Ranking of Pavement Preservation Practices and Methods

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Bradley J. Putman, Ph.D.
Jennifer H. Ogle, Ph.D.
Yongxi Huang, Ph.D.
Logan Reed

Glenn Department of Civil Engineering
Clemson University
Clemson, SC 29634

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16. Abstract

The cost for maintaining and upgrading South Carolina's Department of Transportation (SCDOT) roadway system is costly, and deferring the timely maintenance of the infrastructure results in proportionately greater rehabilitation costs at a later date, while contributing to congestion and accident rates. In addition, deficient pavement conditions are the cause of the majority of the tort claims received by SCDOT, costing the DOT thousands of dollars each year that could be expended on maintenance and rehabilitation. Pavement preservation represents a proactive approach to maintaining the existing transportation system. The primary research objective of this study was to identify methods to improve the implementation of pavement preservation strategies on asphalt concrete roadways in South Carolina with specific attention to pavements in the Non-Federal Aid Secondary system.

The results of this study led to several recommendations for SCDOT to consider that will potentially help decision makers efficiently use funds to improve the roadway network health in South Carolina and increase the number of pavement sections in good condition over time. These recommendations include: methods to easily identify pavement sections that qualify as preservation candidates and visualize the locations of these candidate sections using GIS; local level pavement evaluation system; preservation treatment selection support tool; treatment tracking methodology to support future benefit-cost ratio analysis; and training materials for SCDOT personnel.

17. Key Words *Pavement Preservation; Pavement Management; Preventive Maintenance*	18. Distribution Statement No restriction

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Table of Contents

List of Tables

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List of Figures

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CHAPTER 1. Introduction

The South Carolina Department of Transportation (SCDOT) maintains a roadway network consisting of 41,377 centerline miles (90,598 lane-miles) of paved roads—the fourth largest state maintained system in the US. This network consists of four different systems as shown in Figure 1.1: Interstate, Primary, Federal Aid Eligible Secondary, and Non-Federal Aid Eligible Secondary. As shown in Figure 1.1, 46% (41,393 lane-miles) of the SCDOT system consists of secondary roads that are not eligible for federal aid, meaning that the construction and maintenance of this portion of the system is supported by funds generated solely by the state. While the Non-Federal Aid Secondary system comprises nearly half of the SCDOT overall network, it only handles about 7% of the traffic as illustrated in Figure 1.2 (SCDOT 2015).

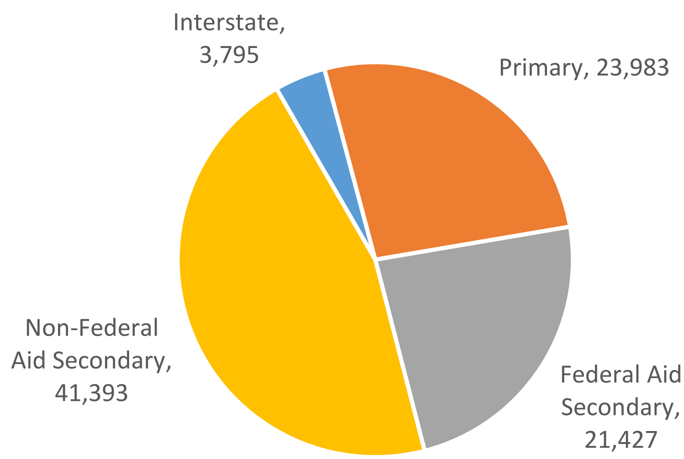


Figure 1.1. Distribution of the SCDOT pavement system by lane-miles (SCDOT 2015).

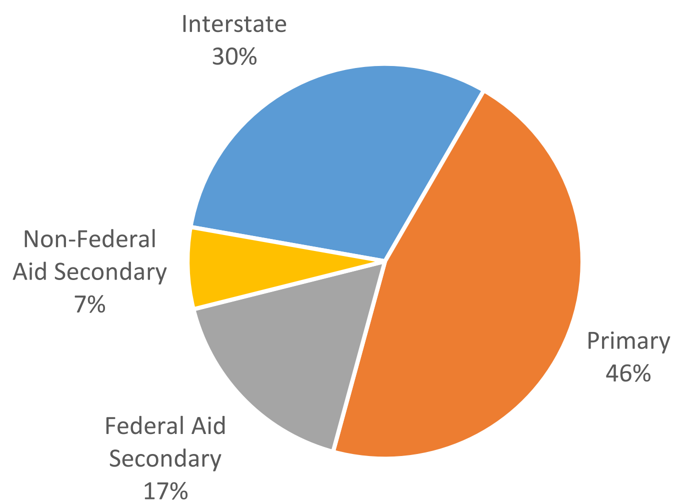


Figure 1.2. Distribution of the SCDOT pavement system by daily vehicle miles traveled (DVMT) (SCDOT 2015).

With such a large pavement network, the SCDOT is challenged to maximize available funds to maintain the network in the best condition possible for the traveling public. This is a difficult task when managing such a large network as shown in Figure 1.3 that shows that more the half (53%) of the overall network (based on lane-miles) is in poor condition. The SCDOT uses Pavement Quality Index (PQI) as the primary measure of pavement condition as summarized in Table 1.1 (SCDOT 2015).

