EUAC, which is obtained from equation (9):

$$EUAC = NPV \times \frac{discount\ rate(1+discount\ rate)^{analysis\ period}}{(1+discount\ rate)^{analysis\ period}-1}, \tag{9}$$

The BCR used the index benefit values and divided them by EUAC during the analysis period. This ratio quantifies the benefit of each individual unit area relative to its cost. BCR offers a more precise indicator than EUAC because it considers not only the service life extension but also the immediate performance improvement provided by the treatment. For instance, when two treatments have the same service life extension, but one exhibits a greater immediate performance improvement (project 1 in Figure 7), the more favorable treatment results in a higher index benefit than the other (project 2 in Figure 7), indicating that the treatment can offer better quality over the same service life in terms of improved user satisfaction, safety, and sustainability.

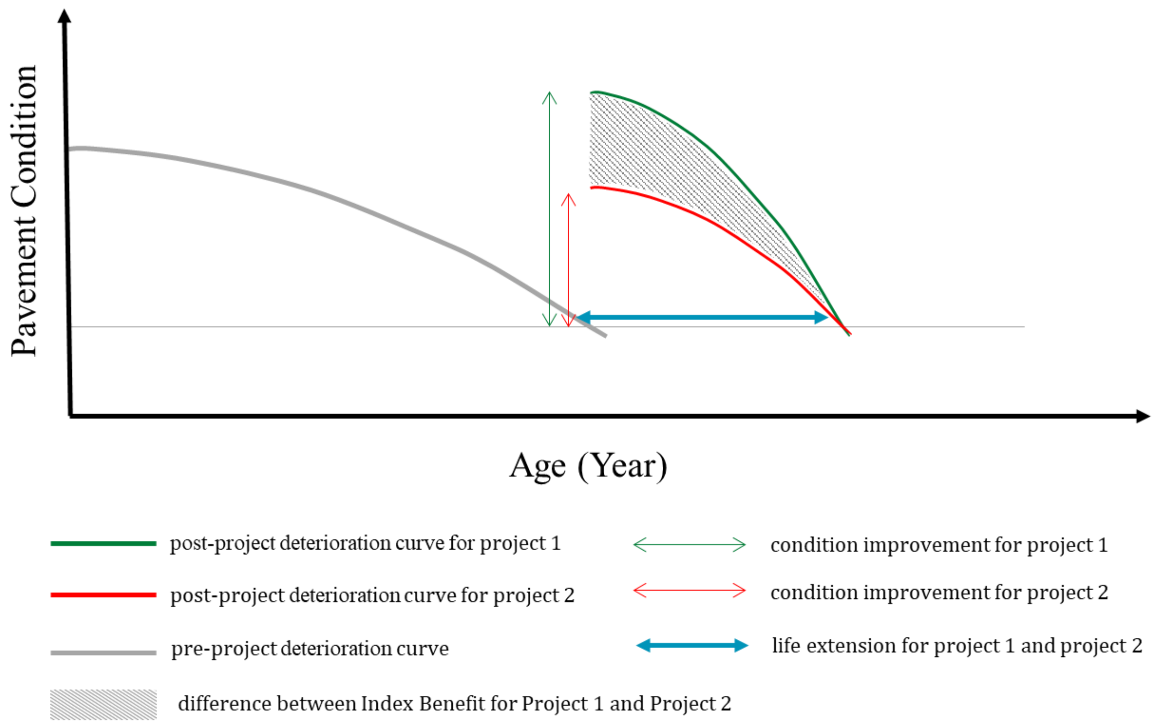


Figure 7. Comparison of index benefit for two projects offering equal service life extensions

BCR's ability to capture such immediate benefits makes it a valuable tool in assessing and comparing the cost-effectiveness of different pavement preservation strategies. BCR is calculated by equation (10):

$$BCR = \frac{Index\ Benefit}{EUAC}, \tag{10}$$

In the benefit-cost analysis undertaken for this project, the dataset was classified based on certain factors to create classes of pavement data. The classification criteria resulted from a literature review. We decided to classify our pavement sections into groups based on traffic, truck traffic, and pavement condition. Figure 8 shows the criteria for each classification.

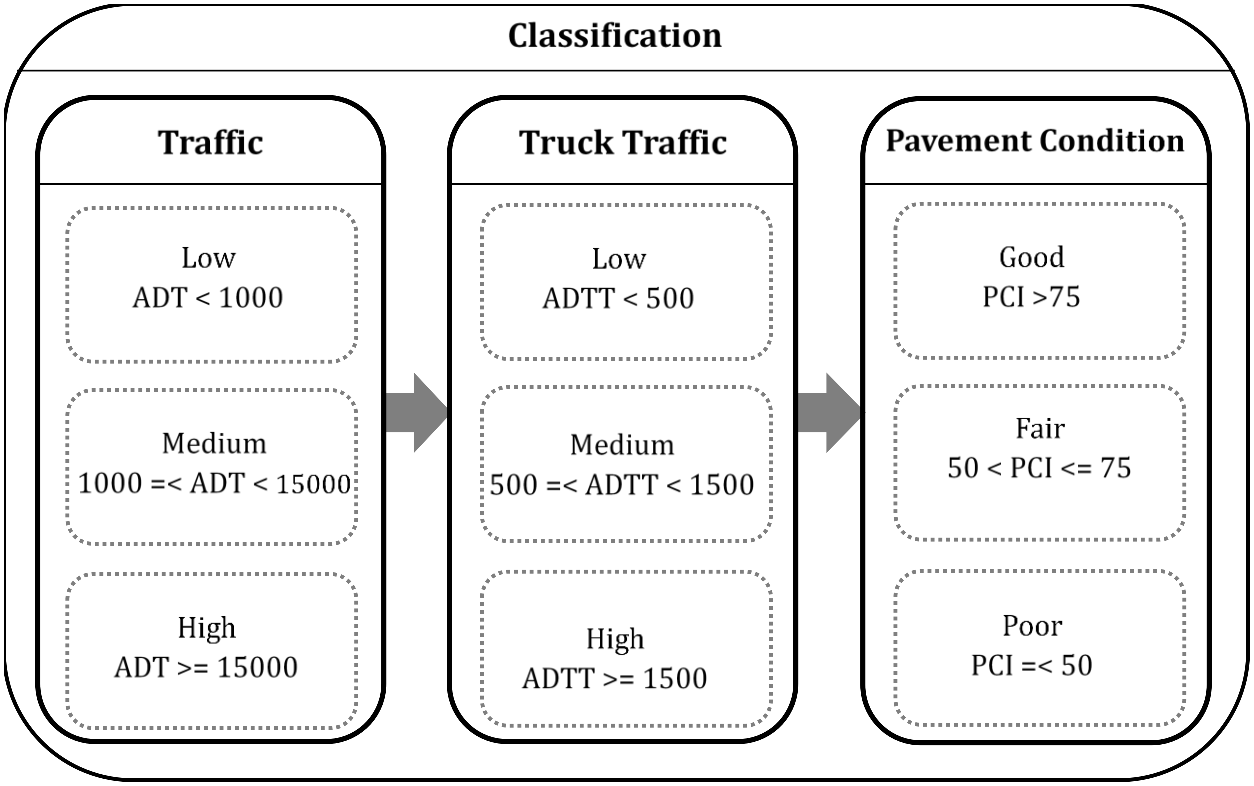


Figure 8. Classification for cost-benefit analysis

RESULTS

Phase I

Table 4 and Table 5 provide a comprehensive analysis of various treatments for flexible and composite pavements, respectively, offering insights into their IB and calculated LE values. The breakdown includes the percentages of sections categorized as good, fair, and poor and the total number of sections that received each treatment.

Table 4. PCI-based LE and IB for flexible pavement

Treatment	IB	LE (years)	Good (%)	Fair (%)	Poor (%)	No. of Sections
Microsurfacing	126	5	17	64	19	47
Patching	106	3	50	50	0	12
Slurry Seal	134	4	0	100	0	6
Crack Sealing/Filling	135	6	17	58	25	12
HMA Overlay	517	10	10	46	45	246
Seal Coat	153	6	0	38	63	24

Table 5. PCI-based LE and IB for composite pavement

Treatment	IB	LE (years)	Good (%)	Fair (%)	Poor (%)	No. of Sections
Microsurfacing	151	4	39	42	18	157
Patching	57	3	26	65	9	65
Slurry Seal	48	2	12	59	29	49
Crack Sealing/Filling	133	5	12	71	18	17
HMA Overlay	445	10	8	53	39	1472
Seal Coat	340	9	0	50	50	8

Note that sections labeled as being in poor condition (PCI ≤ 50) were excluded from further analysis. This decision was based on the understanding that preventive methods are not recommended for pavements in poor condition. By excluding these sections from our assessment, we aimed to align our analysis with recommended practices. Our focus instead was on evaluating treatments specifically appropriate for pavements in good and fair condition, where preservation strategies are considered suitable.

Table 6 and Table 7 provide detailed information on the performance of each type of treatment for flexible and composite pavement sections, respectively. The tables highlight the life extension and the immediate improvement in pavement condition, measured in terms of PCI, for each treatment. Additionally, these tables present the average age of the road sections on which the treatments were applied, the effectiveness of each treatment in terms of its index benefit, and the average underlying condition (in terms of PCI) of the pavements before treatment. This comprehensive information explains how each treatment contributes to enhancing the serviceability and durability of pavements. The LE and IB values for the treatments are compared in Figure 9 through Figure 12 for both flexible and composite pavements.

Table 6. Calculated information for each preservation treatment for flexible pavement

Treatment	Age	No. of Sections	Life Extension	Index Benefit	Immediate Improvement	Underlying Condition
Microsurfacing	11.6	38	4.26	125	4	66
Patching	10.8	6	3.23	106	-11	61
Slurry Seal	9.9	9	4.33	125	3	65
Crack Sealing/Filling	6.1	12	5.89	135	-3	73
HMA Overlay	8.9	136	9.52	456	18	64
Seal Coat	12.4	9	4.77	111	9	60

Table 7. Calculated information for each preservation treatment for composite pavement

Treatment	Avg. Age	No. of Sections	Life Extension	Index Benefit	Immediate Improvement	Underlying Condition
Microsurfacing	9.2	128	3.88	119	4	76
Patching	7.9	35	2.46	42	-4	65
Slurry Seal	15.1	14	1.70	41	-1	61
Crack Sealing/Filling	6.2	59	5.11	141	-2	69
HMA Overlay	9.0	892	9.47	345	16	65
Seal Coat	14.3	4	6.52	139	23	61

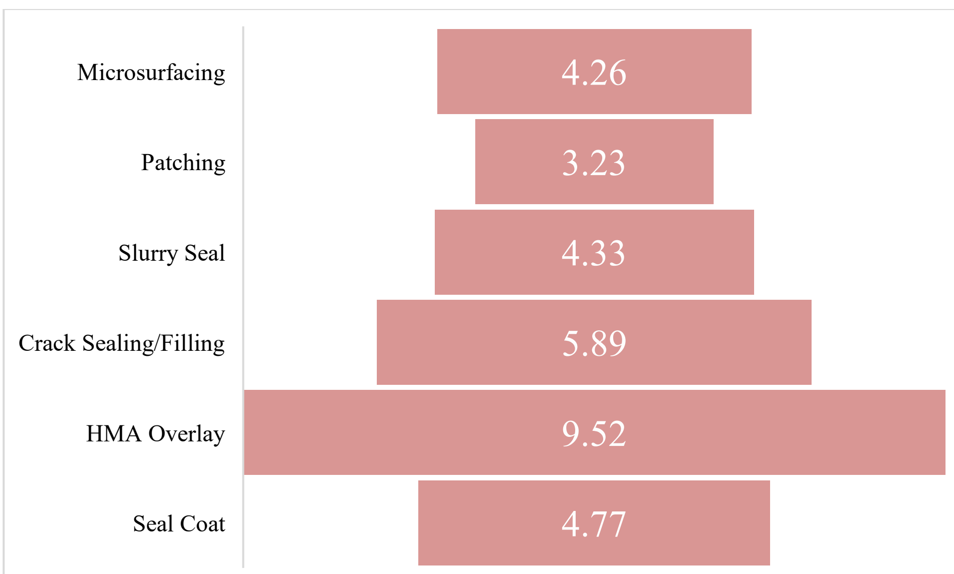


Figure 9. Life extension of preservation treatments for flexible pavement

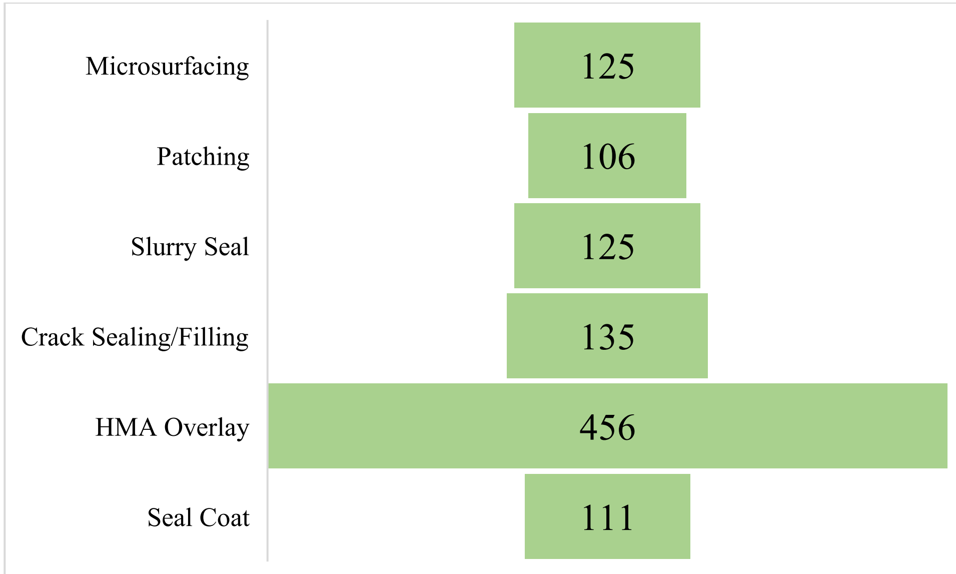


Figure 10. Index benefit of preservation treatments for flexible pavement

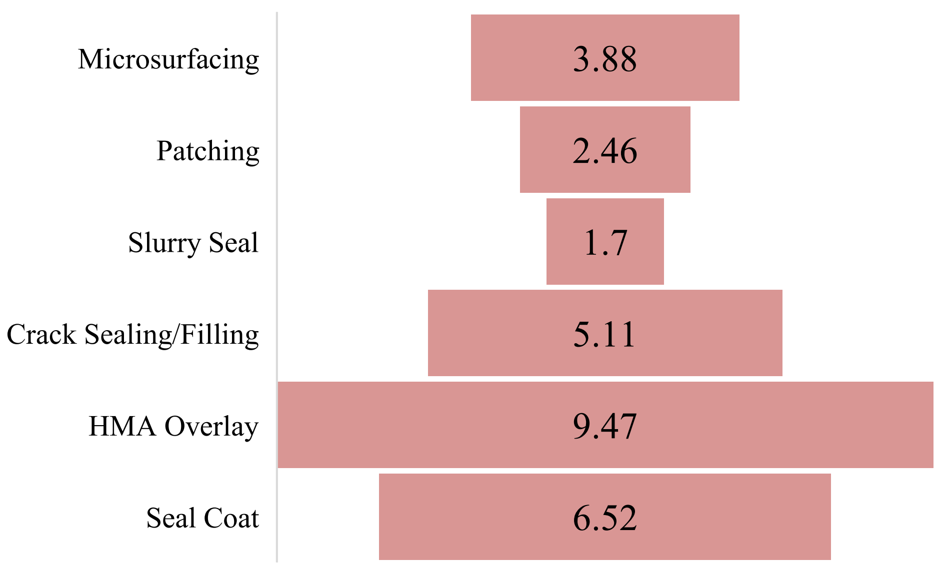


Figure 11. Life extension of preservation treatments for composite pavement

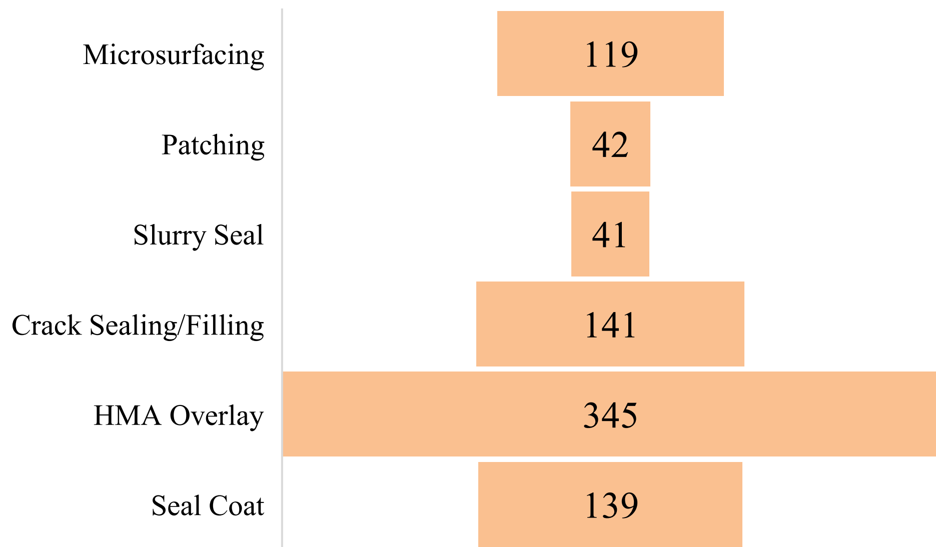


Figure 12. Index benefit of preservation treatments for composite pavement

The life extension and index benefit for each preservation treatment were further assessed in terms of the pre-treatment PCI values of the target pavements. The results revealed noteworthy observations, particularly the absence of patching and seal coat projects on flexible pavements in good condition. Similarly, seal coat projects were not implemented on composite pavements in good condition. The details of these findings are presented in Table 8 for flexible pavements and Table 9 for composite pavements.

Table 8. Life extension and index benefit of each preservation treatment for flexible pavement in good and fair condition

	Life Extension		Index Benefit	
Treatment	**Good**	**Fair**	**Good**	**Fair**
Microsurfacing	2.3	4.8	25.4	151.3
Patching	NA	3.2	NA	105.9
Slurry Seal	5.5	4.0	278.9	80.7
Crack Sealing/Filling	4.7	7.1	89.2	180.6
HMA Overlay	6.9	10.1	221.9	506.3
Seal Coat	NA	4.8	NA	110.7

Table 9. Life extension and index benefit of each preservation treatment for composite pavement in good and fair condition

Treatment	Life Extension		Index Benefit	
	Good	**Fair**	**Good**	**Fair**
Microsurfacing	2.3	5.4	44.8	189.2
Patching	2.1	2.6	8.5	47.0
Slurry Seal	2.0	1.7	42.8	40.2
Crack Sealing/Filling	3.7	5.7	77.1	167.3
HMA Overlay	5.9	10.0	117.8	382.0
Seal Coat	NA	6.5	NA	139.1

The visual representations in Figure 13 and Figure 14 offer a comparative analysis of the life extension and index benefit values, respectively, associated with each treatment for flexible pavements in good and fair condition. The results indicate a general trend in which the HMA overlay, crack sealing/filling, and microsurfacing treatments show increased effectiveness when applied to flexible pavements in fair condition. Interestingly, slurry seal proves to be more beneficial for flexible pavements in good condition than flexible pavements in fair condition.