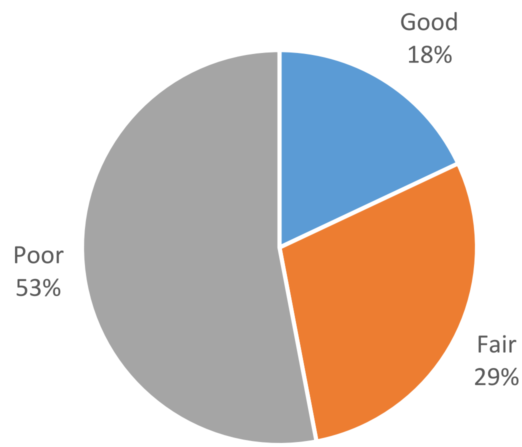


Figure 1.3. Pavement condition of the overall SCDOT pavement network (based on lane-miles) (SCDOT 2015).

Table 1.1. Categorization of pavement condition based on PQI (SCDOT 2015).

Condition	**PQI Range**
Good	3.4 – 5.0
Fair	2.7 – 3.3
Poor	0.0 – 2.6

The condition of the secondary roadway system is summarized in Figure 1.4, which shows that the condition of the Non-Federal Aid Eligible Secondary system is slightly worse than the Federal Aid Eligible portion. The historical trend of the condition of the Non-Federal Aid Secondary system is shown in Figure 1.5. This data shows that the percentage of the system that is in Good condition has remained fairly steady since 2008. However, the real change in the system is that the portion of the system in Fair condition has been on the decline year after year as these miles have deteriorated from Fair to Poor condition. During the period from 2008 to 2015, approximately 22% of the system has deteriorated from Fair to Poor condition (SCDOT 2015).

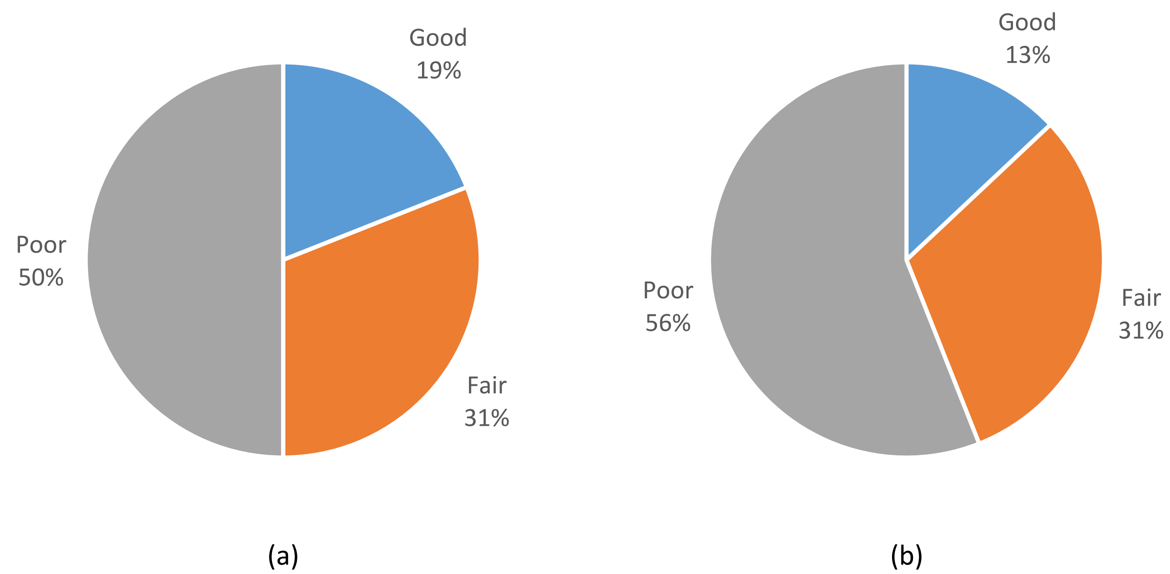


Figure 1.4. Pavement condition of the SCDOT secondary system (based on lane-miles) (a) federal aid eligible and (b) non-federal aid eligible (SCDOT 2015).

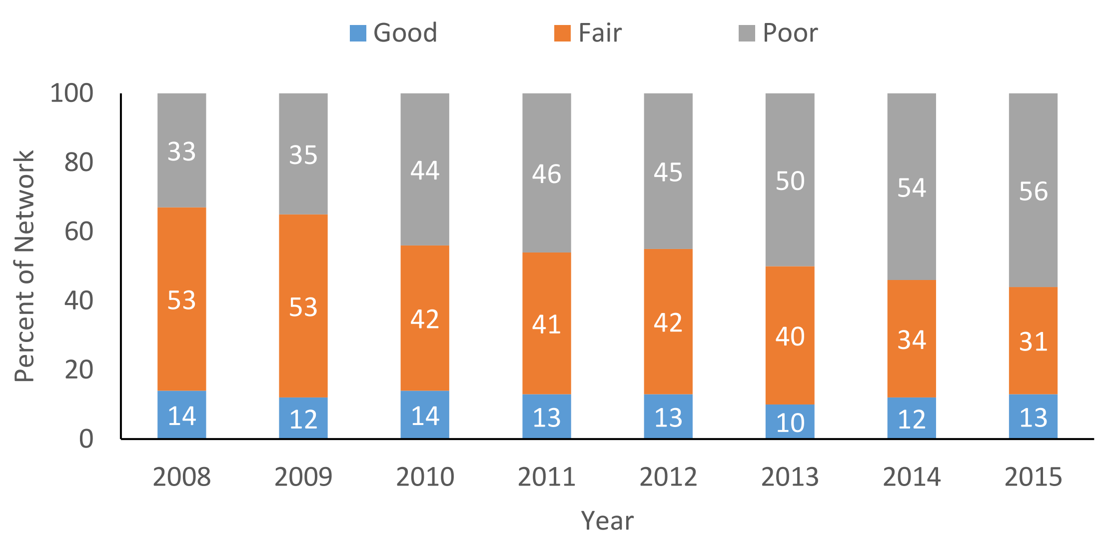


Figure 1.5. Pavement condition of the SCDOT non-federal aid secondary system from 2008 to 2015 (SCDOT 2015).