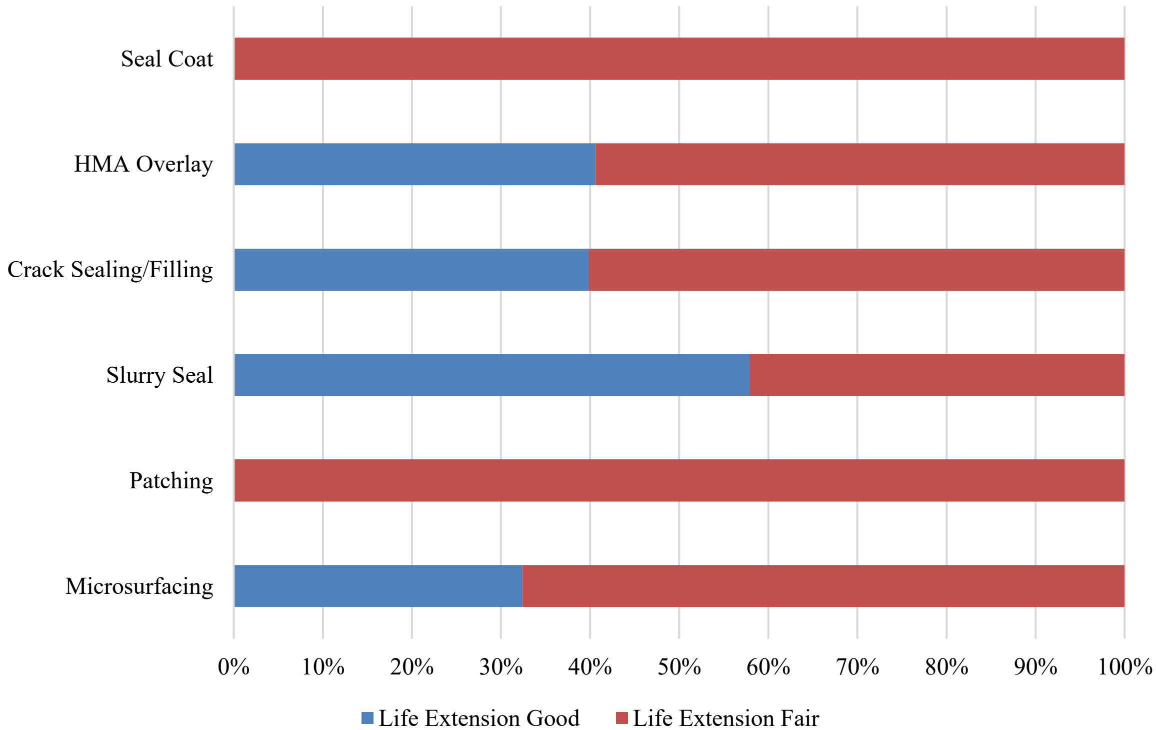


Figure 13. Comparison of each treatment's life extension for flexible pavements in good and fair condition

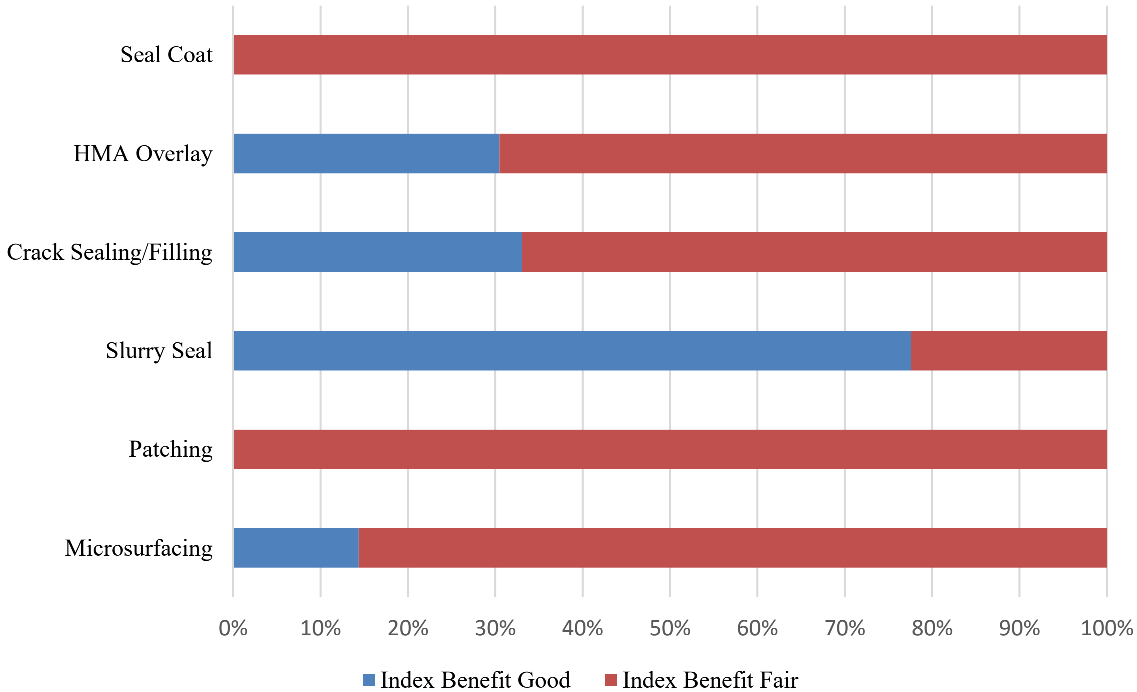


Figure 14. Comparison of each treatment's index benefit for flexible pavements in good and fair condition

Figure 15 and Figure 16 similarly compare the life extension and index benefit for each treatment on composite pavements in good and fair condition. According to these results, the HMA overlay, crack sealing/filling, patching, and microsurfacing treatments are generally more effective for composite pavements in fair condition. Conversely, slurry seal proves to be more beneficial for composite pavements in good condition. These results align with the life extension findings for flexible pavements presented in Figure 13. However, the outcomes for composite pavements also highlight that the difference in index benefit becomes more pronounced when comparing the effectiveness of treatments on pavements in good and fair condition. It is worth mentioning that, similar to the results for flexible pavements, patching demonstrates a greater extension of pavement life than microsurfacing. However, the analysis of the index benefit results indicates that microsurfacing confers more substantial benefits to composite pavements.

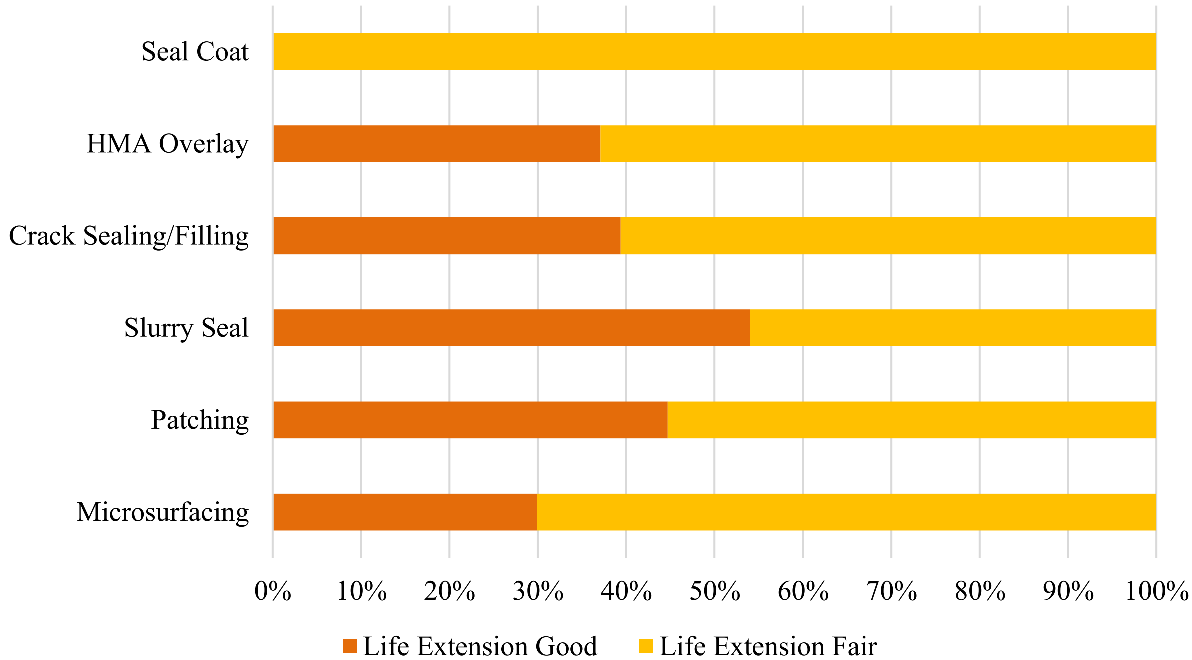


Figure 15. Comparison of each treatment's life extension for composite pavements in good and fair condition

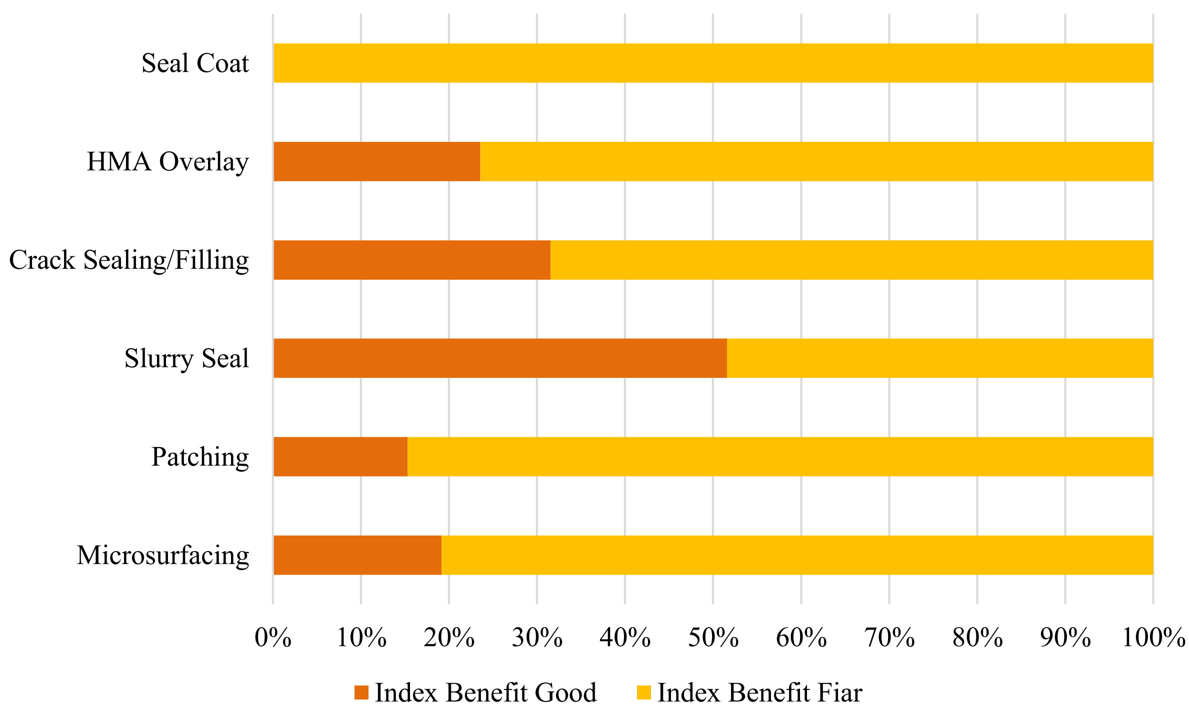


Figure 16. Comparison of each treatment's index benefit for composite pavements in good and fair condition

According to the results of the life extension and index benefit analyses for both flexible and composite pavements, an intriguing observation arises from the contrasting performance of patching and microsurfacing. While patching demonstrates superior life extension compared to microsurfacing, the index benefit analysis reveals that microsurfacing offers a more advantageous impact on pavement condition. This result underscores the importance of considering both life extension and index benefit for a comprehensive evaluation of the effectiveness of preservation treatments under varying pavement conditions.

Table 10 and Figure 17 provide a comprehensive analysis of the life extension values offered by different preservation treatments for flexible pavements. The evaluation is broken down into key indices: PCI, riding index, rutting index, and cracking index.

Table 10. Life extension based on different indices for flexible pavements

Treatment	No. of Sections	Life Extension – Flexible			
		PCI	Riding Index	Rutting Index	Cracking Index
Microsurfacing	38	4.3	4.0	4.5	4.4
Patching	6	3.2	0.0	0.0	9.0
Slurry Seal	9	4.3	2.3	2.7	1.8
Crack Sealing/Filling	12	5.9	8.0	10.2	7.5
HMA Overlay	136	9.5	11.2	9.2	9.5
Seal Coat	9	4.8	4.8	2.9	4.2

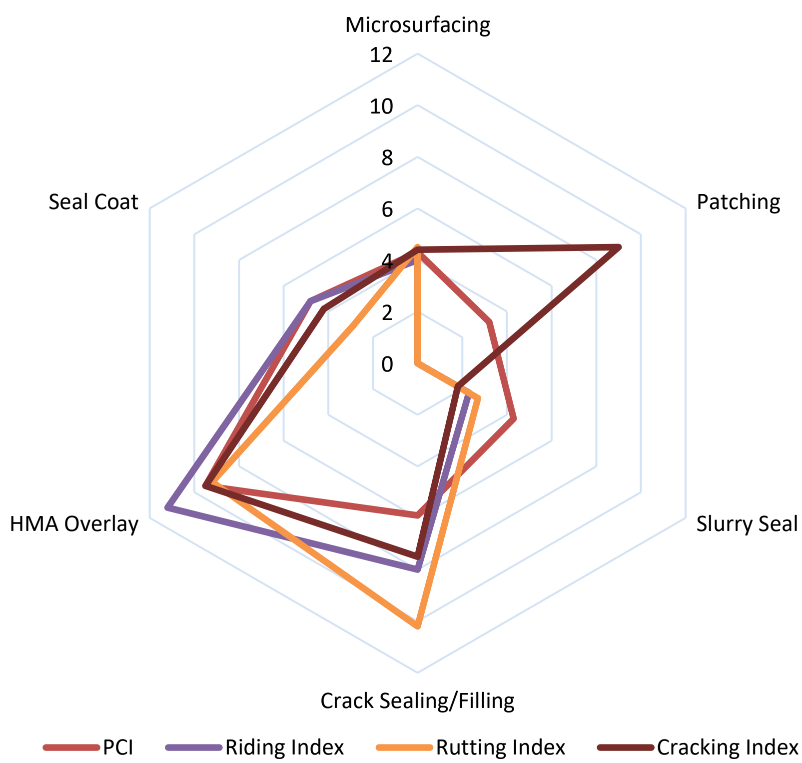


Figure 17. Life extension based on different indices for flexible pavements

Microsurfacing shows a moderate life extension of 4.3 for flexible pavements. This treatment demonstrates a balanced improvement across all indices, with notable enhancements in PCI, riding index, rutting index, and cracking index, indicating a positive impact on overall pavement condition.

Patching shows a life extension of 3.2. While it has a moderate effect on PCI, its impact on riding index and rutting index is minimal, and it scores significantly higher on cracking index, suggesting a specific efficacy in addressing cracking-related issues.

Slurry seal demonstrates a life extension of 4.3. This treatment shows improvements in PCI, riding index, and rutting index, with a particularly strong effect on the cracking index, indicating effectiveness in mitigating cracking-related concerns.

Crack sealing/filling stands out with a relatively high life extension of 5.9. This treatment excels in improving PCI, riding index, rutting index, and especially cracking index, showing its effectiveness in reducing pavement distress, particularly cracking.

HMA overlay shows the highest life extension of 9.5 for flexible pavements. This treatment significantly improves PCI, riding index, rutting index, and cracking index, indicating its effectiveness in overall pavement rehabilitation and life extension.

Finally, seal coat demonstrates a moderate life extension of 4.8. It provides improvements across all indices, with a balanced effect on PCI, riding index, and cracking index but a less pronounced impact on rutting index. This treatment contributes to an overall condition improvement for flexible pavements, especially when there are ride quality and cracking issues.

It is evident that the choice of pavement treatment has a significant impact on various indices, each of which addresses a specific aspect of pavement distress. HMA overlay, for instance, stands out as highly effective across all indices, while treatments like crack sealing/filling excel at addressing cracking-related concerns. These findings offer valuable insights for decision-makers tasked with selecting the most appropriate pavement treatment based on the specific conditions and distress factors observed in pavement sections.

Table 11 and Figure 18 provide a detailed assessment of the life extension values offered by various preservation treatments for composite pavements. The evaluation is categorized into key indices, including PCI, rutting index, riding index, and cracking index.

Table 11. Life extension based on different indices for composite pavements

Treatment	No. of Sections	Life Extension – Composite PCI	Riding Index	Rutting Index	Cracking Index
Microsurfacing	128	3.9	3.7	3.3	4.4
Patching	41	2.5	2.0	1.9	4.4
Slurry Seal	14	1.7	2.4	2.2	3.1
Crack Sealing/Filling	59	5.1	6.7	4.3	7.5
HMA Overlay	905	9.5	11.7	8.5	6.9
Seal Coat	4	6.5	6.0	5.7	7.5

Figure 18. Life extension based on different indices for composite pavements

Microsurfacing yields a moderate life extension of 3.9 for composite pavements. Noteworthy improvements are observed in PCI, riding index, rutting index, and cracking index, indicating the treatment's effectiveness in addressing specific distress factors in composite pavements.

Patching demonstrates a life extension of 2.5. While it shows moderate enhancements in PCI and cracking index, its impact on riding index and rutting index is comparatively lower, suggesting targeted effectiveness for certain distress types.

Slurry seal exhibits a modest life extension of 1.7. It demonstrates improvements in PCI and rutting index, with a more effective impact on cracking index, indicating its potential for mitigating cracks in composite pavements.

Crack sealing/filling shows a relatively higher life extension of 5.1, excelling in addressing PCI, riding index, and cracking index. This emphasizes the treatment's effectiveness in managing overall pavement distress, particularly in addressing cracking.

HMA overlay boasts the highest life extension of 9.5 for composite pavements, with significant improvements observed, especially in riding index. The results indicate the treatment's broad effectiveness in enhancing the overall condition of composite pavements, especially in addressing roughness issues.

Seal coat demonstrates a notable life extension of 6.5, showing improvements across all indices but a higher impact on cracking index.

Table 12 presents a comprehensive examination of various preservation treatments for flexible pavements based on pre-treatment pavement condition. Life extension values are provided for PCI, rutting index, riding index, and cracking index.

Table 12. Life extension based on different indices and pavement condition for flexible pavements

Treatment	PCI-Based Condition	Life Extension – Flexible			
		PCI	Riding Index	Rutting Index	Cracking Index
Microsurfacing	Good	2.3	2.8	0.6	2.6
	Fair	4.8	4.3	5.5	4.8
Patching	Good	NA	NA	NA	NA
	Fair	3.2	0.0	0.0	9.0
Slurry Seal	Good	5.5	4.0	4.0	0.0
	Fair	4.0	2.0	2.5	2.2
Crack Sealing/Filling	Good	4.7	8.0	10.2	7.5
	Fair	7.1	NA	NA	NA
HMA Overlay	Good	6.9	9.0	8.9	6.4
	Fair	10.1	11.7	9.3	10.3
Seal Coat	Good	NA	NA	NA	NA
	Fair	4.8	4.8	2.9	4.2

Microsurfacing demonstrates notable differences in life extension for flexible pavements based on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 2.3, with positive impacts on PCI, riding index, and rutting index. This result aligns with the expectation that microsurfacing is more effective in maintaining pavement quality when applied proactively to pavements in relatively good condition. However, for pavements in fair condition, the life extension significantly increases to 4.8, with improved performance across all indices, particularly rutting and cracking. This suggests that microsurfacing is particularly effective for addressing distress factors in pavements that are already exhibiting signs of wear.

Patching, in contrast, lacks data for pavements in good condition but shows a life extension of 3.2 for pavements in fair condition, predominantly through its influence on cracking index. This emphasizes the targeted effectiveness of patching in addressing specific types of distress, particularly those associated with cracking. The absence of data for pavements in good condition may indicate that patching is not commonly applied as a preventive measure but rather as a reactive solution in pavements already experiencing issues.

Slurry seal exhibits varying outcomes based on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 5.5, notably improving PCI and riding index. This reinforces the notion that slurry seal is effective in maintaining the overall pavement quality when applied proactively. However, for pavements in fair condition, the life extension decreases to 4.0, but the treatment still demonstrates positive effects on PCI, rutting index, and cracking index. This indicates that slurry seal can provide benefits even in pavements with existing distress, albeit to a slightly lesser extent.

Crack sealing/filling shows differences in performance based on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 4.7, with substantial improvements in PCI, riding index, and rutting index. This underscores the preventive nature of crack sealing/filling and its ability to address potential distress factors before they escalate. For pavements in fair condition, though data are not available for riding index, the treatment achieves a higher life extension of 7.1, particularly impacting rutting and cracking. This highlights the efficacy of crack sealing/filling in reactively mitigating existing distress, particularly in the form of cracking.

HMA overlay exhibits significant variations in life extension for pavements in good and fair condition. For pavements in good condition, it achieves a life extension of 6.9, especially influencing PCI and riding index. This emphasizes the proactive nature of HMA overlay, in that it provides substantial improvements in pavement quality when applied before significant distress occurs. For pavements in fair condition, the life extension substantially increases to 10.1, with improvements evident across all indices. This suggests that HMA overlay is highly effective not only in preventing distress but also in rehabilitating pavements with existing issues, making it a versatile treatment option.