Problem Statement

The cost for maintaining and upgrading South Carolina's Department of Transportation (SCDOT) roadway system is costly, and deferring the timely maintenance of the infrastructure results in proportionately greater rehabilitation costs at a later date, while contributing to congestion and accident rates. In addition, deficient pavement conditions are the cause of the majority of the tort claims received by SCDOT, costing the DOT thousands of dollars each year that could be expended on maintenance and rehabilitation. Pavement preservation represents a proactive approach to maintaining the existing transportation system. Although SCDOT utilizes several pavement preservation practices, it is not known to what extent these preservation methods are contributing, or will contribute to the overall success and long-term benefit of the state's roadway system in terms of reducing costly, time consuming rehabilitation and reconstruction projects in the future, and enhancing pavement longevity.

There are a number of pavement preservation treatments that are employed to extend the life of pavements. The cost range of these treatments varies as well as the perceived benefits of each treatment. Generally, there are accepted ranges of years of service-life that are added to a pavement by the application of a preservation treatment. The number of years of added life may depend on a number of factors to include the traffic volume and the condition of the pavement when the treatment is applied.

Study Objectives & Scope

The primary research objective of this study was to identify methods to improve the implementation of pavement preservation strategies on asphalt concrete roadways in South Carolina with specific attention to pavements in the Non-Federal Aid Secondary system. To accomplish the primary objective, the scope of this study included a series of tasks discussed in the individual chapters within this report.

Chapter 2. Conduct a literature review to compile basic and detailed information about pavement preservation and practices.

Chapter 3. Conduct a survey of SCDOT pavement preservation practices.

Chapter 4. Evaluate methods to determine appropriate timing of pavement preservation treatments and identification of preservation candidates.

Chapter 5. Develop a decision support tool to support pavement preservation treatment selection and timing.

Chapter 6. Identify data elements that should be recorded to track the performance of pavement preservation treatments in South Carolina.

Chapter 7. Identify economic benefits of pavement preservation treatments.

Chapter 8. Summarize conclusions and develop recommendations.

CHAPTER 2. Literature Review

Pavements are one of the largest assets of the SCDOT, or any other state transportation agency, and represent a tremendous investment. With such resources dedicated to pavements, and with them being under the public eye, it is imperative that the serviceability of pavements be maintained in an efficient and effective manner to get the most out of the investment. The most effective method for maintaining pavement serviceability is to implement a pavement preservation program, which is a planned system of pavement surface treatments designed to extend the life of a pavement using the fewest resources (money, materials, energy, and time). To sum up the objective of a pavement preservation program, it is deciding on "***the right treatment on the right pavement at the right time***" (FHWA n.d.).

Pavement Preservation

As the demands on our Nation's roadway infrastructure increase, highway officials face greater challenges than ever before on the Nation's roadways, such as expansion of new roadways and maintenance of an existing, aging roadway system[2]. Since the majority of the Nation's major roadway expansion has occurred, the primary concern of Interstate System of National and Defense Highway is preservation and maintenance of this investment (FHWA 1998). Roadways are continuing to deteriorate and budgets for roadway maintenance are also reducing. The investment in the Nations roadway system is estimated at $1.75 trillion dollars (FHWA 2004). Maintenance of this investment falls to state and local departments of transportation. As funds for maintenance decrease and become more limited, it becomes extremely vital for agencies to allocate funds properly.

Based on the growing demands anticipated on the Nation's roadways, it became vital for transportation officials to determine the consumer's biggest concerns. In 1995, the National Quality Initiative survey was conducted by transportation officials and the results of this survey found that roadway users had two major concerns. The first concern pertained to pavement condition and second concern was the increased and ever present work zones. Transportation officials interpreted this survey information as public dissatisfaction. Specifically, the public's perception was that agencies were not utilizing funds or materials in roadway maintenance. Based on the anticipated growth and ever increasing utilization of roadways, it became important for highway agencies to become more proactive in their maintenance strategies (Geiger 2005). Although traffic volumes are steadily increasing on the Nation's roadways, preventative maintenance strategies can be utilized to ensure that the roadways can remain in operation and in good condition. This survey lead to the concept of pavement preservation.

Pavement preservation is a proactive approach to dealing with an ever-growing problem, specifically, the problem of our Nation's roadways deterioration. In the past, agencies were reactive in their approach to dealing with roadway deterioration and roadway maintenance (FHWA 2004). This reactive policy of dealing with roadway deterioration and roadway maintenance is known as "worst first". The worst first mentality was to fix roadways in the worst condition rather than working to maintain and keep good roadways in good conditions (FHWA 2004). The pavement preservation approach is a concept that utilizes the idea of performing timely maintenance and upkeep on roadways before they reach levels of deterioration. Pavement preservation can be utilized to repair and rehabilitate roadway deterioration and utilize funding to ensure that roadways are getting the necessary attention needed to ensure that they do not fall below a threshold where reconstruction is the appropriate alternative. Performing regular maintenance provides the public with continually safe roadways, the extension of pavement life, less congestion due to construction, and smoother, longer lasting roadways (Geiger 2005).