Seal coat lacks data for pavements in good condition but demonstrates a life extension of 4.8 for pavements in fair condition. It contributes to enhancements across PCI, riding index, and cracking index, indicating its overall efficacy in improving pavement condition, particularly in its ability to address cracking concerns. The absence of data for pavements in good condition may suggest that seal coat is primarily applied reactively to pavements already exhibiting distress, with a focus on improving overall pavement condition.

Table 13 offers a comprehensive examination of various pavement treatments for composite pavement based on pre-treatment pavement condition. Life extension values are provided for PCI, rutting index, riding index, and cracking index.

Table 13. Life extension based on different indices and pavement condition for composite pavements

Treatment	PCI-Based Condition	Life Extension – Composite			
		PCI	Riding Index	Rutting Index	Cracking Index
Microsurfacing	Good	2.3	2.9	2.5	2.9
	Fair	5.4	4.4	4.0	5.6
Patching	Good	2.1	NA	NA	NA
	Fair	2.6	2.0	1.9	4.4
Slurry Seal	Good	2.0	4.0	2.0	3.2
	Fair	1.7	2.0	2.2	3.0
Crack Sealing/Filling	Good	3.7	5.5	5.0	6.9
	Fair	5.7	7.6	3.7	7.9
HMA Overlay	Good	5.9	8.0	5.6	4.8
	Fair	10.0	12.1	8.9	7.2
Seal Coat	Good	NA	NA	NA	NA
	Fair	6.5	6.0	5.7	7.5

Microsurfacing exhibits diverse outcomes contingent on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 2.3, especially impacting rutting index, riding index, and cracking index. However, for pavements in fair condition, the life extension notably increases to 5.4 and the treatment demonstrates improved effectiveness across all evaluated indices, particularly cracking. The treatment's greater impact on pavements in fair condition suggests that microsurfacing is more potent when applied reactively to pavements with existing distress.

Patching varies in performance depending on pre-treatment pavement condition, with a life extension of 2.1 for pavements in good condition and a life extension of 2.6 for pavements in fair condition. While the data for riding index is unavailable for pavements in good condition, patching shows efficacy in influencing rutting index and cracking index for pavements in fair condition. The absence of data for pavements in good condition suggests that patching is not commonly applied as a proactive measure. However, for pavements in fair condition, patching proves effective in addressing rutting and cracking issues.

Slurry seal yields varying outcomes depending on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 2.0, with positive impacts on riding index and cracking index. For pavements in fair condition, the life extension decreases to 1.7, but slurry seal still demonstrates improvements in rutting index and cracking index, indicating its effectiveness in addressing specific distress factors.

Crack sealing/filling varies in performance depending on pre-treatment pavement condition. For pavements in good condition, it achieves a life extension of 3.7, with substantial improvements in riding index, rutting index, and cracking index. For pavements in fair condition, the life extension increases to 5.7, and the treatment shows efficacy in addressing various distress factors, particularly cracking. The greater impact for pavements in fair condition underscores the effectiveness of crack sealing/filling as a reactive measure.

HMA overlay shows notable differences in life extension for pavements in good and fair condition. For pavements in good condition, it achieves a life extension of 5.9, especially influencing riding index, rutting index, and cracking index. For pavements in fair condition, the life extension substantially increases to 10.0, showcasing the versatility of HMA overlay in both preventing and rehabilitating pavement distress. The higher impact for pavements in fair condition indicates that HMA overlay is particularly effective when applied reactively to pavements with existing distress.

Seal coat lacks data for pavements in good condition but demonstrates a life extension of 6.5 for pavements in fair condition. This treatment contributes to improvements in riding index, rutting index, and cracking index, which indicate its efficacy in enhancing the overall condition of composite pavement, especially when used to address issues related to cracking. The absence of data for pavements in good condition suggests that seal coat is primarily applied reactively to pavements with existing distress.

Based on an analysis of bid items and project quantities, an eight-year average cost was determined for each preservation treatment, as shown in Table 14 and Figure 19. The items used to calculate the cost of each treatment are shown in Table 44 in the Appendix, and the project-based cost breakdowns for the treatments are shown in Table 45 to Table 50 in the Appendix.

Table 14. Project information obtained from historical bid tabulations for cost analysis

Treatment	No. of Projects	Total Lane-Miles	Preservation Cost ($/Lane-Mile)
Microsurfacing	72	2836	20,995
Crack Sealing/Filling	200	4800	4,412
Patching	140	1742	66,000
Slurry Sealing	66	1741	7,830
HMA Overlay	41	556	98,556
Seal Coat	22	1863	11,390

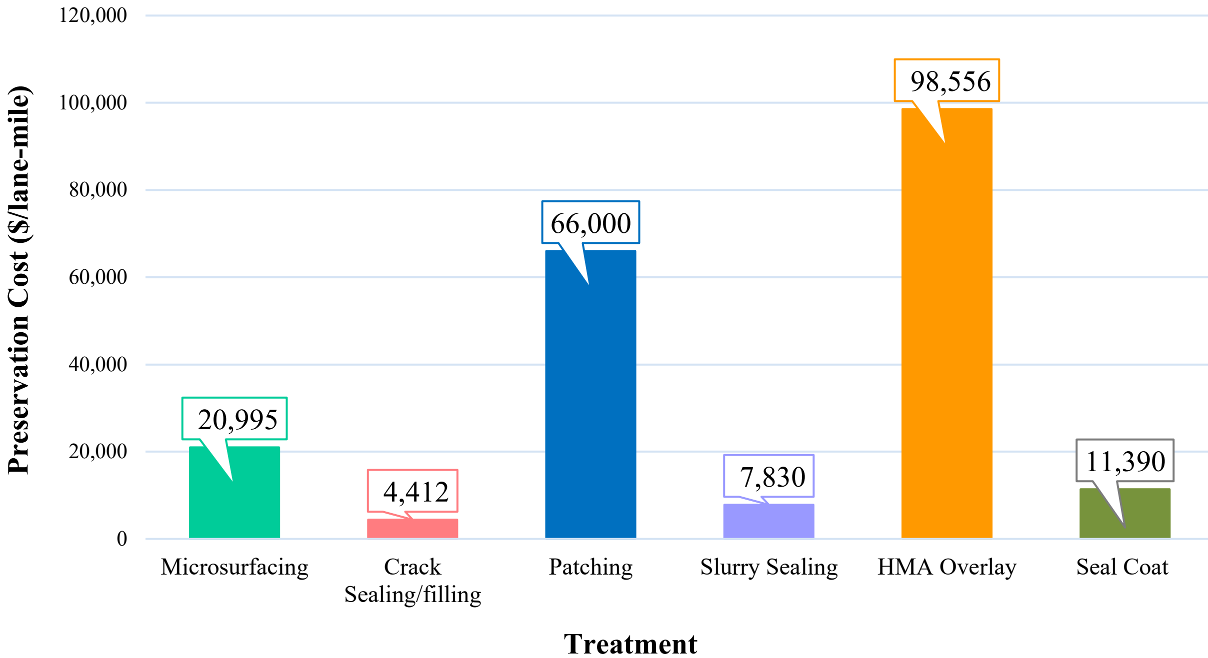


Figure 19. Cost for each preservation treatment

Detailed tables of results for the cost-benefit analysis are presented in Table 32 to Table 39 in the Appendix. The analysis was conducted for four analysis periods: 10, 15, 20, and 30 years. The decision matrices for flexible and composite pavements for each analysis period are presented in Table 15 through Table 22. In each category, the treatment with the maximum benefit-cost ratio is recommended as the most cost-effective treatment.

Table 15. Decision matrix for flexible pavement, 10-year analysis period

Flexible		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Slurry Seal
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Slurry Seal	Crack Sealing/Filling
	Medium	Microsurfacing	Microsurfacing
	High	HMA Overlay	Microsurfacing
High	**Low**	NA	NA
	Medium	NA	NA
	High	Microsurfacing	HMA Overlay (Only)

Table 16. Decision matrix for flexible pavement, 15-year analysis period

Flexible		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Slurry Seal
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Slurry Seal	Crack Sealing/Filling
	Medium	Microsurfacing	Microsurfacing
	High	HMA Overlay	Microsurfacing
High	**Low**	NA	NA
	Medium	NA	NA
	High	Microsurfacing	HMA Overlay (Only)

Table 17. Decision matrix for flexible pavement, 20-year analysis period

Flexible		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Seal Coat
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Slurry Seal	Crack Sealing/Filling
	Medium	Microsurfacing	Microsurfacing
	High	HMA Overlay	Microsurfacing
High	**Low**	NA	NA
	Medium	NA	NA
	High	Microsurfacing	HMA Overlay (Only)

Table 18. Decision matrix for flexible pavement, 30-year analysis period

Flexible		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Microsurfacing
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Slurry Seal	Crack Sealing/Filling
	Medium	Microsurfacing	Microsurfacing
	High	HMA Overlay	Microsurfacing
High	**Low**	NA	NA
	Medium	NA	NA
	High	Microsurfacing	HMA Overlay (Only)

Table 19. Decision matrix for composite pavement, 10-year analysis period

Composite		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Seal Coat
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Crack Sealing/Filling	Slurry Seal
	Medium	Crack Sealing/Filling	Slurry Seal
	High	Microsurfacing	Crack Sealing/Filling
High	**Low**	NA	Crack Sealing/Filling
	Medium	Crack Sealing/Filling (Only)	HMA Overlay
	High	Microsurfacing	HMA Overlay (Only)

Table 20. Decision matrix for composite pavement, 15-year analysis period

Composite		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Seal Coat
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Crack Sealing/Filling	Slurry Seal
	Medium	Crack Sealing/Filling	Slurry Seal
	High	Microsurfacing	HMA Overlay
High	**Low**	NA	Crack Sealing/Filling
	Medium	Crack Sealing/Filling (Only)	HMA Overlay
	High	Microsurfacing	HMA Overlay (Only)

Table 21. Decision matrix for composite pavement, 20-year analysis period

Composite		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Seal Coat
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Crack Sealing/Filling	Slurry Seal
	Medium	Crack Sealing/Filling	Slurry Seal
	High	Microsurfacing	Crack Sealing/Filling
High	**Low**	NA	Crack Sealing/Filling
	Medium	Crack Sealing/Filling (Only)	HMA Overlay
	High	Microsurfacing	HMA Overlay (Only)

Table 22. Decision matrix for composite pavement, 30-year analysis period

Composite		PCI-Based Condition	
AADT	**TRUCK**	**Good**	**Fair**
Low	**Low**	HMA Overlay (Only)	Seal Coat
	Medium	NA	NA
	High	NA	NA
Medium	**Low**	Crack Sealing/Filling	Slurry Seal
	Medium	Crack Sealing/Filling	Slurry Seal
	High	Microsurfacing	HMA Overlay
High	**Low**	NA	NA
	Medium	Crack Sealing/Filling (Only)	HMA Overlay
	High	Microsurfacing	HMA Overlay (Only)

Table 23 presents a decision matrix for pavement preservation treatments based on the dominant distress type observed in a pavement, where users can select cracking, IRI, or rutting as the primary distress indicator. The purpose of this matrix is to help decision-makers select the optimum treatment for each specific combination of pavement type and condition while considering the major distresses prevailing in a given road segment.

Table 23. Decision matrix based on dominant distress indicator

		Dominant Distress Indicator		
Pavement Type	**PCI-Condition**	**Cracking**	**IRI**	**Rutting**
Flexible	**Good**	Slurry Sealing	Slurry Sealing	Slurry Sealing
	Fair	Microsurfacing	Seal Coat	Microsurfacing
Composite	**Good**	Crack Sealing/Filling	Crack Sealing/Filling	Crack Sealing/Filling
	Fair	Crack Sealing/Filling	Seal Coat	HMA Overlay

This analysis is typically performed internally within many pavement management systems. Ideally, the selection of the appropriate treatment at the right time is guided by optimization, that is, maximizing the benefits of a treatment within given constraints.

In addition to considering the benefits and costs of the feasible treatments, selection of the optimal preservation treatment involves considering the variety of project constraints that affect treatment selection. Project constraints that should be considered when selecting preservation treatments include the following:

- Availability of qualified contractors
- Availability of quality materials
- Agency practice or local preference
- Time (of year) of construction
- Initial costs
- User preferences
- Pavement noise
- Facility downtime

- Surface friction

The effects of these constraints will vary from project to project and should be taken into consideration as the final treatments are selected for inclusion in a pavement preservation program.

Phase II

As explained in earlier chapters, Phase II of this study expanded the deterministic performance modeling framework by introducing enhanced modeling techniques to address the data limitations identified during Phase I. The objective here was to strengthen the modeling framework while preserving the interpretability and engineering relevance of the methodology. Rather than replacing the deterministic approach, we augmented it by incorporating systematic denoising procedures, engineering realism constraints, and machine learning–based modeling methods capable of leveraging additional contextual information such as traffic, climate, and pavement characteristics. Transfer learning techniques were also used to supplement the Iowa PMIS dataset with nationally collected pavement performance data from the LTPP program, thereby improving model generalization in treatment categories with limited local observations.

The outputs of the Phase II modeling process remained consistent with the core performance metrics developed in Phase I. Specifically, treatment effectiveness continued to be evaluated using LE, IB, and BCA. However, Phase II results provided more stable deterioration curve estimations, better representation of treatment variability across pavement and traffic conditions, and more reliable predictions for treatment categories with historically limited observations.

Table 24 summarizes the estimated life extension and index benefit values for each preservation treatment applied to flexible pavements, along with the number of pavement sections used in the analysis.

Table 24. Phase II life extension and index benefit values for flexible pavement treatments

Treatment	No. of Sections	Life Extension	Index Benefit
Microsurfacing	13	5.87	159.97
Patching	3	5.10	363.19
Slurry Seal	7	6.34	336.81
Crack Sealing/Filling	5	1.52	7.11
HMA Overlay	90	10.77	3031.54

As seen in the table, HMA overlay continues to produce the largest life extension and index benefit values among all treatments. With an average life extension of approximately 10.77 years and a substantially larger index benefit than other treatments, HMA overlay represents the most impactful intervention in terms of restoring pavement condition. Other treatments such as slurry seal and microsurfacing also demonstrate meaningful performance improvements. Slurry seal yields a life extension of approximately 6.34 years, while microsurfacing provides approximately 5.87 years of life extension. Patching also demonstrates a notable benefit relative to the limited number of sections analyzed for this treatment. Crack sealing/filling produced a relatively small life extension in the Phase II results, which may reflect the limited number of observations available in the dataset and the localized nature of this treatment.

Seal coat was excluded from the Phase II analysis because, upon review, the project classified as a seal coat was part of a larger reconstruction project. Therefore, the calculated value did not accurately represent the impacts of a seal coat treatment alone

Table 25 presents the life extension and index benefit results for composite pavements derived from the Phase II modeling framework. The results for composite pavements exhibit patterns similar to those observed for flexible pavements. HMA overlay again produces the highest life extension and index benefit values, with a life extension of approximately 10.10 years. Microsurfacing and crack sealing/filling also show strong performance for composite pavements, with life extensions of approximately 6.20 and 6.56 years, respectively. Patching demonstrates a relatively high life extension value (8.65 years), although this estimate is based on a relatively small number of sections. Slurry seal provides a moderate life extension of approximately 4.8 years for composite pavements. Overall, the results indicate that preservation treatments can significantly extend pavement service life when applied appropriately to composite pavement systems.

Table 25. Phase II life extension and index benefit for composite pavement treatments

Treatment	No. of Sections	Life Extension	Index Benefit
Microsurfacing	50	6.20	974.78
Patching	7	8.65	293.41
Slurry Seal	9	4.8	96.04
Crack Sealing/Filling	31	6.56	237.63
HMA Overlay	505	10.10	2720.78

Observations have shown that treatment effectiveness varies significantly depending on the condition of the pavement at the time the treatment is applied. To investigate this effect, the Phase II analysis evaluated life extension and index benefit values separately for pavements classified as being in good condition and those classified as fair or poor.

In this regard, Table 26 compares treatment effectiveness for flexible pavements based on whether the pavement was in good condition or fair/poor condition at the time of treatment. HMA overlay produces substantial benefits regardless of pavement condition, although the index benefit is significantly higher when the treatment is applied to pavements in good condition. Microsurfacing also demonstrates strong performance when applied to pavements in good condition, producing a life extension of approximately 6.53 years. Slurry seal appears to be more effective when applied to pavements in fair or poor condition, where it produces a greater life extension value than when applied to pavements in good condition. Patching and crack sealing/filling are largely applied to pavements already experiencing distress, which explains the absence of results for pavements in good condition for these treatments.

Table 26. Life extension and index benefit by pavement condition: flexible pavements

Treatment	Life Extension		Index Benefit	
	Good	**Fair/Poor**	**Good**	**Fair/Poor**
Microsurfacing	6.53	5.81	1100.5	74.47
Patching	NA	5.1	NA	363.19
Slurry Seal	4	6.73	92.79	377.48
Crack Sealing/Filling	NA	1.52	NA	7.11
HMA Overlay	10.87	10.69	3767.99	637.79

Error! Not a valid bookmark self-reference. summarizes treatment effectiveness for composite pavements across pavement condition categories. As the table shows, several treatments provide greater benefits when applied to pavements in fair or poor condition. For example, microsurfacing shows significantly higher index benefit values when applied to pavements in fair/poor condition than when applied to pavements in good condition. HMA overlay again provides the highest life extension values in both condition categories. Crack sealing/filling also demonstrates meaningful performance improvements, particularly for pavements in fair condition where cracking-related distresses are likely to be present.

Table 27. Life extension and index benefit by pavement condition: composite pavements

Treatment	Life Extension		Index Benefit	
	Good	**Fair/Poor**	**Good**	**Fair/Poor**
Microsurfacing	8.64	6.17	52	1041
Patching	10	8.43	37.02	336.14
Slurry Seal	NA	4.8	NA	96.04
Crack Sealing/Filling	5.73	6.67	53.3	263.96
HMA Overlay	10.32	9.94	4097.41	1124.98

To better understand which treatments are most appropriate under different distress conditions, the Phase II analysis evaluated treatment effectiveness in terms of dominant distress indicators. Table 28 identifies the treatments that performed best for different combinations of pavement type, pavement condition, and dominant distress indicator. HMA overlay consistently performs well across multiple distress categories, particularly when roughness (IRI) is the dominant issue. For flexible pavements, microsurfacing performs well in addressing rutting-related distress when the pavement is in fair or poor condition. For composite pavements, crack sealing/filling performs effectively in addressing cracking-related distresses. These findings demonstrate the importance of aligning treatment selection with the dominant distress mechanism affecting pavement performance.

Table 28. Recommended treatments by pavement condition and dominant distress indicator

Pavement Type	PCI-Condition	Dominant Distress Indicator		
		Cracking	IRI	Rutting
Flexible	Good	Patching	HMA Overlay	HMA Overlay
	Fair/Poor	HMA Overlay	HMA Overlay	Microsurfacing
Composite	Good	HMA Overlay	HMA Overlay	Crack Sealing/Filling
	Fair/Poor	HMA Overlay	Crack Sealing/Filling	HMA Overlay

Figure 20 presents the calculated life extension values for the different preservation treatments applied to flexible pavements using the Phase II modeling framework. The results illustrate the expected extension in pavement service life associated with each treatment type when applied to pavements in good and fair/poor condition categories. As the figure shows, HMA overlay provides the greatest life extension, reaching approximately 10.87 years for pavements in good condition and 10.69 years for pavements in fair or poor condition. Microsurfacing also demonstrates a substantial life extension, particularly when applied to pavements in good condition, with an extension of approximately 6.53 years. Slurry seal provides moderate benefits, with life extension values of approximately 4 years for pavements in good condition and 6.73 years for pavements in fair/poor condition. Patching shows relatively limited life extension for pavements in good condition but performs better for pavements in fair/poor condition, where it provides a life extension of approximately 5.1 years. Crack sealing/filling produces a smaller life extension effect compared to other treatments, reflecting its primarily preventive role rather than an ability to provide structural improvement.