Effective pavement preservation programs must be broad; covering all aspects of roadway management. This means that it is extremely important for agents and officers in state and local departments of transportation work together closely to develop preservation goals for roadways. This is extremely important because correctly defining and communicating goals will improve working relationships between agents as they will all be working towards the common goal of properly maintaining roadways and utilizing the agreed to methodologies in the approved pavement preservation program.

The FHWA notes that a pavement preservation program is composed of three components: preventative maintenance, minor or nonstructural rehabilitation and finally routine maintenance activities (Geiger 2005).

Preventative maintenance, as defined by AASHTO, "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without substantially increasing structurally capacity" (Geiger 2005). Preventative maintenance is a tool utilized for pavement preservation. It is specifically utilized on pavements that are in good condition with a considerably long remaining service life. The strategy of pavement maintenance is to extend the service life of a roadway as it applies cost effective treatments to the surface (FHWA 1999; Geiger 2005).

Minor or nonstructural rehabilitation, is defined by AASHTO as, "structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatment and structural overlays." The purposes of rehabilitation projects are to extend the life of an existing pavement structure and works to restore roadways to their original structural capacity. Rehabilitation may include increasing pavement thickness to strengthen existing roadways to accommodate existing or future traffic load conditions. Minor or nonstructural rehabilitation can be divided into two categories: minor rehabilitation and major rehabilitation (Geiger 2005).

Minor rehabilitation involves nonstructural improvements. It is utilized to help improve pavements by working to eliminate age related, top down surface cracking that has developed in roadway pavements. Major rehabilitation involves structural improvements that can both extend the service life of existing roadway pavements or can improve the load capacity of a roadway (Geiger 2005).

Routine maintenance is defined by AASHTO as, "work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service" (Geiger 2005).

The flow chart in Figure 2.1 is the beginning point for the Pavement Preservation Decision Tree process. Decision trees provide decision makers with the basic information to select, treat and monitor treated pavements to ensure that they are properly diagnosing and treating the pavement problem. The idea is to first identify the types of distresses encountered, help identify the cause of the distress, provide viable options to treat the distress, costs associated with treatment options, selecting and tracking of the treatment option.

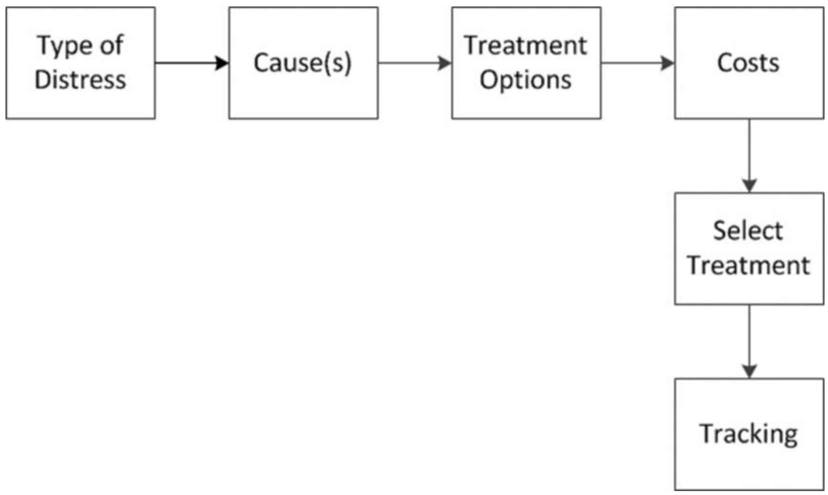


Figure 2.1. Pavement preservation flow chart/decision tree concept

Pavement Management Systems

A Pavement Management System (PMS) is a tool that transportation agencies utilize to maintain roadways. Pavement Management System's contains specific tools/methods that allow agency decision makers to develop a strategy for maintaining roadway assets. Specifically, a successful PMS must include a dependable pavement inventory along with roadway condition information. This information aids transportation agents by helping to identify, prioritize maintenance needs as well as the necessary rehabilitation needs for a section of roadway. Understanding and utilizing this information allows for agents to have an idea of what the costs for maintenance would be as well as any limits that may be present in a specific location of a roadway. This is extremely important as the information noted above, as it allows for the most cost effective maintenance method and rehabilitation needs for a roadway. This means that agencies are effectively making decisions and are working efficiently (Asphalt Institute 2007).

Selecting the proper tool for any job is essential. Pavement preservation is no different; it requires the right tool at the right time to fix roadway problems. Selecting the proper preservation technique requires detailed knowledge of the techniques available and making sure that the tool box is sufficiently stocked with the necessary tools to fix roadway problems. Table 2.1, provides basic information such as repair techniques, the type of repair, and a description of what the repair technique is as well as when to utilize this repair technique and can assist in selecting the proper tool from the toolbox.

Table 2.1. Maintenance treatments/techniques.