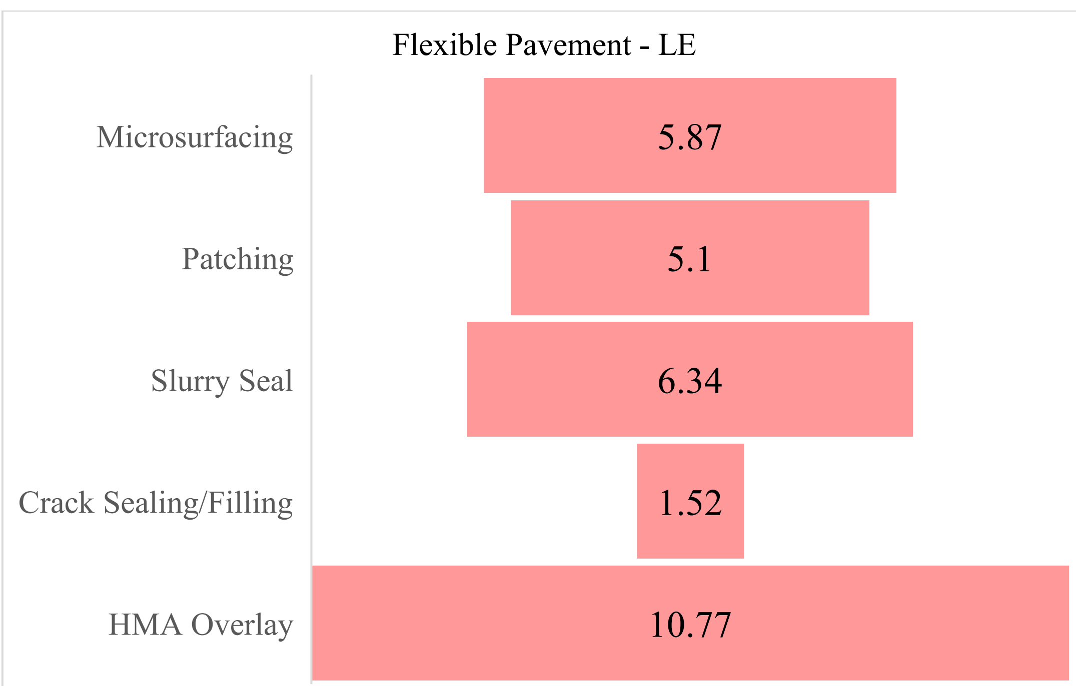


Figure 20. Life extension for flexible pavements under different preservation treatments

Figure 21 illustrates the index benefit values associated with the preservation treatments applied to flexible pavements. The index benefit represents the cumulative improvement in pavement condition achieved by the treatment compared with the expected deterioration in a do-nothing scenario. The results show that HMA overlay generates the largest index benefit, reaching approximately 3767.99 for pavements in good condition and 637.79 for pavements in fair or poor condition. Microsurfacing also produces a substantial benefit for pavements in good condition, with an index benefit exceeding 1100. In contrast, treatments such as slurry seal and patching generate moderate benefits depending on pavement condition. Note that while some treatments may produce similar life extension values, their index benefit may differ significantly depending on the magnitude of the immediate condition improvement. For example, patching provides a relatively small index benefit for pavements in good condition but performs better when applied to pavements already exhibiting deterioration.

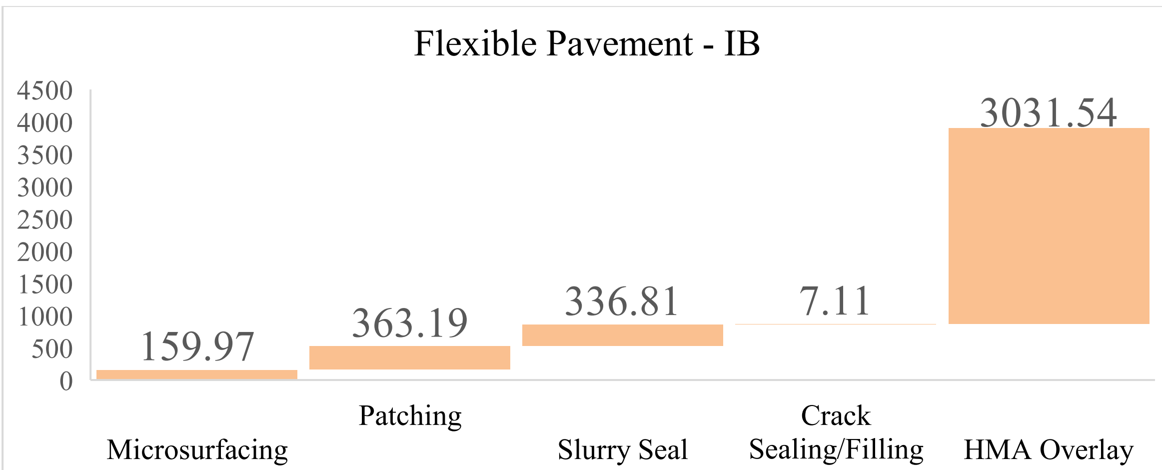


Figure 21. Index benefit for flexible pavements under different preservation treatments

Figure 22 and Figure 23, which show life extension and index benefit values for composite pavements, demonstrate that the treatment effectiveness patterns for composite pavements are broadly consistent with those observed for flexible pavements. Structural treatments such as HMA overlay provide the largest improvements in both life extension and index benefit, while other preservation treatments produce smaller but still meaningful benefits depending on pavement condition and distress type.

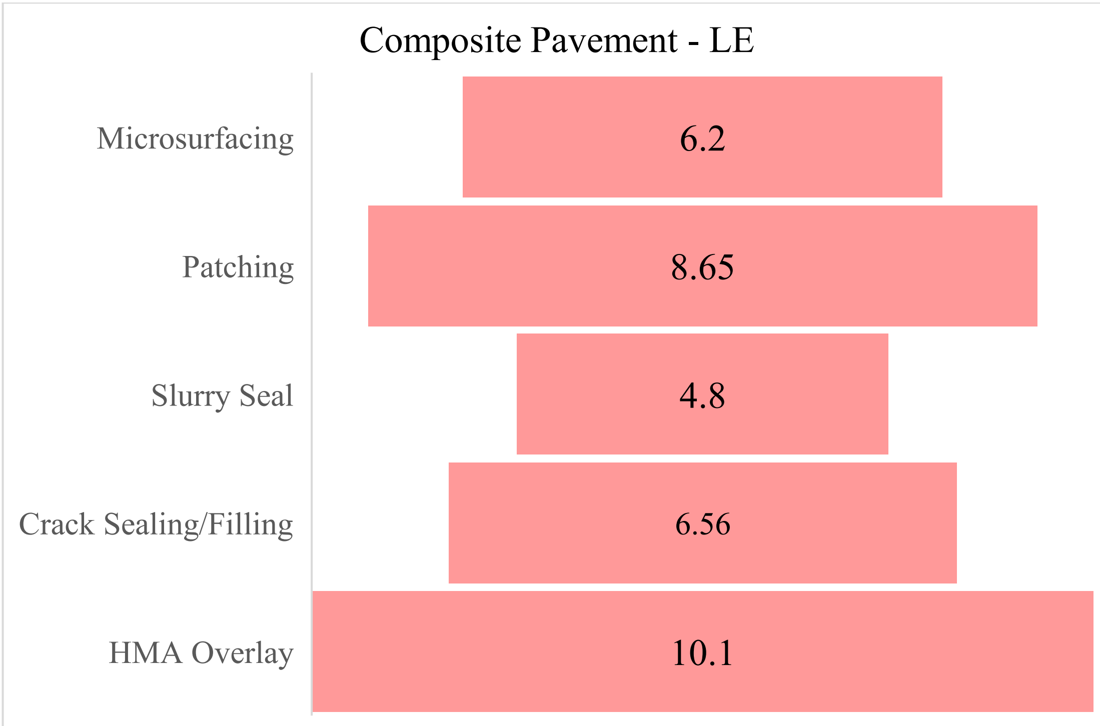


Figure 22. Life extension for composite pavements under different preservation treatments

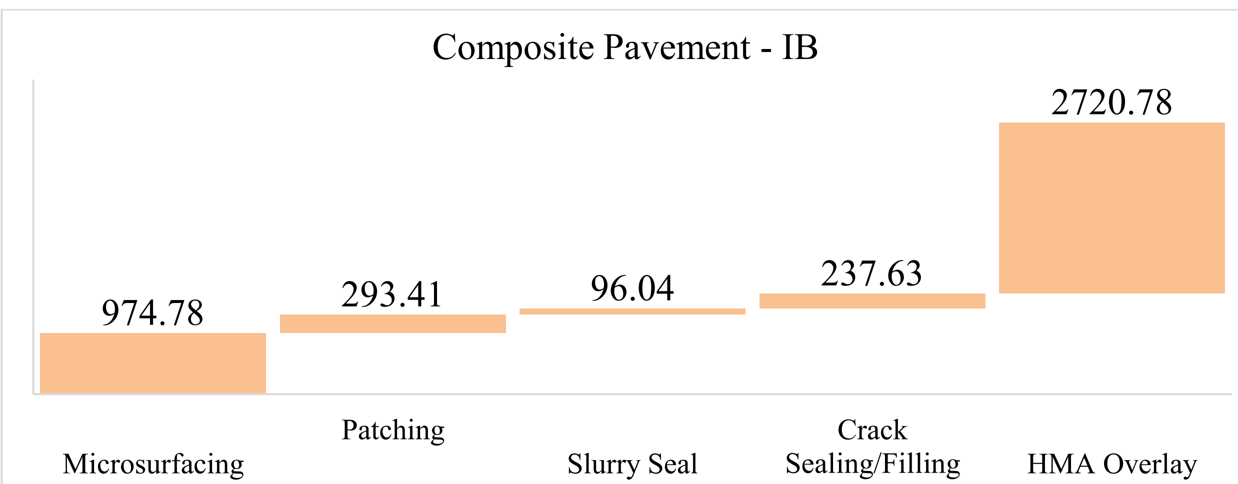


Figure 23. Index benefit for composite pavements under different preservation treatments

Figure 24 through Figure 27 provide a comparative view of the effect of underlying pavement condition on the performance of preservation treatments. The LE and IB achieved by each treatment is shown for pavements in good condition versus pavements in fair or poor condition. Overall, the results show a consistent trend across both pavement types: most treatments provide greater performance benefits when applied to pavements in fair condition than when applied to pavements in good condition. This trend is particularly evident for treatments such as microsurfacing, crack sealing/filling, and HMA overlay. When pavements are already experiencing moderate deterioration, these treatments produce larger improvements in condition and consequently generate greater life extension and index benefit values. For example, microsurfacing and crack sealing/filling demonstrate significantly higher life extension and index benefit values when applied to pavements in fair condition than when applied to pavements in good condition.

HMA overlay consistently demonstrates the largest life extension and index benefit values across all scenarios, regardless of pavement type or condition. However, the difference in performance between pavements in good and fair condition is still noticeable, particularly in terms of index benefit. When applied to pavements in fair condition, HMA overlays tend to generate substantially higher index benefit values due to the larger improvement in pavement condition that can be achieved relative to the baseline deterioration curve.

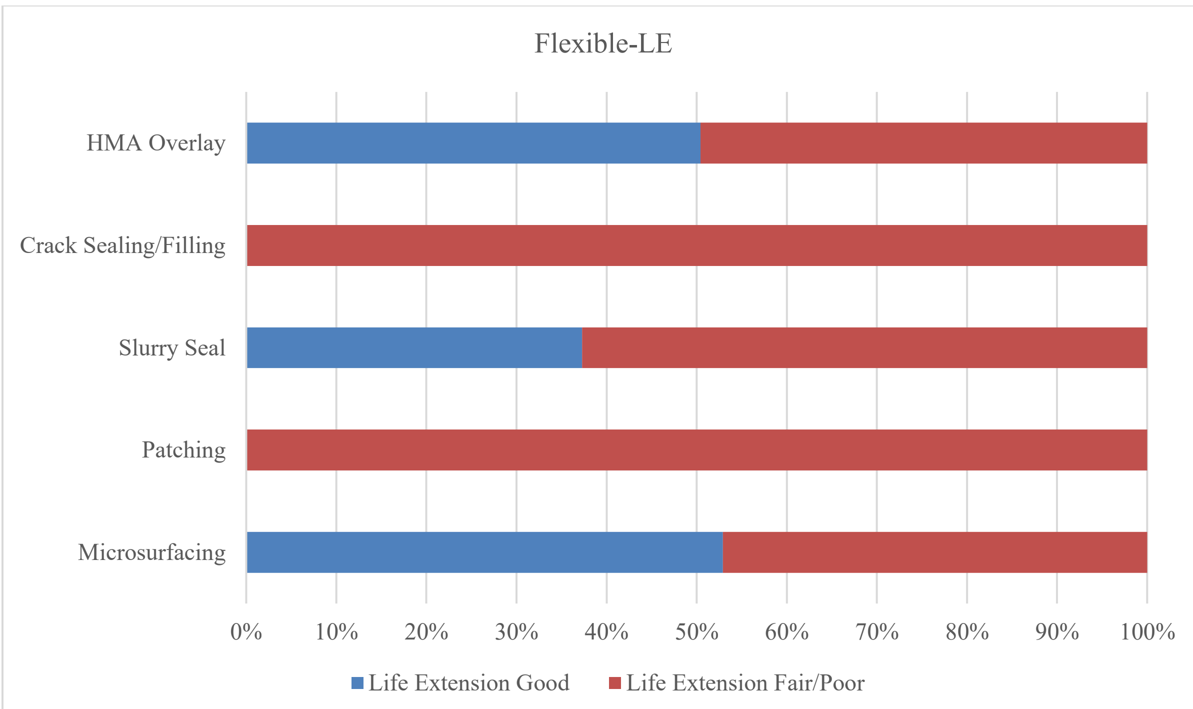


Figure 24. Comparison of life extension for flexible pavements in good and fair/poor condition

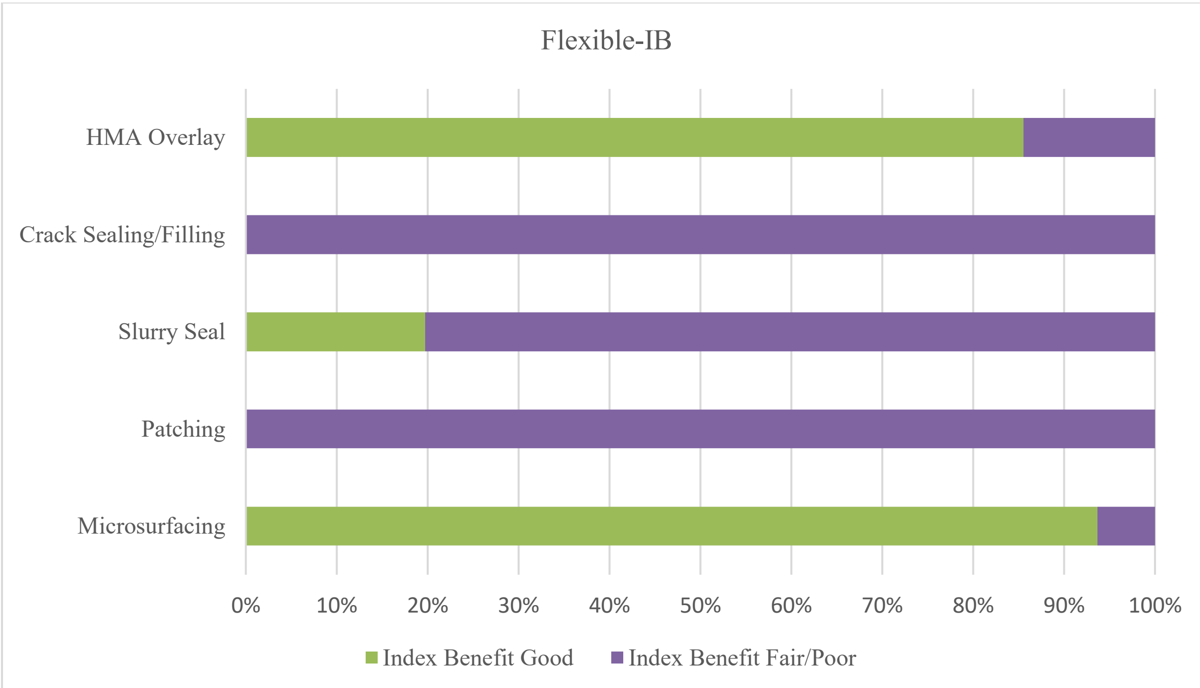


Figure 25. Comparison of index benefit for flexible pavements in good and fair/poor condition

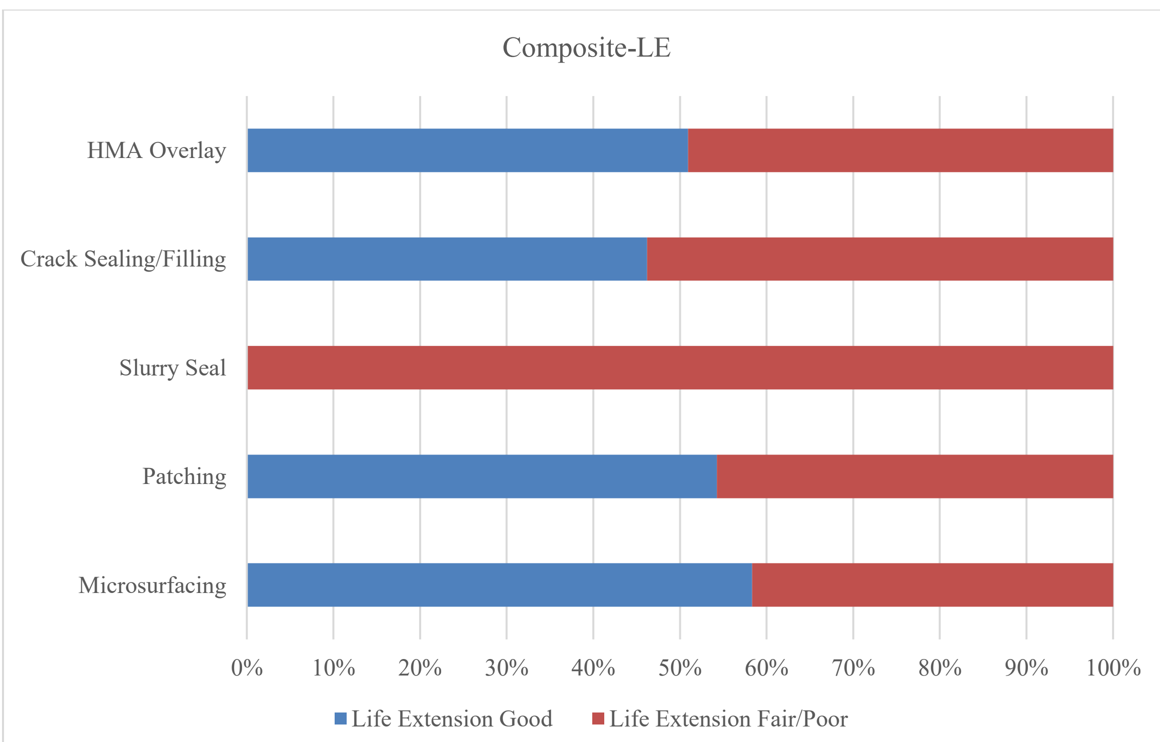


Figure 26. Comparison of life extension for composite pavements in good and fair/poor condition

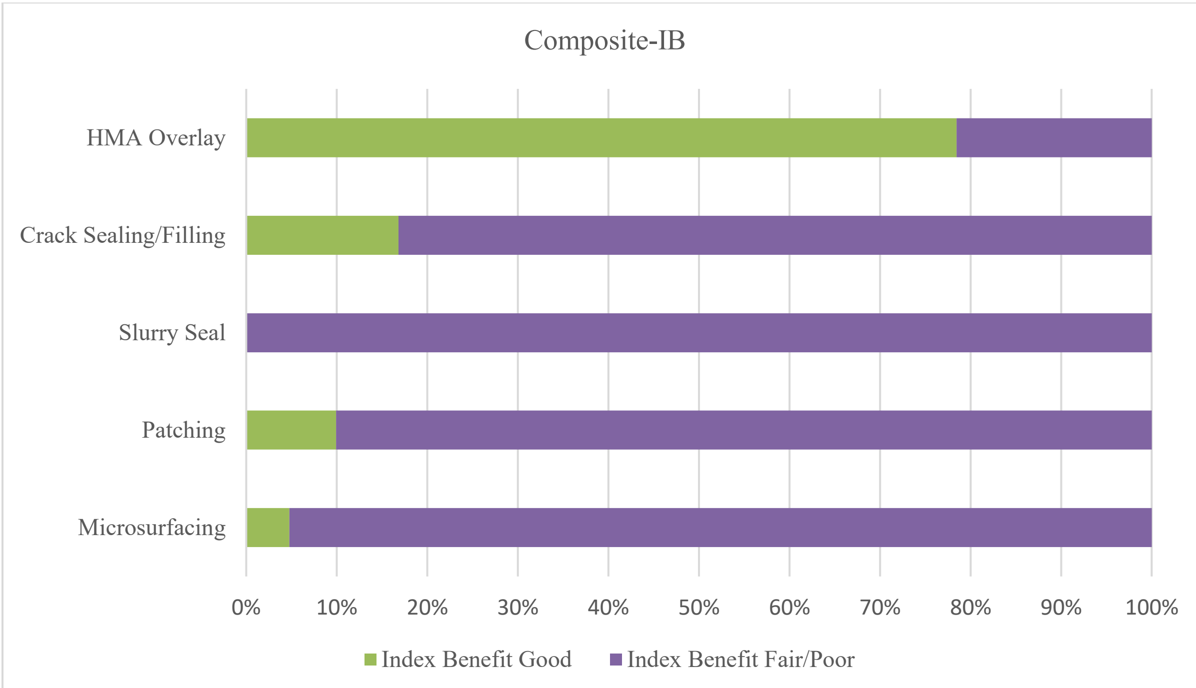


Figure 27. Comparison of index benefit for composite pavements in good and fair/poor condition

The final step of the Phase II analysis involved translating the modeling results into practical decision matrices that can guide treatment selection under different traffic conditions.

For each pavement type (flexible and composite), six matrices based on BCR results rather than EUAC calculations were developed that show recommendations for two traffic indicators (whether AADT or truck traffic) and three analysis periods (10, 15, and 20 years). For flexible pavements, all tables yielded identical recommendations for both traffic indicators and across all analysis periods. Because the treatment rankings based on benefit-cost ratio remained identical for all scenarios, the six original tables for this pavement type were consolidated into a single decision matrix without loss of information. This stability indicates that the relative cost-effectiveness of the evaluated treatments is robust with respect to the assumed analysis horizon and traffic metric.

Table 29 shows the consolidated decision matrix developed for flexible pavements, which presents consistent treatment recommendations across all analysis periods (10, 15, and 20 years) and across both traffic indicators (AADT and truck traffic, AADTT).

Table 29. Decision matrix for flexible pavements based on traffic level and pavement condition (all analysis periods)

Traffic Indicator	Traffic Level	Good Condition	Fair/Poor Condition
AADT	Low/Medium	HMA Overlay	Slurry Seal
	High	HMA Overlay	HMA Overlay
AADTT (Truck Traffic)	Low/Medium	HMA Overlay	Slurry Seal
	High	HMA Overlay	HMA Overlay

Note: The same recommendations were obtained for the 10-, 15-, and 20-year analysis periods.

Across all cases, HMA overlay is the preferred treatment for pavements in good condition, regardless of traffic level. This outcome reflects the substantial performance improvement and life extension associated with HMA overlay, which consistently produces the highest index benefits among the evaluated treatments.

For pavements in fair or poor condition, the recommended treatment depends on traffic level. Under low or medium traffic volumes, slurry seal emerges as the most cost-effective option. In these cases, the treatment provides sufficient improvement in pavement condition at a relatively low cost, resulting in a favorable benefit-cost ratio. However, when traffic levels are high, HMA overlay becomes the preferred treatment, even for pavements in fair or poor condition. The greater structural and functional improvements associated with HMA overlay offset its higher cost under heavier traffic loads.

The fact that the AADT-based and truck traffic–based matrices yield identical recommendations suggests that the treatment effectiveness patterns observed in the dataset are driven primarily by pavement condition and overall traffic demand rather than by differences between total traffic and truck traffic metrics. Overall, the consolidated matrix provides a simple and stable guideline for flexible pavement treatment selection based on pavement condition and traffic level.

For composite pavements, all tables based on AADT resulted in identical treatment recommendations across all analysis periods. For tables based on truck traffic (AADTT), the recommended treatment when the traffic level is low/medium and the pavement is in fair/poor condition shifts from crack sealing to HMA overlay; however, the results otherwise remain consistent across the analysis periods.

The consolidated decision matrix for composite pavements based on AADT, presented in Table 30, shows consistent treatment recommendations across the three analysis periods (10, 15, and 20 years), indicating that the relative cost-effectiveness of the evaluated treatments remains stable regardless of the assumed evaluation horizon.

Table 30. Decision matrix for composite pavements based on AADT (all analysis periods)

AADT Level	Good Condition	Fair/Poor Condition
Low/Medium	HMA Overlay	Crack Sealing/Filling
High	HMA Overlay	Microsurfacing

Across all scenarios, HMA overlay is the preferred treatment for pavements in good condition, regardless of traffic level or traffic indicator. This reflects the strong performance improvement and the long life extension provided by HMA overlay, which consistently produced the highest index benefits in the Phase II modeling results. For pavements in fair or poor condition, treatment recommendations vary depending on the traffic indicator and traffic level. Under AADT-based classification, crack sealing/filling is recommended for roads with low or medium traffic volumes. In these cases, addressing cracking-related distress through targeted sealing treatments provides sufficient improvement in pavement condition at a relatively low cost, resulting in a favorable benefit-cost ratio. However, when traffic levels are high, microsurfacing becomes the preferred option because it provides greater surface improvement and durability under higher traffic demands.

When traffic is evaluated using truck traffic (AADTT), the recommendations differ slightly (Table 31). For low or medium truck traffic levels, HMA overlay becomes the preferred treatment even when pavements are in fair or poor condition. This suggests that the structural and functional improvements associated with HMA overlay produce the highest overall benefit when truck traffic is considered explicitly. Under high truck traffic levels, microsurfacing is recommended for pavements in fair or poor condition, indicating that this treatment can effectively address surface deterioration while maintaining favorable cost-effectiveness in heavily trafficked conditions.

Table 31. Decision matrix for composite pavements based on truck traffic (AADTT) (all analysis periods)

Truck Traffic Level	Good Condition	Fair/Poor Condition
Low/Medium	HMA Overlay	HMA Overlay
High	HMA Overlay	Microsurfacing

PAVEMENT PRESERVATION TREATMENT GUIDE TOOLBOX

ArcGIS Tool

A Pavement Preservation Treatment Guide toolbox, designed specifically for ArcGIS, was developed in Phase I of this project. The toolbox provides decision-makers within the Iowa DOT with a valuable tool for selecting optimal pavement preservation strategies. This user-friendly toolbox streamlines the evaluation process, considering crucial factors like pavement type, current condition, traffic volume, truck traffic, and the desired analysis period. The toolbox analyzes these factors to recommend the most suitable preservation solution for each unique scenario, ensuring informed decision-making and efficient resource allocation.

In essence, the toolbox acts as a visual representation of the decision matrices developed in this comprehensive study. This format allows for the seamless application of these matrices to any PMIS dataset, fostering data-driven decision-making across the entire pavement network. Figure 28 presents a practical example of the toolbox's output when implemented using 2022 PMIS data, which highlights the tool's ability to translate raw data into actionable insights.

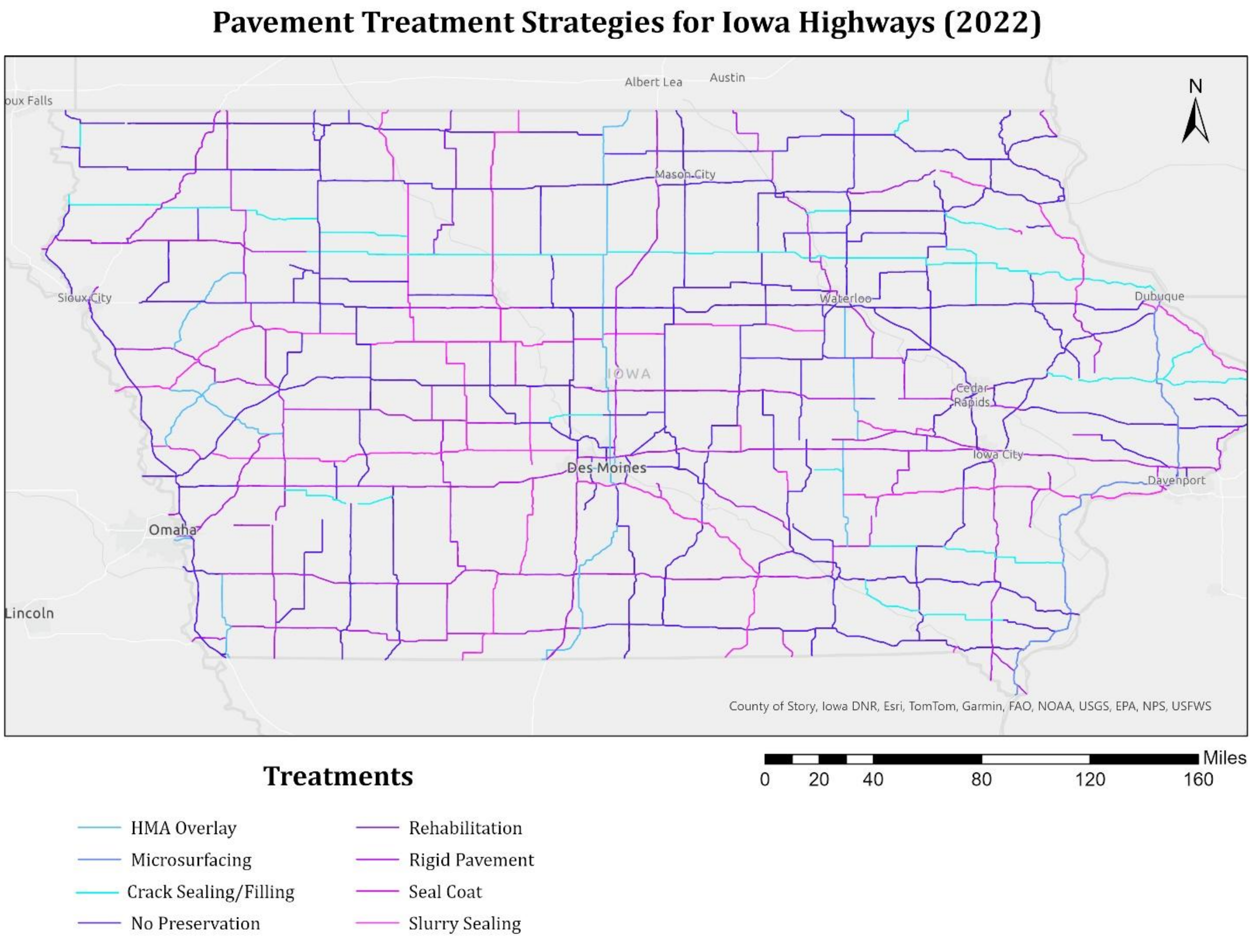


Figure 28. Pavement preservation treatment strategies for Iowa highways based on 2022 PMIS data

To leverage the capabilities of this powerful tool, ArcGIS must be installed on the user's computer, and the user must provide two specific data inputs through the toolbox's geoprocessing window (Figure 29):

- **PMIS CSV File**: This file serves as the foundation for the analysis, containing crucial pavement information like unique route IDs, pavement types, traffic levels (AADT), truck counts, PCI values, and other relevant attributes. This file can be readily accessed from the Iowa DOT website and is referenced within the script's "pmis_csv" parameter for seamless integration.
- **Route Shapefile**: This file defines the geometry of each route segment, including unique route IDs. It plays a vital role in spatial analysis and is referenced using the script's "route_shapefile" parameter.

This toolbox provides flexibility by allowing users to choose from four analysis periods: 10, 15, 20, or 30 years.

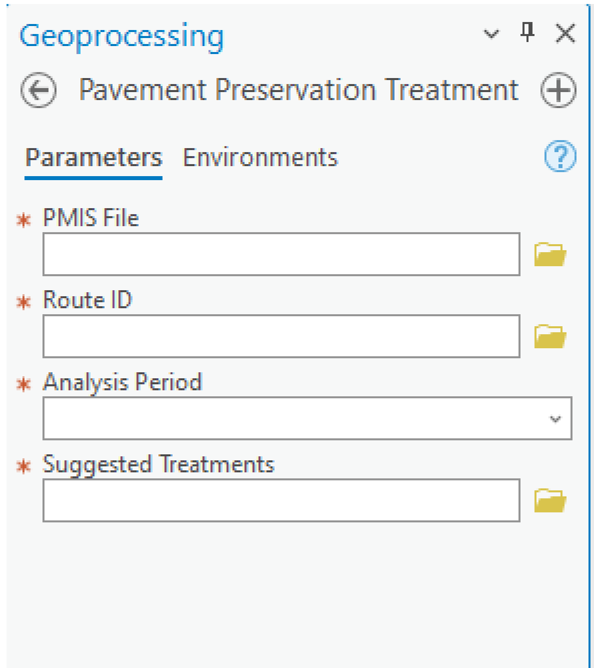


Figure 29. Screenshot of the geoprocessing window within the toolbox interface

The process for using the toolbox is as follows:

1. **Launch ArcGIS Pro:** Begin by opening a new or existing project where the Pavement Preservation Treatment Guide toolbox will be employed.
2. **Access the Python Toolbox:** Within the project, navigate to the Catalog pane and locate the folder containing the project's Python scripts. Find and double-click the "Pavement Preservation Treatment.py" file to open the toolbox and access its functionality.
3. **Run the Tool**: Double-click the Pavement Preservation Treatment tool within the toolbox to configure and execute it.
4. **Configure Tool Parameters**: Set the following input parameters to ensure accurate analysis:
   a. **PMIS File (PMIS_CSV)**: Select the PMIS CSV file containing the pavement data for analysis.
   b. **Route ID (Route_Shapefile)**: Choose the Route Shapefile that defines the geometry of each route segment.
   c. **Analysis Period**: Select the desired analysis period (10, 15, 20, or 30 years) based on the desired planning horizon.
   d. **Suggested Treatments (Output_Shapefile)**: Specify the location in which to save the output shapefile containing the recommended pavement treatments for each route segment.
5. **Run the Tool**: Once the parameters have been configured, click the Run button to initiate the execution of the tool.
6. **Monitor Progress:** As the tool processes the data, observe the progress bar to stay informed about the analysis stage.
7. **Review Results:** Upon successful completion, the tool generates the following outputs:

   a. **Suggested Pavement Treatments Shapefile:** This file contains crucial information, outlining the recommended pavement preservation treatment for each route segment based on the analyzed data and selected parameters.
   b. **Visualization:** The shapefile is automatically added to the project for immediate visualization, allowing users to explore the recommended treatments spatially and gain valuable insights into the overall network condition.
8. **Save the Project:** Remember to save the ArcGIS project to preserve the changes, including the newly added treatment layer, ensuring that the project is readily accessible for future reference and decision-making processes.

By effectively utilizing the Pavement Preservation Treatment Guide toolbox, Iowa DOT personnel can make informed and data-driven decisions regarding pavement preservation strategies. This will ultimately lead to a more efficient and cost-effective transportation network characterized by smooth operation and enhanced public service delivery.

Cost-Benefit Dashboard

To extend the accessibility of the Phase I analysis beyond the ArcGIS environment, Phase II developed a standalone, browser-based Cost-Benefit Dashboard that requires no GIS software, programming skills, or external data connections. The dashboard is entirely self-contained; all empirically derived treatment effectiveness values computed from the historical PMIS analysis are embedded directly within the tool, allowing any decision-maker to conduct cost-benefit evaluations from a standard web browser.

Dashboard Interface and Input Controls

The dashboard interface, shown in Figure 30, is organized around a set of interactive controls that allow the user to tailor the analysis to a specific segment context. The first and most consequential input is the Combination selector, which determines the stratification structure applied to the analysis.

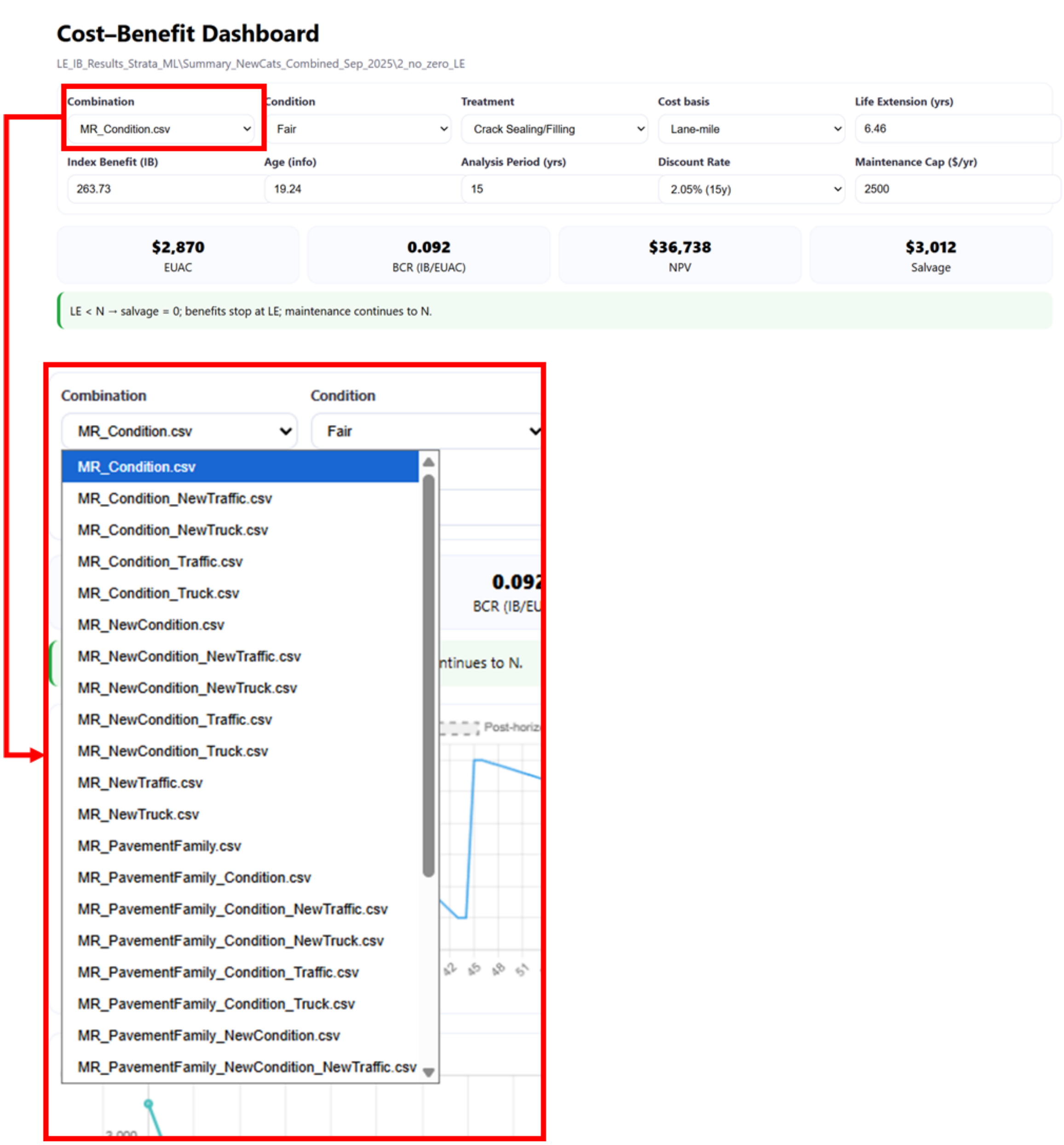


Figure 30. Screenshot of the Cost-Benefit Dashboard

As shown in Figure 30, the dashboard offers an extensive list of stratification combinations derived from the historical analysis of treatment effectiveness conducted for this study, ranging from simple single-dimension groupings (such as condition only or truck traffic only) to multi-dimensional combinations spanning pavement family, condition category, traffic level, and truck volume simultaneously. This flexibility allows users to work at the level of specificity appropriate to their available data and decision context.

Once a combination is selected, the corresponding dimension filters appear dynamically below the Combination selector. Upon choosing a treatment from the Treatment dropdown, the dashboard automatically populates the Life Extension and Index Benefit fields with the empirically derived average values for that specific combination, drawn from historical PMIS project records. The Age field provides contextual reference information about the average age at which that treatment was historically applied in the matching stratum.