Repair Technique	Type	Description	When to Utilize
Full/Deep Depth Patch	Patch	Removal of an entire pavement surface layer (4" or more). Area removed is area of patch. Permanent pavement repair. Extend 1' out of excavation area into good pavement area. Keep cuts rectangular and square edged.	Utilized when making permanent pavement repairs.
Cold mill and thin overlay	Overlay	Consist of removing the surface to a specified depth. Utilizes specialized equipment.	Utilized to remove deteriorated pavement to a desired depth (eliminating failed materials), restores the pavement surface profile, restore / maintain drainage flow, add texture surface for skid resistance and improved bonding of an asphalt overlay, and remove materials (as needed) to provide clearances for structures.
Crack seal or fill	Crack Seal/fill	Single most important maintenance activity. The purpose of the pavement sealing is to keep water out of the pavement structure. The type of crack can vary by width of crack. Crack types can be characterized as: hairline crack, small crack, medium crack and large crack.	A hairline crack is typically 1/8" or less in width. If numerous cracks occur over an area, a surface seal should be provided. Utilize fog seals, chip seals, slurry seals and sand seals. Small cracks are 1/8" - 1/2" wide. Small cracks need to be routed to a width of 1/4" minimum to provide a reservoir for crack sealant and use a backer rod for cracks >2". Medium cracks are 1/2" - 3/4" wide and require cleaning and sealing. Use a backer rod in cracks > 2" deep. Large cracks are wider than 3/4" and need to be filled with asphalt emulsion slurry seal material, a HMA sand mix, or hot poured sealant.
Fog seal	Spray applied sealer	A light application to an existing surface of a slow setting asphalt emulsion diluted with water. It is utilized to renew old Hot Mix Asphalt (HMA) pavement surfaces that have become dry/brittle with age.	Utilized to seal cracks and surface voids, and inhibit raveling.
Slurry seal	Asphalt surface treatment	Mixture of fine aggregate, asphalt emulsion, water and mineral filler (typically Portland Cement). Utilized to prevent and correct asphalt pavement surface treatment.	Utilized to reduce surface distress caused by oxidation of the asphalt and the embrittling of the pavement mixture. It seals surface cracks, stops raveling, makes open surfaces impermeable to air and water and improve skid resistance.

Table 2.1 (continued). Maintenance treatments/techniques.

Repair Technique	Type	Description	When to Utilize
Microsurfacing (aka Polymer - modified slurry seal)	Asphalt surface treatment	Similar to slurry seal except that it consists of a polymer - modified emulsion, a high quality aggregate, mineral filler, additives and water.	Utilized to fill ruts or channels in the traffic wheelpaths (provided pavement is not in plastic flow), to fill ruts, utility cuts, and depressions in the existing surface.
Thin overlay	Maintenance Blanket	Utilized as a preventative maintenance to extend the life of an asphalt pavement.	Utilized to improve the ride quality and correct surface deficiencies such as low skid resistance.
Chip Seal	Asphalt surface treatment	Application of asphalt followed immediately with an aggregate cover. Two (2) layer application is known as a double chip seal; three (3) layer application is referred to as triple chip seal.	Protects pavement from deterioration effects of the sun/water as well as increase skid resistance of the pavement surface.
Surface patch (aka skin patch)	Patch	Temporary repair	Temporary repair, utilized on permanent pavements in relatively good condition with adequate thickness (4"). Can be constructed w/o excavation or can be milled.
Sand Seal	Asphalt surface treatment	Application of asphalt followed immediately with sand coverage.	Protects pavement from deterioration effects of the sun/water as well as increase skid resistance of the pavement surface.
Seal Coat	Asphalt surface treatment	Application of diluted asphalt emulsion without a cover of aggregate.	Utilized to seal and enrich asphalt pavement surface and seal minor cracking.

Pavements are managed and analyzed on numerous levels. Specifically, roads can be broken down and analyzed on the project level, the network level and the strategic level. Roadways that are managed and analyzed on the project level are analyzed and proper maintenance and rehabilitation are specified for particular pavement sections. At the project level, pavement evaluations are conducted to determine the extent of pavement deterioration and what the cause of the deterioration is and what the fix is for the specific roadway deterioration.

On the network level, PMS is again utilized to assist in assessing maintenance and rehabilitation needs, but instead of assessing individual roadways, the entire roadway network is analyzed. At the network level, agency roadway needs are prioritized and fixes are analyzed and the most cost effective maintenance fix is selected for the specific distress. In the beginning, the PMS acts as a broad standard defining the type of work required and the location where the type of work needs to be performed. After the type of work and locations are confirmed, final work plans are developed.

Developing final work plans is an iterative process, meaning that the projects may be rescheduled or combined if they are similar in nature or make better economic sense. Network level priorities and project level priorities and work lists need to be coordinated to ensure that projects final project plans and their necessary, proper treatment are being utilized.

Strategic level analysis is another method of analysis. This level of analysis is typically utilized by government officials, agency management and engineers to all have a say in the decision in selecting the pavement performance targets and establish funding levels to achieve the required performance target levels, dispense fund to districts and establish pavement preservation policies.

Pavement Preservation Treatments

There are several pavement preservation treatments that have been used across the United States with varying degrees of success. Each of the treatments has shown to be both effective and ineffective and the success of the treatment largely depends on the condition of the roadway prior to application of the treatment. In other words, was the correct treatment applied to the roadway in question? Many times, the answer to this question is no. Therefore, it is of the utmost importance to understand where, when, and how a specific pavement preservation treatment should be applied.

The main pavement preservation treatments utilized throughout the United States are included in Table 2.2. This table also includes pertinent information regarding the materials used, application methods, timing of application, treatment benefits, and treatment drawbacks. The same treatments are included in Table 2.3, but here they are categorized based on preservation objective.

Table 2.2. Pavement preservation treatment (from Peshkin et al. 2004).