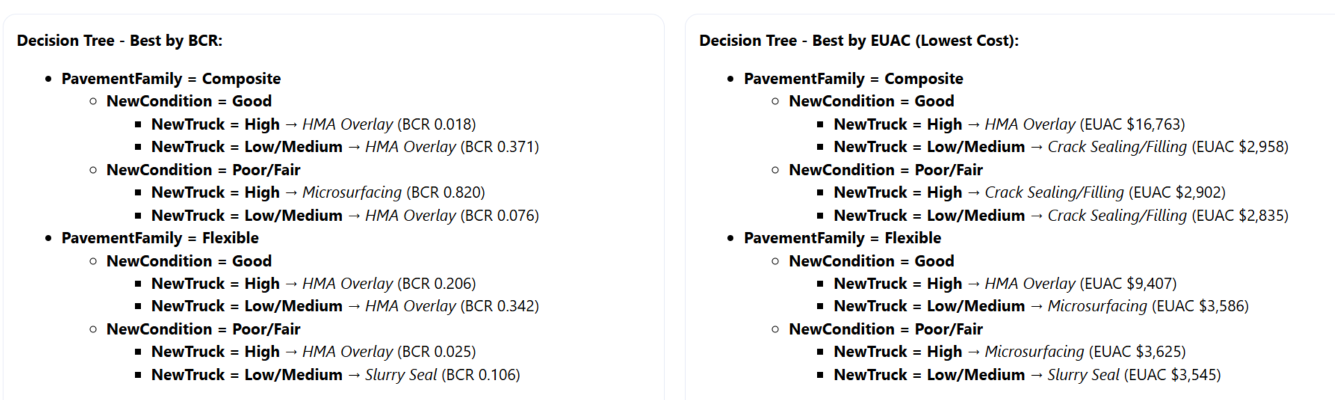
The remaining inputs allow the user to adjust the economic assumptions of the analysis. The cost basis can be set to either lane-mile or per-mile depending on how project costs are tracked. The analysis period can be set to values or 10, 15, and 20 years, with the discount rate updating automatically to the corresponding recommended value (1.9% for 10-year horizons, 2.05% for 15-year horizons, and 2.2% for 20-year horizons). An annual maintenance cap input allows the user to specify the routine maintenance cost ceiling applied during the analysis period; this cap can also be adjusted manually.

Economic Output Metrics

Based on the selected inputs, the dashboard computes four economic indicators in real time, displayed as summary metrics directly below the input panel. The EUAC converts the full stream of treatment, maintenance, and salvage cash flows into a single annualized cost figure. The BCR is computed as the ratio of the IB to the EUAC, providing a normalized measure of return on investment. The NPV represents the total discounted cost of the treatment program over the analysis horizon, and the salvage value reflects the residual value credited at the end of the analysis period when the treatment's life extension has not been fully consumed.

Decision Trees

A key output of the dashboard is a pair of automatically generated decision trees, shown in Figure 31, which summarize treatment recommendations across all stratification cells simultaneously. Rather than requiring the user to step through each condition-traffic combination individually, the decision trees present a hierarchical structure that maps every combination of the selected stratification dimensions to its recommended treatment in a single compact view.



Decision Tree - Best by BCR:

- **PavementFamily = Composite**
  - **NewCondition = Good**
    - **NewTruck = High** → *HMA Overlay* (BCR 0.018)
    - **NewTruck = Low/Medium** → *HMA Overlay* (BCR 0.371)
  - **NewCondition = Poor/Fair**
    - **NewTruck = High** → *Microsurfacing* (BCR 0.820)
    - **NewTruck = Low/Medium** → *HMA Overlay* (BCR 0.076)
- **PavementFamily = Flexible**
  - **NewCondition = Good**
    - **NewTruck = High** → *HMA Overlay* (BCR 0.206)
    - **NewTruck = Low/Medium** → *HMA Overlay* (BCR 0.342)
  - **NewCondition = Poor/Fair**
    - **NewTruck = High** → *HMA Overlay* (BCR 0.025)
    - **NewTruck = Low/Medium** → *Slurry Seal* (BCR 0.106)

Decision Tree - Best by EUAC (Lowest Cost):

- **PavementFamily = Composite**
  - **NewCondition = Good**
    - **NewTruck = High** → *HMA Overlay* (EUAC $16,763)
    - **NewTruck = Low/Medium** → *Crack Sealing/Filling* (EUAC $2,958)
  - **NewCondition = Poor/Fair**
    - **NewTruck = High** → *Crack Sealing/Filling* (EUAC $2,902)
    - **NewTruck = Low/Medium** → *Crack Sealing/Filling* (EUAC $2,835)
- **PavementFamily = Flexible**
  - **NewCondition = Good**
    - **NewTruck = High** → *HMA Overlay* (EUAC $9,407)
    - **NewTruck = Low/Medium** → *Microsurfacing* (EUAC $3,586)
  - **NewCondition = Poor/Fair**
    - **NewTruck = High** → *Microsurfacing* (EUAC $3,625)
    - **NewTruck = Low/Medium** → *Slurry Seal* (EUAC $3,545)

Figure 31. Example of BCR- and EUAC-optimized decision trees from the dashboard

Two parallel trees are provided, each reflecting a different optimization objective. The BCR-optimized tree recommends the treatment with the highest benefit-cost ratio for each stratum, prioritizing treatments that deliver the greatest return per dollar spent. The EUAC-optimized tree recommends the lowest-cost treatment for each stratum, suitable for contexts where minimizing expenditure is the primary objective. For example, in the MR_NewCondition_NewTruck combination shown in Figure 31, the BCR tree recommends HMA overlay for pavements in good condition under both high and low/medium truck traffic and recommends microsurfacing for pavements in fair/poor condition under high truck traffic, while the EUAC tree favors crack sealing/filling across most fair/poor pavement condition strata due to its lower annualized cost.

For situations where the treatment selection is guided by dominant pavement distress rather than overall condition category, the dashboard also includes a dedicated Dominant Distress section, shown in Figure 32.

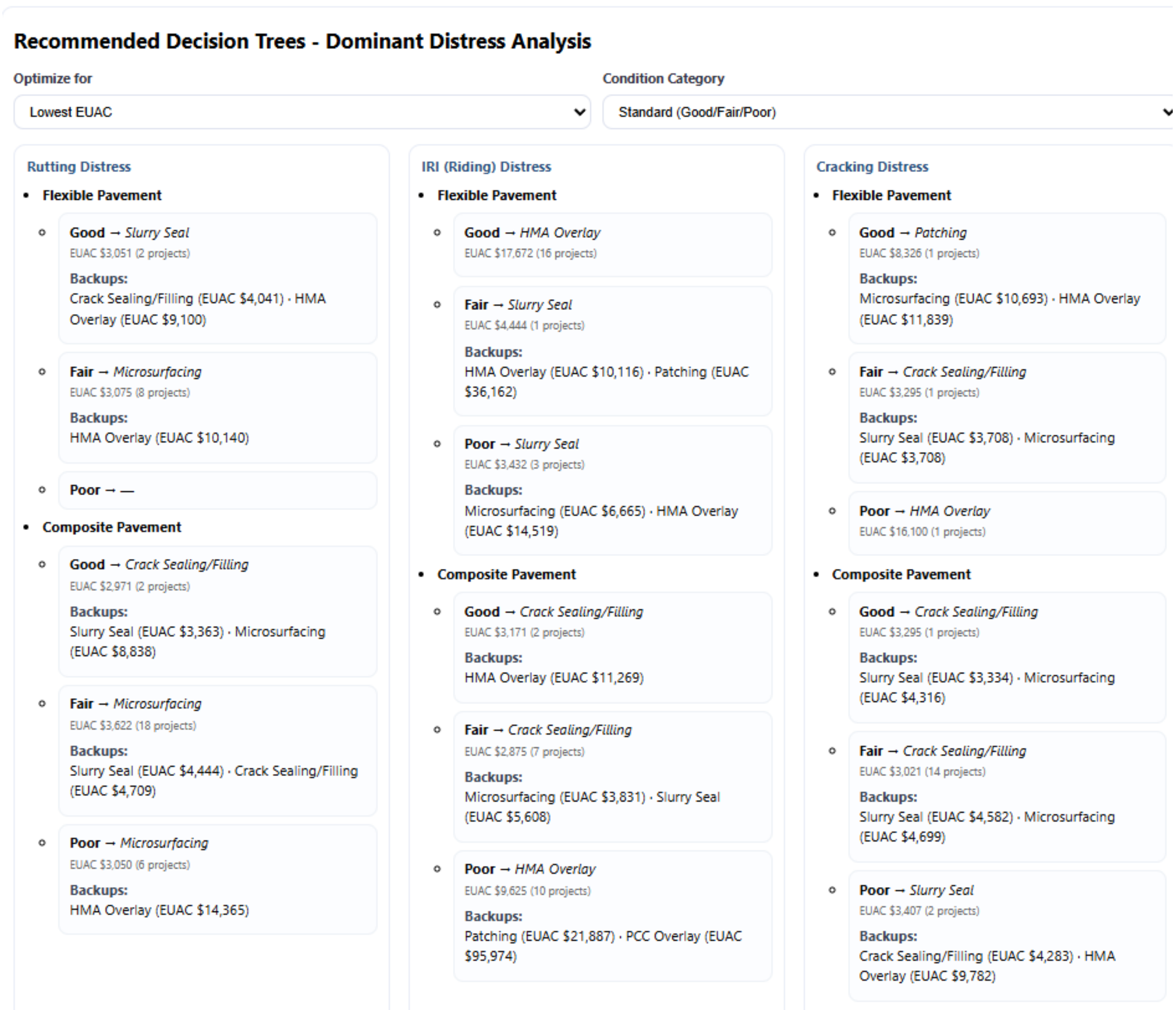


Figure 32. Example of the Dominant Distress section of the dashboard

This section provides two dropdown controls that allow the user to configure the recommendations before viewing them. The first dropdown lets the decision-maker choose between two optimization objectives: Lowest EUAC, which prioritizes minimizing annualized cost, or Highest BCR, which prioritizes maximizing return on investment. The second dropdown allows the user to select the pavement condition classification scheme, with options including the standard three-tier good/fair/poor system or alternative categorizations depending on the data available.

Once configured, the recommendations are organized into three distress columns covering rutting, IRI/riding, and cracking distress, and within each column the results are further divided by pavement family into flexible and composite pavement types. This structure allows decision-makers to target treatments based on the specific failure mode observed in the field rather than relying solely on the composite PCI score. For each distress-pavement family-condition combination, the primary recommended treatment is listed along with its EUAC (or BCR, depending on the selected objective) and the number of historical PMIS projects supporting that recommendation, providing transparency about the empirical basis of each suggestion.

Ranked backup alternatives are also provided for each cell. As shown in Figure 32, each primary recommendation is followed by the next best treatments listed in order, along with their respective EUAC values. This ranked structure gives practitioners meaningful flexibility when the primary recommendation is not feasible due to cost constraints, contractor availability, material supply, or site-specific conditions. Rather than presenting a single rigid prescription, the decision framework functions as a tiered guide that supports informed professional judgment while keeping all recommendations grounded in empirical performance data from the Iowa highway network.

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APPENDIX: ADDITIONAL INFORMATION FOR PAVEMENT PRESERVATION TREATMENT SELECTION

Table 32. LCCA result for flexible pavement with 10-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	4.0	190.5	5.2	6277	0.0114
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	17.0	2.0	63.3	4.2	8005	0.0052
			Fair	11.9	19.0	114.5	4.1	8044	0.0096
		Medium	Good	6.0	1.0	42.3	3.0	10171	0.0051
			Fair	13.0	4.0	250.0	6.6	5846	0.0116
		High	Good	4.7	3.0	3.5	1.0	25245	0.0014
			Fair	13.0	3.0	200.7	6.2	5939	0.0099
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	9.0	2.0	12.1	2.0	14670	0.0021
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	6.0	1.0	0.0	0.0	2848	NA
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.6	5.0	107.0	5.6	2703	0.0135
			Fair	6.4	5.0	216.7	8.5	1974	0.0209
		Medium	Good	7.0	1.0	0.0	0.0	1974	NA
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	10.0	4.0	34.7	1.3	55430	0.0039
		Medium	Good	-	-	-	-	-	-
			Fair	12.5	2.0	248.5	7.1	13729	0.0044
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	3.0	1.0	93.2	4.9	4107	0.0117
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	6.5	2.0	278.9	5.5	3539	0.0275
			Fair	12.0	3.0	135.0	5.7	3517	0.0128
		Medium	Good	-	-	-	-	-	-
			Fair	12.3	3.0	22.2	2.0	6709	0.0083
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	3.0	2.0	89.1	7.9	18793	0.0010
			Fair	7.7	17.0	453.0	10.3	12398	0.0035
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	10.7	7.0	133.8	5.1	22341	0.0023
			Fair	9.4	61.0	486.3	9.0	17915	0.0048
		Medium	Good	9.0	3.0	205.4	5.6	21460	0.0032
			Fair	8.8	12.0	527.7	13.2	10451	0.0034
		High	Good	7.4	10.0	325.6	8.4	18384	0.0035
			Fair	8.9	12.0	392.0	7.9	18811	0.0044
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	8.0	2.0	169.7	7.2	19432	0.0021
			Fair	8.8	10.0	830.5	15.2	9528	0.0049
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	3.0	73.5	3.4	5468	0.0116
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	12.2	6.0	129.4	5.4	4260	0.0107
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 33. LCCA result for flexible pavement with 15-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	4.0	190.5	5.2	6488	0.0166
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	17.0	2.0	63.3	4.2	7778	0.0074
			Fair	11.9	19.0	114.5	4.1	7812	0.0138
		Medium	Good	6.0	1.0	42.3	3.0	9374	0.0075
			Fair	13.0	4.0	250.0	6.6	6146	0.0166
		High	Good	4.7	3.0	3.5	1.0	24730	0.0021
			Fair	13.0	3.0	200.7	6.2	6223	0.0142
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	9.0	2.0	12.1	2.0	13451	0.0035
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	6.0	1.0	0.0	0.0	2727	NA
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.6	5.0	107.0	5.6	2131	0.0256
			Fair	6.4	5.0	216.7	8.5	2131	0.0225
		Medium	Good	7.0	1.0	0.0	0.0	2131	NA
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	10.0	4.0	34.7	1.3	55724	0.0058
		Medium	Good	-	-	-	-	-	-
			Fair	12.5	2.0	248.5	7.1	14406	0.0063
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	3.0	1.0	93.2	4.9	4134	0.0163
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	6.5	2.0	278.9	5.5	3725	0.0392
			Fair	12.0	3.0	135.0	5.7	3708	0.0182
		Medium	Good	-	-	-	-	-	-
			Fair	12.3	3.0	22.2	2.0	6353	0.0136
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	3.0	2.0	89.1	7.9	15939	0.0014
			Fair	7.7	17.0	453.0	10.3	14380	0.0054
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	10.7	7.0	133.8	5.1	22708	0.0034
			Fair	9.4	61.0	486.3	9.0	15131	0.0066
		Medium	Good	9.0	3.0	205.4	5.6	22030	0.0047
			Fair	8.8	12.0	527.7	13.2	13155	0.0049
		High	Good	7.4	10.0	325.6	8.4	15562	0.0048
			Fair	8.9	12.0	392.0	7.9	15956	0.0061
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	8.0	2.0	169.7	7.2	20379	0.0030
			Fair	8.8	10.0	830.5	15.2	9599	0.0057
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	3.0	73.5	3.4	5923	0.0171
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	12.2	6.0	129.4	5.4	4458	0.0154
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 34. LCCA result for flexible pavement with 20-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	4.0	190.5	5.2	6600	0.0217
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	17.0	2.0	63.3	4.2	7649	0.0097
			Fair	11.9	19.0	114.5	4.1	7682	0.0180
		Medium	Good	6.0	1.0	42.3	3.0	9736	0.0099
			Fair	13.0	4.0	250.0	6.6	6270	0.0216
		High	Good	4.7	3.0	3.5	1.0	24485	0.0028
			Fair	13.0	3.0	200.7	6.2	6346	0.0185
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	9.0	2.0	12.1	2.0	13884	0.0044
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	6.0	1.0	0.0	0.0	3108	NA
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.6	5.0	107.0	5.6	2857	0.0255
			Fair	6.4	5.0	216.7	8.5	2206	0.0311
		Medium	Good	7.0	1.0	0.0	0.0	2206	NA
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	10.0	4.0	34.7	1.3	55896	0.0077
		Medium	Good	-	-	-	-	-	-
			Fair	12.5	2.0	248.5	7.1	12618	0.0081
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	3.0	1.0	93.2	4.9	4133	0.0209
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	6.5	2.0	278.9	5.5	3816	0.0510
			Fair	12.0	3.0	135.0	5.7	3800	0.0237
		Medium	Good	-	-	-	-	-	-
			Fair	12.3	3.0	22.2	2.0	6562	0.0169
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	3.0	2.0	89.1	7.9	17172	0.0018
			Fair	7.7	17.0	453.0	10.3	13034	0.0067
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	10.7	7.0	133.8	5.1	22948	0.0045
			Fair	9.4	61.0	486.3	9.0	16446	0.0087
		Medium	Good	9.0	3.0	205.4	5.6	22310	0.0062
			Fair	8.8	12.0	527.7	13.2	11905	0.0060
		High	Good	7.4	10.0	325.6	8.4	16838	0.0063
			Fair	8.9	12.0	392.0	7.9	17187	0.0081
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	8.0	2.0	169.7	7.2	17679	0.0039
			Fair	8.8	10.0	830.5	15.2	11318	0.0082
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	3.0	73.5	3.4	5744	0.0221
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	12.2	6.0	129.4	5.4	4555	0.0201
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 35. LCCA result for flexible pavement with 30-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	4.0	190.5	5.2	5986	0.0360
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	17.0	2.0	63.3	4.2	7949	0.0145
			Fair	11.9	19.0	114.5	4.1	7987	0.0270
		Medium	Good	6.0	1.0	42.3	3.0	9563	0.0147
			Fair	13.0	4.0	250.0	6.6	5915	0.0309
		High	Good	4.7	3.0	3.5	1.0	24218	0.0043
			Fair	13.0	3.0	200.7	6.2	5986	0.0265
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	9.0	2.0	12.1	2.0	13616	0.0067
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	6.0	1.0	0.0	0.0	3186	NA
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.6	5.0	107.0	5.6	2895	0.0377
			Fair	6.4	5.0	216.7	8.5	2285	0.0420
		Medium	Good	7.0	1.0	0.0	0.0	2285	NA
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	10.0	4.0	34.7	1.3	55891	0.0115
		Medium	Good	-	-	-	-	-	-
			Fair	12.5	2.0	248.5	7.1	13364	0.0121
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	3.0	1.0	93.2	4.9	4120	0.0301
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	6.5	2.0	278.9	5.5	3893	0.0749
			Fair	12.0	3.0	135.0	5.7	3877	0.0349
		Medium	Good	-	-	-	-	-	-
			Fair	12.3	3.0	22.2	2.0	6512	0.0255
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	3.0	2.0	89.1	7.9	16306	0.0027
			Fair	7.7	17.0	453.0	10.3	13133	0.0099
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	10.7	7.0	133.8	5.1	23024	0.0067
			Fair	9.4	61.0	486.3	9.0	15623	0.0128
		Medium	Good	9.0	3.0	205.4	5.6	22360	0.0093
			Fair	8.8	12.0	527.7	13.2	12108	0.0089
		High	Good	7.4	10.0	325.6	8.4	15994	0.0093
			Fair	8.9	12.0	392.0	7.9	16319	0.0120
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	8.0	2.0	169.7	7.2	18750	0.0058
			Fair	8.8	10.0	830.5	15.2	9921	0.0110
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	13.0	3.0	73.5	3.4	5820	0.0327
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	12.2	6.0	129.4	5.4	4632	0.0296
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 36. LCCA result for composite pavement with 10-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	14.0	3	22.0	3.7	8,270	0.002091
			Fair	13.7	36	144.9	4.5	7,854	0.010791
		Medium	Good	11.7	3	58.1	4.0	8,079	0.004946
			Fair	11.8	13	152.7	5.7	6,087	0.008226
		High	Good	5.1	53	46.4	2.1	12,561	0.008491
			Fair	9.8	17	311.0	6.9	5,755	0.013590
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	4.7	3	25.6	2.0	14,670	0.004357
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.0	7	151.9	5.0	3,175	0.024690
			Fair	6.1	16	215.5	7.0	2,766	0.019414
		Medium	Good	6.3	4	61.4	3.1	3,678	0.019383
			Fair	6.9	17	154.3	5.2	2,881	0.020392
		High	Good	6.0	4	0.2	1.4	5,507	0.000191
			Fair	6.0	3	93.4	3.0	3,690	0.030540
	High	Low	Good	-	-	-	-	-	-
			Fair	7.0	4	168.6	7.5	2,743	0.013910
		Medium	Good	6.0	2	0.3	5.0	2,895	0.000047
			Fair	3.5	2	0.0	0.0	1,974	NA
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	7.0	2	27.4	2.0	41,885	0.001633
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	11.0	2	0.0	0.0	27,758	NA
			Fair	7.0	14	70.9	3.0	34,461	0.002540
		Medium	Good	7.0	2	3.2	2.4	28,537	0.000225
			Fair	8.7	11	36.3	2.7	27,751	0.001886
		High	Good	6.0	2	5.4	3.0	1,974	0.003358
			Fair	9.5	2	0.0	0.0	#VALUE!	NA
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.5	2	42.8	2.0	6,709	0.015939
			Fair	16.3	10	35.9	1.6	7,445	0.020330
		Medium	Good	-	-	-	-	-	-
			Fair	19.0	2	61.7	2.0	6,709	0.022982
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	1.0	1	91.3	11.3	11,587	0.000659
HMA Overlay	Low	Low	Fair	6.6	19	491.8	12.3	10,944	0.003346
HMA Overlay	Low	Medium	Good	-	-	-	-	-	-
HMA Overlay	Low	Medium	Fair	-	-	-	-	-	-
HMA Overlay	Low	High	Good	-	-	-	-	-	-
HMA Overlay	Low	High	Fair	-	-	-	-	-	-
HMA Overlay	Medium	Low	Good	7.7	23	134.9	5.9	21,004	0.002013
HMA Overlay	Medium	Low	Fair	9.3	302	370.8	9.7	17,422	0.003403
HMA Overlay	Medium	Medium	Good	9.3	26	73.4	4.2	30,229	0.001571
HMA Overlay	Medium	Medium	Fair	8.9	253	377.3	10.0	17,294	0.003393
HMA Overlay	Medium	High	Good	7.9	51	137.8	6.9	19,758	0.001765
HMA Overlay	Medium	High	Fair	8.7	137	384.1	10.8	11,970	0.002867
HMA Overlay	High	Low	Good	-	-	-	-	-	-
HMA Overlay	High	Low	Fair	6.3	3	405.4	7.6	19,096	0.004756
HMA Overlay	High	Medium	Good	-	-	-	-	-	-
HMA Overlay	High	Medium	Fair	7.1	8	358.6	8.3	18,452	0.003843
HMA Overlay	High	High	Good	11.3	13	45.3	4.1	30,355	0.000985
HMA Overlay	High	High	Fair	10.3	56	390.4	9.3	17,740	0.003763
Seal Coat	Low	Low	Good	-	-	-	-	-	-
Seal Coat	Low	Low	Fair	12.0	1	306.8	5.9	4,172	0.023026
Seal Coat	Low	Medium	Good	-	-	-	-	-	-
Seal Coat	Low	Medium	Fair	-	-	-	-	-	-
Seal Coat	Low	High	Good	-	-	-	-	-	-
Seal Coat	Low	High	Fair	-	-	-	-	-	-
Seal Coat	Medium	Low	Good	-	-	-	-	-	-
Seal Coat	Medium	Low	Fair	15.0	3	83.2	6.7	4,054	0.005395
Seal Coat	Medium	Medium	Good	-	-	-	-	-	-
Seal Coat	Medium	Medium	Fair	-	-	-	-	-	-
Seal Coat	Medium	High	Good	-	-	-	-	-	-
Seal Coat	Medium	High	Fair	-	-	-	-	-	-
Seal Coat	High	Low	Good	-	-	-	-	-	-
Seal Coat	High	Low	Fair	-	-	-	-	-	-
Seal Coat	High	Medium	Good	-	-	-	-	-	-
Seal Coat	High	Medium	Fair	-	-	-	-	-	-
Seal Coat	High	High	Good	-	-	-	-	-	-
Seal Coat	High	High	Fair	-	-	-	-	-	-