Treatment Description	Materials & Application	Timing & Cost	Benefits	Drawbacks
Fog Seal: Very light application of a diluted asphalt emulsion placed directly on the pavement surface with no aggregate.	Slow-setting emulsion. Requires approximately 2 hours for curing depending on emulsion before opening to traffic.	Can last 1-2 years when placed for preventive maintenance and costs in the range of \$0.30 to \$0.45 per yd^2.	Seals the pavement, inhibits raveling, rejuvenates oxidized asphalt, and provides some shoulder delineation.	Will not improve pavement friction. Must be applied to a pavement in good condition.
Chip Seal: Asphalt emulsion is applied to the pavement surface followed by aggregate chips that are rolled with a pneumatic-tired roller to embed the chips.	Surface must be clean and treatment applied during warm weather. Requires approximately 2 hours to cure before opening to traffic. Total thickness may approach 1-in.	Can last 4-7 years and costs in the range of \$0.75 to \$0.90 per yd^2 for single application and \$1.10 to \$1.25 per yd^2 for double application.	Seals the pavement surface and improves friction.	High speed, high volume roadways are avoided due to the potential for loose aggregates, therefore, limited to rural roadways. Can potentially accelerate stripping in susceptible pavements.
Microsurfacing: Mixture of polymer-modified emulsion, aggregate, mineral filler, water, and other additives applied similar to slurry seals. Best performance has been seen in warm climates with low daily temperature changes.	Fast breaking polymer modified emulsion and high quality fine aggregate are mixed in a modified traveling plant mixer and applied to the pavement using a spreader box. The treatment is applied at a depth of approximately 3/8-in. Lane closure must remain until the treatment is completely cured, which could be as early as 1 hour depending on materials and weather.	Can last 4-7 years and extend the life of the pavement by about 5 years if applied to a pavement in fair condition. Cost is in the range of \$0.90 to \$1.25 per yd^2.	Seals cracks, halts raveling, improves skid resistance, reduces oxidation, longer lasting than slurry seal.	More expensive than other treatments such as chip seals and fog seals. Can accelerate development of stripping in susceptible pavements.

Table 2.2. Pavement preservation treatment (from Peshkin et al. 2004).

Treatment Description	Materials & Application	Timing & Cost	Benefits	Drawbacks
Slurry Seal: Mixture of well graded fine aggregate/filler and asphalt emulsion spread over the surface in a thin layer.	Mixture of emulsion, fine aggregate, and mineral filler mixed in a modified traveling plant mixer and applied with a spreader box. The seal is applied at a typical thickness of 1/8 to 1/4-in. Lane closure must remain in place until the seal has completely cured, which will depend on materials and environmental conditions.	Can last 3-5 years and extend the life of the pavement by about 5 years if applied to a pavement in fair condition. Cost is in the range of \$0.70 to \$1.00 per yd^2.	Less expensive than HMA overlays; can be applied and opened to traffic in 2-12 hours; no loose surface material. Seals the pavement, thus reducing moisture intrusion, oxidation. Can also fill shallow rutting.	More expensive than treatments such as chip seals and fog seals. Can accelerate development of stripping in susceptible pavements.
Scrub Seal: Four step process: (1) application of polymer-modified asphalt emulsion that is broomed into voids and cracks, (2) application of sand/small-sized aggregate, (3) second application of polymer-modified asphalt by brooming, and (4) rolling with a pneumatic-tired	Polymer-modified asphalt emulsion and sand/small aggregate. Can be effective in all climates, but performs best in hot, arid climates. Surface must be clean and special equipment is needed for brushing.	Can last 1-3 years when placed for preventive maintenance and costs in the range of \$0.75 to \$1.25 per yd^2.	Rejuvenate surface, fills voids and surface cracks, reduces moisture intrusion, inhibits raveling.	May reduce pavement friction if applied to tight surfaces.
Crack Sealing: Sealant operation addressing cracks that open and close with changes in temperature (i.e., cracks that undergo little movement)	Typically thermo-plastic materials and should be applied during cool, dry weather. Proper crack cleaning is necessary to achieve good bond and maximum performance.	Can last 2-6 years and costs in the range of \$0.30 to \$1.50 per linear foot, including routing; \$0.30 per linear foot for crack filling.	Provides no structural benefit, but reduces moisture intrusion. Only practical if there is little to know structural cracking.	

Table 2.2. Pavement preservation treatment (from Peshkin et al. 2004).

Treatment Description	Materials & Application	Timing & Cost	Benefits	Drawbacks
Thin HMA Overlay: Plant mixed HMA applied in thicknesses between 0.75 and 1.5-in.	Can be dense-graded, open-graded, or stone matrix mixture types. Must consider maximum allowable pavement drop-off at edge of pavement. Surface must be clean and tack coat applied properly.	Can last 7-10 years when placed as a preventive maintenance treatment and costs in the range of \$1.75 to \$2.00 per yd^2.	Improves pavement friction, reduces moisture intrusion if overlay is constructed properly, and also provides structural support.	Can be more expensive than other preservation treatments.
Ultrathin Friction Course: Polymer-modified, gap-graded HMA layer placed on a heavy polymer-modified tack coat. Also known as "Novachip."	Gap-graded, polymer modified HMA placed in a thin layer (0.4-0.8-in.). Requires special equipment for placement.	Can last 7-10 years when placed as a preventive maintenance treatment and costs in the range of \$2.50 to \$3.00 per yd^2.	Increases pavement friction and provides some structural capacity.	More expensive than other treatments. Requires a license to apply it because of the proprietary nature. Not appropriate for rutted pavements.

Table 2.3. Pavement preservation treatments categorized by preservation objective (Peshkin et al. 2004).