Table 37. LCCA result for composite pavement with 15-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	14.0	3	22.0	3.7	8,996	0.003066
			Fair	13.7	36	144.9	4.5	7,646	0.015484
		Medium	Good	11.7	3	58.1	4.0	7,843	0.007140
			Fair	11.8	13	152.7	5.7	6,341	0.011846
		High	Good	5.1	53	46.4	2.1	13,308	0.012470
			Fair	9.8	17	311.0	6.9	6,071	0.019324
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	4.7	3	25.6	2.0	13,451	0.007386
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.0	7	151.9	5.0	3,259	0.033514
			Fair	6.1	16	215.5	7.0	2,957	0.027239
		Medium	Good	6.3	4	61.4	3.1	3,637	0.026464
			Fair	6.9	17	154.3	5.2	3,049	0.028905
		High	Good	6.0	4	0.2	1.4	5,432	0.000277
			Fair	6.0	3	93.4	3.0	3,648	0.041759
	High	Low	Good	-	-	-	-	-	-
			Fair	7.0	4	168.6	7.5	3,024	0.014870
		Medium	Good	6.0	2	0.3	5.0	3,059	0.000067
			Fair	3.5	2	0.0	0.0	2,131	NA
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
Patching	Low	Low	Fair	7.0	2	27.4	2.0	37,717	0.002819
Patching	Low	Medium	Good	-	-	-	-	-	-
Patching	Low	Medium	Fair	-	-	-	-	-	-
Patching	Low	High	Good	-	-	-	-	-	-
Patching	Low	High	Fair	-	-	-	-	-	-
Patching	Medium	Low	Good	11.0	2	0.0	0.0	28,150	NA
Patching	Medium	Low	Fair	7.0	14	70.9	3.0	33,117	0.003965
Patching	Medium	Medium	Good	7.0	2	3.2	2.4	28,870	0.000320
Patching	Medium	Medium	Fair	8.7	11	36.3	2.7	28,792	0.002727
Patching	Medium	High	Good	6.0	2	5.4	3.0	2,131	0.004206
Patching	Medium	High	Fair	9.5	2	0.0	0.0	2,131	NA
Patching	High	Low	Good	-	-	-	-	-	-
Patching	High	Low	Fair	-	-	-	-	-	-
Patching	High	Medium	Good	-	-	-	-	-	-
Patching	High	Medium	Fair	-	-	-	-	-	-
Patching	High	High	Good	-	-	-	-	-	-
Patching	High	High	Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
Slurry Seal	Low	Low	Fair	-	-	-	-	-	-
Slurry Seal	Low	Medium	Good	-	-	-	-	-	-
Slurry Seal	Low	Medium	Fair	-	-	-	-	-	-
Slurry Seal	Low	High	Good	-	-	-	-	-	-
Slurry Seal	Low	High	Fair	-	-	-	-	-	-
Slurry Seal	Medium	Low	Good	5.5	2	42.8	2.0	6,353	0.026166
Slurry Seal	Medium	Low	Fair	16.3	10	35.9	1.6	7,408	0.029816
Slurry Seal	Medium	Medium	Good	-	-	-	-	-	-
Slurry Seal	Medium	Medium	Fair	19.0	2	61.7	2.0	6,353	0.037727
Slurry Seal	Medium	High	Good	-	-	-	-	-	-
Slurry Seal	Medium	High	Fair	-	-	-	-	-	-
Slurry Seal	High	Low	Good	-	-	-	-	-	-
Slurry Seal	High	Low	Fair	-	-	-	-	-	-
Slurry Seal	High	Medium	Good	-	-	-	-	-	-
Slurry Seal	High	Medium	Fair	-	-	-	-	-	-
Slurry Seal	High	High	Good	-	-	-	-	-	-
Slurry Seal	High	High	Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	1.0	1	91.3	11.3	13,886	0.000983
			Fair	6.6	19	491.8	12.3	13,479	0.004886
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	7.7	23	134.9	5.9	21,671	0.002927
			Fair	9.3	302	370.8	9.7	14,680	0.004644
		Medium	Good	9.3	26	73.4	4.2	28,590	0.002325
			Fair	8.9	253	377.3	10.0	14,563	0.004624
		High	Good	7.9	51	137.8	6.9	20,655	0.002533
			Fair	8.7	137	384.1	10.8	14,122	0.004332
	High	Low	Good	-	-	-	-	-	-
			Fair	6.3	3	405.4	7.6	16,219	0.006595
		Medium	Good	-	-	-	-	-	-
			Fair	7.1	8	358.6	8.3	15,625	0.005297
		High	Good	11.3	13	45.3	4.1	28,700	0.001459
			Fair	10.3	56	390.4	9.3	14,971	0.005152
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	12.0	1	306.8	5.9	4,389	0.032836
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	15.0	3	83.2	6.7	4,292	0.007642
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 38. LCCA result for composite pavement with 20-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	14.0	3	22.0	3.7	8,604	0.004020
			Fair	13.7	36	144.9	4.5	7,518	0.020219
		Medium	Good	11.7	3	58.1	4.0	7,711	0.009342
			Fair	11.8	13	152.7	5.7	6,460	0.015501
		High	Good	5.1	53	46.4	2.1	12,865	0.016580
			Fair	9.8	17	311.0	6.9	5,550	0.023779
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	4.7	3	25.6	2.0	13,884	0.009207
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.0	7	151.9	5.0	3,291	0.042553
			Fair	6.1	16	215.5	7.0	2,907	0.031157
		Medium	Good	6.3	4	61.4	3.1	3,771	0.034974
			Fair	6.9	17	154.3	5.2	3,132	0.037523
		High	Good	6.0	4	0.2	1.4	5,573	0.000364
			Fair	6.0	3	93.4	3.0	3,783	0.055164
	High	Low	Good	-	-	-	-	-	-
			Fair	7.0	4	168.6	7.5	2,889	0.022168
		Medium	Good	6.0	2	0.3	5.0	3,141	0.000086
			Fair	3.5	2	0.0	0.0	2,206	NA
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	7.0	2	27.4	2.0	38,916	0.003515
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	11.0	2	0.0	0.0	25,893	NA
			Fair	7.0	14	70.9	3.0	32,434	0.005000
		Medium	Good	7.0	2	3.2	2.4	29,026	0.000416
			Fair	8.7	11	36.3	2.7	25,886	0.004044
		High	Good	6.0	2	5.4	3.0	2,206	0.005565
			Fair	9.5	2	0.0	0.0	2,206	NA
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.5	2	42.8	2.0	6,562	0.032595
			Fair	16.3	10	35.9	1.6	7,389	0.039296
		Medium	Good	-	-	-	-	-	-
			Fair	19.0	2	61.7	2.0	6,562	0.046997
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

HMA Overlay	Low	Low	Good	1.0	1	91.3	11.3	12,577	0.001214
			Fair	6.6	19	491.8	12.3	12,203	0.006003
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	7.7	23	134.9	5.9	21,963	0.003850
			Fair	9.3	302	370.8	9.7	16,021	0.006105
		Medium	Good	9.3	26	73.4	4.2	27,707	0.003084
			Fair	8.9	253	377.3	10.0	15,908	0.006077
		High	Good	7.9	51	137.8	6.9	17,932	0.003284
			Fair	8.7	137	384.1	10.8	12,795	0.005365
	High	Low	Good	-	-	-	-	-	-
			Fair	6.3	3	405.4	7.6	17,415	0.008749
		Medium	Good	-	-	-	-	-	-
			Fair	7.1	8	358.6	8.3	16,895	0.006998
		High	Good	11.3	13	45.3	4.1	27,815	0.001936
			Fair	10.3	56	390.4	9.3	16,296	0.006781
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	12.0	1	306.8	5.9	4,489	0.042804
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	15.0	3	83.2	6.7	4,042	0.009150
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 39. LCCA result for composite pavement with 30-year analysis period

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Microsurfacing	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	14.0	3	22.0	3.7	8,662	0.005990
			Fair	13.7	36	144.9	4.5	7,357	0.029805
		Medium	Good	11.7	3	58.1	4.0	8,021	0.013963
			Fair	11.8	13	152.7	5.7	6,532	0.022997
		High	Good	5.1	53	46.4	2.1	12,912	0.024781
			Fair	9.8	17	311.0	6.9	5,843	0.035971
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	4.7	3	25.6	2.0	13,616	0.014081
			Fair	-	-	-	-	-	-
Crack Sealing/Filling	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.0	7	151.9	5.0	3,318	0.060779
			Fair	6.1	16	215.5	7.0	3,031	0.047596
		Medium	Good	6.3	4	61.4	3.1	3,795	0.050713
			Fair	6.9	17	154.3	5.2	3,211	0.054898
		High	Good	6.0	4	0.2	1.4	5,595	0.000538
			Fair	6.0	3	93.4	3.0	3,808	0.079992
	High	Low	Good						
			Fair	7.0	4	168.6	7.5	3,034	0.029644
		Medium	Good	6.0	2	0.3	5.0	3,220	0.000126
			Fair	3.5	2	0.0	0.0	2,285	NA
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
Patching	Low	Low	Good	-	-	-	-	-	-
			Fair	7.0	2	27.4	2.0	37,906	0.005413
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	11.0	2	0.0	0.0	26,658	NA
			Fair	7.0	14	70.9	3.0	31,674	0.007884
		Medium	Good	7.0	2	3.2	2.4	29,017	0.000611
			Fair	8.7	11	36.3	2.7	26,798	0.005859
		High	Good	6.0	2	5.4	3.0	2,285	0.007844
			Fair	9.5	2	0.0	0.0	2,285	NA
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
Slurry Seal	Low	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	5.5	2	42.8	2.0	6,512	0.049268
			Fair	16.3	10	35.9	1.6	7,367	0.058282
		Medium	Good	-	-	-	-	-	-
			Fair	19.0	2	61.7	2.0	6,512	0.071036
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Treatment	AADT	Truck Traffic	PCI-Based Condition	Age	No. of Sections	IB	LE	EUAC	BCR
HMA Overlay	Low	Low	Good	1.0	1	91.3	11.3	12,730	0.001800
			Fair	6.6	19	491.8	12.3	12,388	0.008870
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	7.7	23	134.9	5.9	21,992	0.005768
			Fair	9.3	302	370.8	9.7	15,214	0.008961
		Medium	Good	9.3	26	73.4	4.2	28,817	0.004613
			Fair	8.9	253	377.3	10.0	15,104	0.008916
		High	Good	7.9	51	137.8	6.9	19,016	0.004931
			Fair	8.7	137	384.1	10.8	12,924	0.007967
	High	Low	Good	-	-	-	-	-	-
			Fair	6.3	3	405.4	7.6	16,529	0.012942
		Medium	Good	-	-	-	-	-	-
			Fair	7.1	8	358.6	8.3	16,047	0.010316
		High	Good	11.3	13	45.3	4.1	28,941	0.002894
			Fair	10.3	56	390.4	9.3	15,480	0.009965
Seal Coat	Low	Low	Good	-	-	-	-	-	-
			Fair	12.0	1	306.8	5.9	4,562	0.063173
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	Medium	Low	Good	-	-	-	-	-	-
			Fair	15.0	3	83.2	6.7	4,238	0.013886
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
	High	Low	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		Medium	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-
		High	Good	-	-	-	-	-	-
			Fair	-	-	-	-	-	-

Table 40. Flexible – rutting index

Project Family	PCI-Condition Category	Condition Category (Rutting Index)	No. of Sections	Index Benefit	Life Extension
Microsurfacing	Good	Good	6	1.9	0.6
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	11	77.9	3.6
		Fair	13	103.2	6.9
		Poor	1	220.5	8.0
Patching	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	1	0.0	0.0
		Fair	1	0.0	0.0
		Poor	-	-	-
Slurry Seal	Good	Good	1	122.4	4.0
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	2	84.3	2.0
		Fair	3	86.6	2.8
		Poor	-	-	-
Crack Sealing/Filling	Good	Good	2	68.9	10.2
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
HMA Overlay	Good	Good	16	286.3	8.5
		Fair	5	102.6	10.3
		Poor	-	-	-
	Fair	Good	57	281.3	8.5
		Fair	38	493.7	10.3
		Poor	-	-	-
Seal Coat	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	4	66.7	2.5
		Fair	5	72.8	3.2
		Poor	-	-	-

Table 41. Composite – rutting index

Project Family	PCI-Condition Category	Condition Category (Rutting Index)	No. of Sections	Index Benefit	Life Extension
Microsurfacing	Good	Good	42	52.6	2.4
		Fair	5	88.8	3.5
		Poor	-	-	-
	Fair	Good	30	31.6	3.0
		Fair	24	123.0	5.2
		Poor	-	-	-
Patching	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	5	8.8	1.9
		Fair	-	-	-
		Poor	-	-	-
Slurry Seal	Good	Good	2	78.2	2.0
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	8	43.1	2.3
		Fair	2	43.3	2.0
		Poor	-	-	-
Crack Sealing/Filling	Good	Good	11	238.2	5.0
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	14	180.1	3.8
		Fair	1	1.5	2.9
		Poor	-	-	-
HMA Overlay	Good	Good	78	103.1	4.8
		Fair	7	292.2	14.1
		Poor	-	-	-
	Fair	Good	457	202.6	7.8
		Fair	208	472.6	11.4
		Poor	7	488.9	7.0
Seal Coat	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	4	93.9	5.7
		Fair	-	-	-
		Poor	42	52.6	2.4

Table 42. Flexible – cracking index

Project Family	PCI-Condition Category	Condition Category (Cracking Index)	No. of Sections	Index Benefit	Life Extension
Microsurfacing	Good	Good	5	14.4	2.3
		Fair	1	274.5	4.3
		Poor	-	-	-
	Fair	Good	4	98.5	2.0
		Fair	12	139.9	5.7
		Poor	9	220.2	4.7
Patching	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	1	698.9	10.0
		Fair	1	245.9	8.0
		Poor	-	-	-
Slurry Seal	Good	Good	1	0.0	0.0
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	1	0.0	0.0
		Fair	4	99.3	2.7
		Poor	-	-	-
Crack Sealing/Filling	Good	Good	2	306.6	7.5
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
HMA Overlay	Good	Good	21	105.1	6.4
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	25	464.2	9.9
		Fair	50	612.0	10.6
		Poor	20	688.1	9.9
Seal Coat	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	4	66.7	2.9
		Fair	5	72.8	4.6
		Poor	-	-	-

Table 43. Composite – cracking index

Project Family	PCI-Condition Category	Condition Category (Cracking Index)	No. of Sections	Index Benefit	Life Extension
Microsurfacing	Good	Good	46	82.9	2.9
		Fair	1	87.1	4.2
		Poor	-	-	-
	Fair	Good	6	23.0	2.4
		Fair	31	240.2	6.1
		Poor	17	297.3	5.9
Patching	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	3	63.5	4.0
		Fair	2	151.5	5.0
		Poor	-	-	-
Slurry Seal	Good	Good	1	0.0	0.0
		Fair	1	163.2	6.5
		Poor	-	-	-
	Fair	Good	-	-	-
		Fair	5	90.9	4.0
		Poor	5	30.5	2.0
Crack Sealing/Filling	Good	Good	11	153.6	6.9
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	3	0.0	0.0
		Fair	11	373.0	9.4
		Poor	1	606.2	16.0
HMA Overlay	Good	Good	84	117.8	4.8
		Fair	1	1.4	3.2
		Poor	-	-	-
	Fair	Good	395	219.0	6.2
		Fair	210	428.1	8.6
		Poor	60	556.5	8.7
Seal Coat	Good	Good	-	-	-
		Fair	-	-	-
		Poor	-	-	-
	Fair	Good	-	-	-
		Fair	3	416.8	7.6
		Poor	1	211.5	7.4

Table 44. Iowa DOT bid tabulation line items

Preservation	Bid-Line Item	Unit	Item Code
Microsurfacing	AGGREGATE FOR MICROSURFACING, FRICTION L-2	Ton	2320-0000002
	AGGREGATE FOR MICROSURFACING, FRICTION L-4	Ton	2320-0000004
	AGGREGATE FOR MICROSURFACING, NO SPECIAL FRICTION REQUIREMENT	Ton	2320-0000005
	PREPARATION OF SURFACE FOR MICROSURFACING	Mile	2320-0000020
	PAINTED PAVEMENT MARKINGS	Stations	2527-9263109
	EMULSIFIED ASPHALT FOR MICROSURFACING	Gallon	2320-0000030
	TRAFFIC CONTROL	Lump Sum	2528-8445110
	MOBILIZATION	Lump Sum	2533-4980005
Slurry Seal	SLURRY LEVELING	Mile	2319-1000000
	PAINTED PAVEMENT MARKINGS	Stations	2527-9263109
	SURFACE PREPARATION FOR SLURRY WEDGE	Mile	2319-2000200
	STRIP SLURRY TREATMENT COARSE AGGREGATE	Ton	2319-3000101
	STRIP SLURRY TREATMENT FINE AGGREGATE	Ton	2319-3000102
	SURFACE PREPARATION FOR STRIP SLURRY TREATMENT	Mile	2319-3000200
	ASPHALT EMULSION FOR SLURRY LEVELING, SLURRY WEDGE, AND SLURRY TREATMENT	Gallon	2319-4000000
	TRAFFIC CONTROL	Lump Sum	2528-8445110
	FLAGGERS	Each	2528-8445113
	PILOT CARS	Each	2528-8445115
	MOBILIZATION	Lump Sum	2533-4980005

Preservation	Bid-Line Item	Unit	Item Code
Patching	CLEANING AND PREPARATION OF BASE	Mile	2212-0475095
	PATCHES, FULL-DEPTH REPAIR	Square Yard	2212-5070310
	PATCHES BY COUNT (REPAIR)	Each	2212-5070330
	PAVEMENT SCARIFICATION	Square Yard	2214-5145150
	PATCHES, FULL-DEPTH FINISH, BY AREA	Square Yard	2529-5070110
	PATCHES, FULL-DEPTH FINISH, BY COUNT	Each	2529-5070120
	HOT MIX ASPHALT SURFACE PATCHES	Ton	2212-5075001
	SUBBASE (PATCHES)	Square Yard	2529-8174010
	TRAFFIC CONTROL	Lump Sum	2528-8445110
	FLAGGERS	Each	2528-8445113
	MOBILIZATION	Lump Sum	2533-4980005
	PATCHES, PARTIAL-DEPTH REPAIR, HOT MIX ASPHALT	Square Yard	2212-5070322
	PAINTED PAVEMENT MARKINGS (If needed)	Stations	2527-9263109
Crack Sealing/Filling	CRACK AND JOINT CLEANING AND SEALING (HMA SURFACES)	Mile	2541-1004011
	SEALER MATERIAL (HMA SURFACES)	Pound (lb)	2541-1005001
	CLEANING AND FILLING CRACKS (PAVEMENT MAINTENANCE)	Mile	2544-1001100
	FILLER MATERIAL (MAINTENANCE)	Gallon	2544-1003000
	PAINTED PAVEMENT MARKINGS (If needed)	Stations	2527-9263109
	FLAGGERS	Each	2528-8445113
	TRAFFIC CONTROL	Lump Sum	2528-8445110
	MOBILIZATION	Lump Sum	2533-4980005

Preservation	Bid-Line Item	Unit	Item Code
HMA Overlay	HMA THIN LIFT SURFACE, 3/8"	Ton	2303-0003380
	ASPH BINDER, PG 64-34E+	Ton	2303-1264347
	ASPHALT BINDER, PG 58-34E+, EXTREMELY HIGH TRAFFIC, 90% ELASTIC RECOVERY	Ton	2303-1258347
	ASPHALT BINDER, PG 58-34E, EXTREMELY HIGH TRAFFIC	Ton	2303-1258346
	PILOT CAR	Each	2528-8445115
	FLAGGER	Each	2528-8445113
	TRAFFIC CONTROL	Lump Sum	2528-8445110
	MOBILIZATION	Lump Sum	2533-4980005

Table 45. Cost breakdown based on project number for microsurfacing

Contract ID	Lane-Mile	Price per Lane-Mile
08-0304-108	62	9843.439113
43-1831-050	30.4	13868.59898
65-0294-708	16	16038.22344
70-0068-045	20.4	27022.52853
77-0801-716	12	16547.419
88-0254-708	13.8	25459.50906
91-0355-712	43.6	13704.04592
67-0293-723	32.4	18939.76173
2022	**Average**	**17677.94072**
56-0611-189	20.8	28067.84327
36-0291-118	17.6	30232.44341
23-C023-124	7.8	19303.14615
17-0357-074	214.4	17272.28814
77-0804-094	4	51366.18125
77-0801-715	50	7498.796872
01-0253-035	24.2	19483.171
56-0029-032	68.8	23180.18122
77-0354-296	1.3	51720.38558
2021	**Average**	**27569.38188**
95-0699-047	10.4	27382.00204
99-0172-709	50	9237.43764
98-0358-051	186	9392.05871
2020	**Average**	**15337.16613**

Contract ID	Lane-Mile	Price per Lane-Mile
26-0028-037	80.4	9019.888396
85-0351-713	25	24691.27
35-0356-132	342	2315.76
41-0182-712	19.74	30947.37791
17-1222-713	13.6	17089.3375
47-0596-045	24.8	11497.28528
48-0806-394	4.8	176589.1583
74-0045-045	37.48	19294.06902
88-C088-060	11.92	24143.85193
2019	**Average**	**35065.33315**
97-0311-045	9.4	21065.55316
40-0351-706	56.8	11742.58099
11-0032-072	28.4	22890.26286
35-0356-131	81.92	16378.61078
85-0651-701	8.8	31230.91932
67-0295-256	99.2	8458.88876
61-C061-111	7.42	30169.37898
61-C061-112	11.33	32381.92145
61-C061-113	9.12	26773.40702
15-0484-701	11.2	9010.694696
79-0801-706	18.2	28524.48022
88-C088-057	80.24	12852.22698
2018	**Average**	**20956.5771**
08-0304-090	62	5971.831613
13-0043-035	33.2	16381.1558
60-0091-048	27.2	17521.99743
92-0222-076	25.2	9551.175865
17-0357-071	125.17757	17263.894
35-0352-724	37.51548	12037.18076
15-1484-707	13.8	15831.98478
79-0801-705	18.2	26532.82692
89-0029-031	52.4	12977.48612
17-0352-725	27.4	10272.8727
2017	**Average**	**14434.2406**
36-0021-104	7.8	18247.64487
98-0358-050	55.76	16337.56689
38-0572-705	No data	No data
36-0024-713	4	13860.26925
2016	**Average**	**16148.49367**

Contract ID	Lane-Mile	Price per Lane-Mile
35-0352-721	24.4	10895.07541
97-0293-713	56	6927.718304
02-1484-704	22	16264.99634
17-0658-056	11.4	56535.29982
66-2182-710	22.6	13119.29093
54-0781-019	72.8	15050.74491
48-0806-715-A	22	19090.9088
81-1103-702	3	38167.59213
99-0692-705	12.3	15899.49695
73-C073-125-A	15	42315.049
24-0302-158	21.16	38420.92977
11-0717-055	19.06	10935.88017
24-1413-065	28.6	24312.58042
52-0223-011	39.6	5077.602588
35-0352-719	32.44	7883.420623
60-0091-046	26.54	22862.05576
01-0804-712-A	49.6	9346.609052
2015	**Average**	**20770.89712**
Average cost per lane mile		**20995**

Table 46. Cost breakdown based on project number for crack filling and sealing

Contract ID	Lane-Mile	Price per Lane-Mile
31-1366-704	102.493	4804.484648
22-0132-714	147.92	7024.62571
41-0182-713	52.4	5417.996183
01-C001-120	77.8	3055.461028
77-0801-718-A	90	3092.495
08-0171-715	3	11047.16111
16-0806-713	50	8343.062
42-1751-712	19.24	4157.644262
2022	**Average**	**5867.866243**

Contract ID	Lane-Mile	Price per Lane-Mile
31-1516-705	119.57	3647.209563
45-0632-707	120.4	5780.20515
98-0092-704	172.98	5460.378656
04-0025-708	49.2	6882.760793
54-1495-714	25.4	9069.478449
70-0225-703	69	5872.884232
77-2351-707	24	4176.5
17-0352-731	60	3270.035033
2021	**Average**	**5519.931485**
07-0202-710	174.8	3453.572998
49-0526-717	84.1	3520.903686
92-0015-712	22	7728.435045
93-0655-707	134.8	4633.052092
63-C063-133	33.4	3110.05988
62-1461-701	82.8	3743.928357
77-0061-725	97.8	2092.203477
85-0691-712	172.6	3425.61066
00-0003-736	65.4	4063.888379
01-C001-110	20.8	2810.892308
91-0655-710	5.1	18474.4549
2020	**Average**	**5187.000162**
82-4616-703	14.6	5834.246575
91-0355-711	52	2361.627308
04-C004-107	102.8	2893.785603
07-2182-713	102.6	1863.031238
12-0142-709	215.5	4491.90877
22-0182-703	19.6	5919.468549
85-2101-704	24.2	2865.743802
35-0352-725	90.4	2075.254425
2019	**Average**	**3538.133284**

Contract ID	Lane-Mile	Price per Lane-Mile
49-0646-711	6.6	4458.607456
92-0016-712	18.75	4050.721384
03-0762-708	23.29333333	3555.318611
17-0652-713	20.8	4813.201923
00-0003-730	242.4	2910.354785
63-C063-130	25	2478.28
70-0065-702	113.6	5533.005018
45-0092-709	44.4	3498.873874
48-0806-719	6.9	2375.492754
2018	**Average**	**3741.539534**
00-0003-727	127.6	1350.149687
01-C001-099	51.4	2651.819066
33-0032-706	89.2	2600.526906
29-0345-704	43.6	4575.860092
63-C063-126	16.02	4339.450687
57-3806-720	72	1563.055556
17-0352-726	6.9	4178.043478
31-0526-719	16.6	2805.48223
2017	**Average**	**3008.048463**
27-0695-705	23.1	4629.62624
39-0041-701	38.8	4122.139175
50-0061-708	32.8	5754.786585
57-3806-718	32.4	5027.82716
27-0351-143	91.6	2834.307112
2016	**Average**	**4473.737255**
00-0003-719	143.2	3209.979609
00-0003-720	156.8	2798.039381
20-0345-705	70.6	5405.207054
2544-1003000	42.8	5580.559579
99-0172-708	179	3661.512291
57-3806-714-A	32.4	5451.851852
59-0145-703	32.4	4531.36321
77-0651-711	14.2	2794.394366
52-3806-710-A	136	3216.31875
60-0093-707	149.7	2994.06356
2015	**Average**	**3964.328965**
Average cost per lane mile		**4412**

Table 47. Cost breakdown based on project number for patching

Contract ID	Lane-Mile	Price per Lane-Mile
25-2101-003	1.9	104303.7105
26-0631-101	6.8	89786.57353
42-0205-087	10.6	28228.54264
77-1417-064	7.8	155435.4667
98-0659-021	2.178	179148.6841
77-0694-134	3	80312.71833
49-C049-089	2	13300.85943
48-C048-094	12.171	24902.84282
63-0926-039	8.8	61629.78977
08-9300-024	3.6	94610.80333
67-C067-092	11.3	31650.10265
24-0595-063	11.06	40759.35127
40-0696-025	22.8	106596.7967
23-1361-108	8.64	12364.81481
27-0691-060	39.24	22522.5446
59-C059-071	8.68	22571.48387
12-0147-041	0.482	700776.1307
78-0293-238	1.14	679157.4561
12-0571-037	8.18	31392.62983
16-0807-178	28.8	17354.82639
22-0133-050	19.12	42212.25397
25-1694-069	9.5	55468.08505
15-0801-474	38.2	14853.82868
97-0201-175	12.6	37208.77857
08-C008-088	2.302	35602.62163
48-0806-527	111.6	7710.079104
03-0762-063	12.26	38276.91387
51-C051-082	2.22	195887.973
90-1491-090	39.52	22156.05263
44-0784-029-A	11.16	19138.94937
2022	**Average**	**98844.05547**

Contract ID	Lane-Mile	Price per Lane-Mile
01-0802-256-A	23	22763.75061
49-C049-088	8.55	16041.96222
50-0805-381	4.4	60968.27273
50-1171-033	3.8	141988.1421
71-0182-129	2.74	50409.61679
29-8255-609	1.56	155680.9026
31-0618-156	6.5	44456.64769
48-C048-091	4.842	36222.97501
58-C058-062	15.4	95806.26175
93-0651-036	18.66	28242.26615
07-3807-130	19.6	42245.79337
73-6965-617	2.62	157351.6221
78-0594-710	8.44	40630.51896
09-C009-088	0.027	111022.8704
52-2186-704	45.72	2786.790223
21-7170-629	2.2	42966.8
16-C016-111	13.544	34178.84968
40-0355-129	2.8	59216.85714
57-1513-172	20.4	33551.16912
17-4822-638	2.02	394255.9198
18-C018-080	39.6	6257.719444
51-2465-627	1.38	205838.4986
2021	**Average**	**81040.1912**
67-0295-250	6.2	58621.65532
84-0101-081	31.7	26824.67243
85-0655-037	32.4	18838.02481
53-0641-027	13.2	18852.93561
98-0096-081	8.46	43051.58345
49-0642-068	3.34	157008.982
61-C061-117	21.96	20016.13616
24-1920-627	1.6	167026.8975
82-0069-085	6.4	125196.8359
77-1945-847	2.6	41530.25
06-7872-604	2.7	91079.44444
36-2751-041	9.92	26621.97581
74-C074-107	7.8	16876.81603
97-0121-035	3.96	128307.6518
10-0207-042	52.8	13551.74455
2020	**Average**	**63560.37372**

Contract ID	Lane-Mile	Price per Lane-Mile
79-1462-036	9	26486.4
12-0035-085	16.02	31061.43695
85-0354-290	30.4	12355.77303
81-0716-053	17.52	35004.58562
30-C030-057	2.75	10589.81818
36-0021-113	5.86	61580.75939
40-0204-056	9.2	60177.50543
00-0003-732	16.9	10383.20367
13-C013-097	8	15545.997
97-0003-733	1	426044.672
31-0209-253	9.6	58691.38542
65-C065-105	15.202	28629.08262
49-0521-116	6.8	33337.70588
48-2200-018	10.2	26813.01471
85-C085-150	11.152	5754.52161
2019	**Average**	**58260.20334**
49-0521-117	21.6	22534.01204
64-0145-078	6.04	185558.0593
57-0307-197	24.8	63533.38145
78-0061-132	26.2	17187.93053
50-C050-122	23.6	7364.582203
06-0211-703	2.2	45851.81818
06-C006-113	9.54	11595.91195
37-C037-076	4.36	56333.36147
69-0344-704	3.4	18649.9
92-2185-712	11.6	9676.094828
71-0182-115	26.7	24940.97678
71-C071-079	14	7492.737143
00-0006-507	0.4	173803
17-0658-061	2.883	175585.8741
68-C068-083	5.4	34689.31593
2018	**Average**	**56986.46373**

Contract ID	Lane-Mile	Price per Lane-Mile
05-C005-070	10	19406.5992
08-2102-017	11.8	32995.65831
05-C005-068	6.16	38914.21656
11-0717-056	14.08	17982.56641
08-0172-028	30.036	13510.3862
24-0302-166	3.4	82931.83676
62-C062-088-A	4.242	47292.91608
20-0692-024	2.2	81975.36091
22-0132-710	3.378	48548.13499
23-C023-106	6.092	22061.17104
14-0713-706	1.2	185235.5083
52-2184-042	24	27632.65833
63-C063-125	8.738	22891.1783
43-0301-160	9.6	49110.58438
2017	**Average**	**49320.62684**
82-0808-282	41	48296.41941
07-2187-232	8.8	97597.06477
77-8520-010	0.4	200825
97-C097-126	14.096	34071.66934
00-0006-505	0.4	150986.875
15-0801-463	14	21180.89557
04-0051-060	12.8	72507.07234
77-4151-060	12	83652.59167
18-0071-006	28.6	37622.70301
07-2187-231	9.6	45707.51823
69-6360-619-A	2.4	95783.49583
57-0131-052	19	27500.80105
2016	**Average**	**76311.00885**

Contract ID	Lane-Mile	Price per Lane-Mile
67-1751-043	9.8	49389.39388
91-0653-078	2.44	42509.05738
17-0658-056	18	50292.995
28-C028-088	14.282	9241.955608
54-1491-071	1.2	103038.125
64-0961-008	20.2	24995.00495
29-0349-218	8.4	15130.69488
19-0182-707	7.392	22217.08442
29-0349-213-A	46.8	25998.5763
65-C065-098	1.94	64714.12371
06-2186-054	27.4	17495.71898
17-0185-149	5.32	114284.5207
14-1414-028	18.36	28530.8915
2015	**Average**	**43679.8571**
Average cost per lane mile		**66000**

Table 48. Cost breakdown based on project number for slurry sealing

Contract ID	Lane-Mile	Price per Lane-Mile
11-0103-702	48.8	8994.317213
25-0804-719	12.7	5156.17785
32-0152-704	16.6	11532.91416
43-0294-725	48.473333	2920.070718
15-1734-703	11	11636.26391
2022	**Average**	**8047.948769**
83-C083-081	108	976.9425926
78-0594-710	13.2	7532.359848
83-0444-709	31.733333	3868.766736
78-0804-722	51.2	8066.48291
15-0064-706	18.6	4899.741806
2021	**Average**	**5068.858779**
15-0834-705	5	11118.402
36-0294-706	294.8	1835.616401
48-0806-724	48.4	4028.46281
84-0603-703	34	1551.8
2020	**Average**	**4633.570303**

Contract ID	Lane-Mile	Price per Lane-Mile
91-0355-711	37.2	1785.631989
25-1414-710	22.6	7080.012579
36-2754-711	6.4	12135.125
97-0293-722	25	2304.345
65-0294-706	3	9217.36
15-0924-714	15.2	8815.924868
25-0804-716	49.2	6127.745833
78-0294-712	55	2116.649255
88-0344-709	4.6	14890.85065
2019	**Average**	**7293.237418**
83-C083-074	76.5	2661.418301
03-0762-708	29.6	3559.591216
83-0594-709	53.1	4478.628094
43-0295-240	13	9954.790769
07-0212-703	19	7667.903158
97-0293-717	24	3107.067875
2018	**Average**	**5238.233236**
43-1274-705	21.4	4809.326308
01-C001-096	24	4719.459375
25-0804-715	7.8	3129.718974
78-0804-718	58.4	3034.194833
83-C083-068	6	6681.74031
2017	**Average**	**4474.88796**
48-1492-061	20.6	14091.7983
82-0671-144	26.6	13950.58957
00-0003-721	18.4	5506.821467
01-C001-093	14	5024.380893
69-0484-709	23.8	7475.020935
37-1441-713	10	6683.5
53-0386-719	7.8	17304.05128
73-0594-705	38.4	7047.44974
2016	**Average**	**9635.451523**

Contract ID	Lane-Mile	Price per Lane-Mile
06-1512-010	17.8	8463.919404
36-0294-702	39.333333	1972.657785
75-0753-718	8	5376.99375
70-0615-706	18	4937.502778
36-0024-712	2	10444.05
43-0444-703	2.6	136194.5142
73-0484-704	41	2840.97561
83-C083-061	61.4	2500.968241
01-0804-714	12	7772.140833
78-0804-716	27.2	1792.451985
31-0526-715	5.1	8808.529412
49-0526-709	51.4	4189.313575
48-0806-307	2	41997.86
2015	**Average**	**18253.22135**
Average cost per lane mile		**7830**

Table 49. Cost breakdown based on project number for thin HMA overlay

Contract ID	Lane-Mile	Price per Lane-Mile
65-2752-023	17	107798.0135
04-0051-079	39.74	84898.16636
24-0391-028	12.48	63448.03766
24-1413-074	7.024	316610.0936
78-0921-072	8	112148.7956
2021	**84.244**	**136980.6213**

Contract ID	Lane-Mile	Price per Lane-Mile
43-0301-190	16.8	81462.02381
84-0101-081	30	73618.64343
75-0752-113	13.9	38395.6474
43-0295-251	2.8	87323.375
07-3807-129	19.6	69690.47301
83-0594-034	19.6	12582.27512
25-0063-072	24.4	79803.65955
36-2751-041	9.8	101741.5073
30-0861-018	15.2	58140.3701
97-0121-035	7.04	96761.50938
97-0201-174	27.4	123548.6562
50-0654-163	34.5	14448.72841
43-0295-254	4	186759.6
43-0301-171	15.2	70342.02599
05-0714-054	24.2	72567.0512
2020	**264.44**	**77812.36973**
49-0521-119	35.4	38093.45198
81-0716-053	17.52	70754.06564
78-0293-243	9	84529.72889
36-0021-113	5.8	110112.4055
15-0831-028	7.4	87743.32054
2019	**75.12**	**78246.59451**
65-0341-108	12.9	72170.52065
71-0598-032	2	595002.2631
78-0061-132	26	54603.05828
78-0293-230	10.4	99988.21058
82-0671-145	25	31022.56
92-2185-712	11.6	61478.9163
43-0295-253	8	68451.1145
2018	**95.9**	**140388.0919**
21-0182-120	32.2	36547.81211
44-2182-149	3.6	82156.14362
2017	**35.8**	**59351.97787**
Average cost per lane mile		**98556**

Table 50. Cost breakdown based on project number for seal coat (from MnDOT)

Contract ID	Lane-Mile	Price per Lane-Mile
180024	2.245028409	16,192
180178	28.41122159	6,424
180604	102.9761364	12,060
180609	36.40894886	12,774
190025	0.496590909	30,413
190046	0.467329545	18,665
190603	40.57073864	13,728
190604	123.2994318	10,578
190605	213.4278409	12,303
190607	144.64375	9,398
200037	50.92684659	5,738
200142	12.43678977	11,320
200607	54.70681818	8,671
200613	173.0832386	8,518
210081	175.4640625	8,408
210301	262.81875	8,659
210603	274.4085227	$8,624
210608	102.312642	12,995
220001	21.21392045	8,255
220051	42.77485795	9,539
Average cost per lane mile		**11,390**