Pavement Preservation Objective	Treatment Type	Performance Measure
Improve Ride *(Reduce roughness)*	Slurry Seal Microsurfacing Ultrathin Friction Course Thin Overlay	IRI PSI
Noise Control	Ultrathin Friction Course Slurry Seal Microsurfacing	dB
Increase Surface Friction	Chip Seal Slurry Seal Ultrathin Friction Course Thin Overlay	Skid Number Mean Texture Depth IFI
Extend Pavement Life	Crack Sealing Fog Seal Scrub Seal Chip Seal Slurry Seal Microsurfacing Thin Overlay Ultrathin Friction Course	Condition: Cracking Patching Rutting Raveling Potholes
Reduce Moisture Intrusion	Crack Sealing Scrub Seal Chip Seal Slurry Seal Microsurfacing Thin Overlay Ultrathin Friction Course	Condition: Cracking Patching Rutting Raveling Potholes

IRI = International Roughness Index; IFI = International Friction Index; dB = decibel

Timing of Preventive Maintenance Treatments

As previously discussed, there are varying degrees of experience with pavement preservation programs in the United States. One of the key aspects to pavement preservation is identifying the appropriate time to apply the proper treatment to a given pavement. This is typically the main factor that determines the success of a single treatment as well as a pavement preservation program.

Deciding the optimum time to apply a specific treatment to a pavement for preservation purposes has been the subject of only a few studies, but is perhaps the most important factor for a successful pavement preservation program. The impact of timing of a generic treatment is illustrated in Figure 2.2. The solid line represents the "do-nothing" alternative in which the pavement is constructed and then no action is taken to maintain the roadway. In this scenario, the pavement follows the typical asphalt pavement deterioration curve that begins with a gradual decrease in pavement condition for the first 5 to 7 years. After this initial period, however, the rate of deterioration increases rapidly to a point where major rehabilitation is required. Beyond that, complete reconstruction of the roadway is necessary (O'Doherty 2007). As the deterioration curve progresses downward, the life-cycle cost of the pavement increases inversely to the deterioration curve.

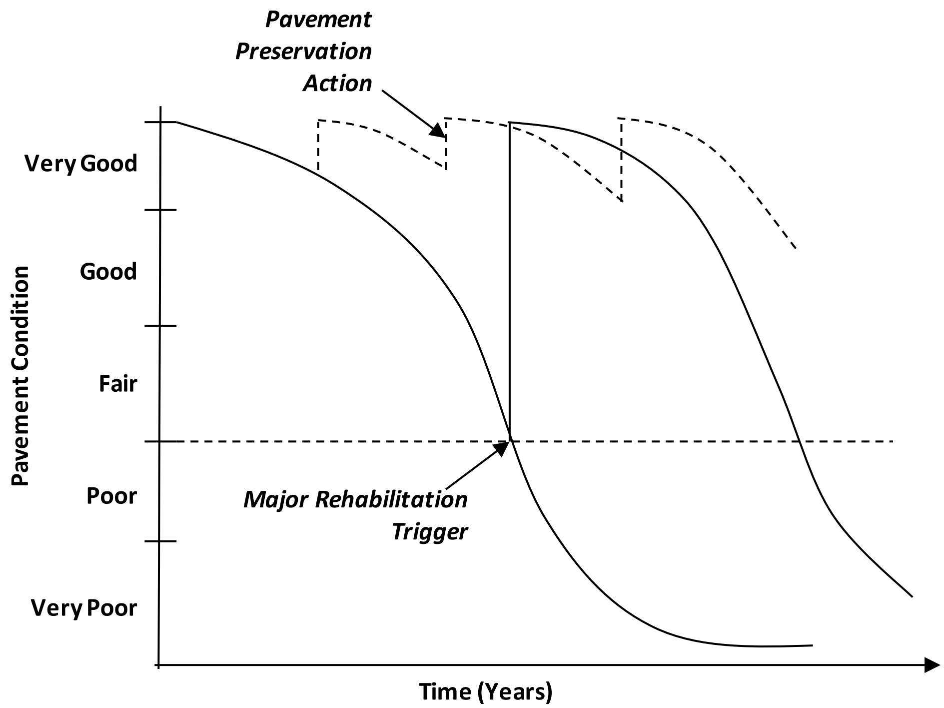


Figure 2.2. Conceptual illustration of "do-nothing" and pavement preservation scenarios (O'Doherty 2007).

Figure 2.2 also illustrates the concept of pavement preservation where preservation treatments are applied to the roadway at regular intervals throughout the life of the pavement. This is shown with the dashed line. The preservation treatments are applied to the roadway while the pavement is still in good condition after only a minor decline in the deterioration curve. These treatments effectively return the condition of the pavement to near that of when it was first opened to traffic (O'Doherty 2007). As the pavement ages, the treatments may become more involved, but the cost of the preservation strategy will always be less than the "do-nothing" alternative over the pavement's life if the right preservation treatments are applied at the right time.

Figure 2.3 illustrates the appropriate timing for different pavement preservation treatments based on the pavement condition. Additionally, Table 2.4 compares the costs of different treatment options based on cost data from Orange County, NY as of October 2009 (Patenaude 2009).

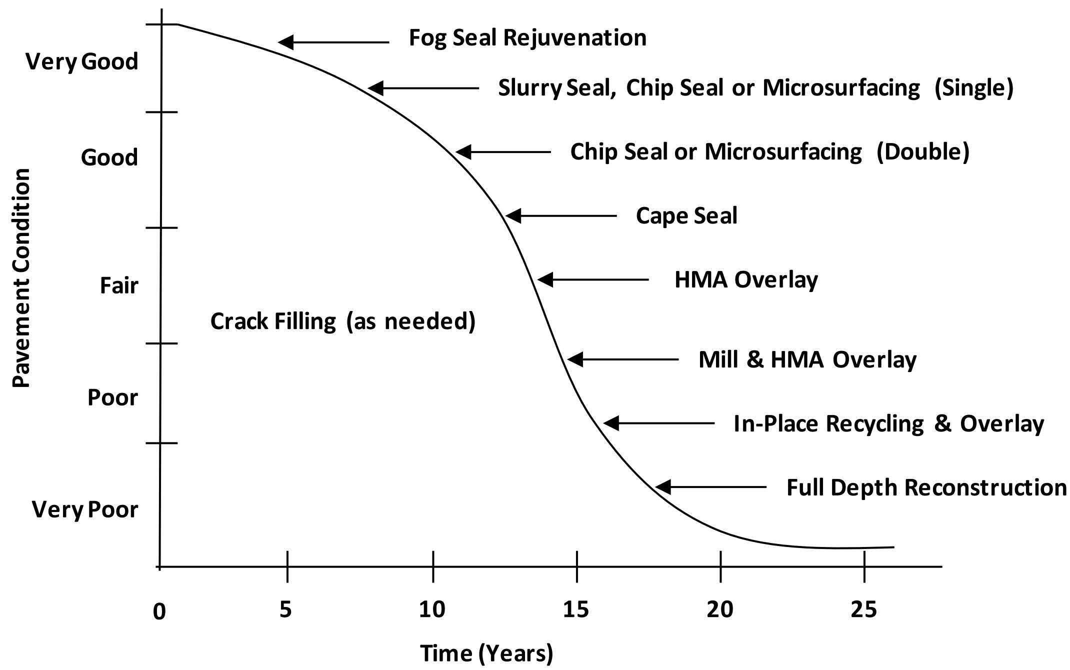


Figure 2.3. Appropriate timing for preservation, rehabilitation, and reconstruction based on pavement condition (Patenaude 2009).

Table 2.4: Equivalent annual pavement management costs (Orange County, NY 2009) (from Patenaude 2009).

Treatment Alternative	**2009 Approximate Unit Cost** ($/lane-mile)*	($/s.y.)	**Estimated Service Life (years)**	**Equivalent Annual Cost ($/s.y./year)**
Fog Seal (GSB-88)	$7,040	$1.00	3	$0.33
1/4" Chip Seal (CRS-2 emulsion)	$10,208	$1.45	4	$0.36
3/8" Chip Seal (CRS-2 emulsion)	$12,672	$1.80	5	$0.36
18 lbs/s.y. Quick Set Slurry Seal (single)	$14,432	$2.05	5	$0.41
32 lbs/s.y. Microsurfacing (double)	$27,808	$3.95	8	$0.49
Cape Seal (3/8" chip seal, plus 25 lb. slurry)	$32,736	$4.65	9	$0.52
Paver Placed Surface Treatment	$46,464	$6.60	10	$0.66
1-3/4" HMA Overlay	$56,320	$8.00	11	$0.73
1-3/4" Mill & HMA Overlay	$70,400	$10.00	11	$0.91
Cold In-Place Recycling with 2" HMA Pavement	$112,640	$16.00	15	$1.07
Full Depth Stabilized Reclamation with 4" HMA Pavement	$176,000	$25.00	20	$1.25

** Based on 12' lane width*

Utilizing this type of information, Peshkin *et al.* (2004) developed a decision tool to determine the optimum timing for different types of pavement preservation treatments on a roadway. This tool, OPTime, was the product of NCHRP Project 14-14. OPTime is a Microsoft® Excel based application that uses a series of user inputs to calculate the Effectiveness Index of a particular treatment applied at a particular time during the life of the pavement. The Effectiveness Index is essentially the Benefit/Cost ratio of the treatment where the benefit is related to the overall improvement in pavement performance and the cost is equivalent uniform annual cost of the treatment. Additionally, OPTime can provide an estimate the expected extension of pavement life resulting from the treatment.

A decision support tool, such as OPTime can be an important factor in achieving optimal results. However, decision tools are only as good as the data on which the decisions are based. Currently, SCDOT collects pavement performance data for US, SC, and secondary roads on a three year rotation. Interstates, NHS, and HPMS sample sites are all collected annually. A data collection system based on current condition level may need to be implemented to make the most of such a system. For instance, if the PQI threshold is set at 3.0 (minimum for non-federal aid secondary roads) for implementation of preventive maintenance, and during a regular 3-year performance review a secondary road rated 3.3 (i.e., good condition), then that road could potentially go another 3 years before it is flagged for treatment. During this 3-year period, however, the traffic on this pavement could change significantly and lead to accelerated deterioration resulting in a PQI well below 3.0, which would now require more costly maintenance or rehabilitation measures. If this pavement had been evaluated on a more regular basis (even at the local level), the appropriate preservation measures could have been taken at the right time to prevent such a rapid decrease in pavement condition. To address this, roadways that are within a certain condition threshold range for the route type and traffic volume should be placed on a more frequent data collection schedule.

Remaining Service Life

A popular concept used in making pavement management decisions is the Remaining Service Life (RSL) concept. This concept is based on the premise that a pavement section has a period of time remaining before the pavement reaches a point at which it is considered to have reached a minimum operating condition as illustrated in Figure 2.4. When this point is reached, the pavement will typically require major rehabilitation or reconstruction, depending on how the pavement management system is set up. If the RSL of a pavement segment is 10 years, then it is estimated that it has 10 years of use before it reaches the terminal threshold. If the RSL is 0, then the segment has already reached the threshold.

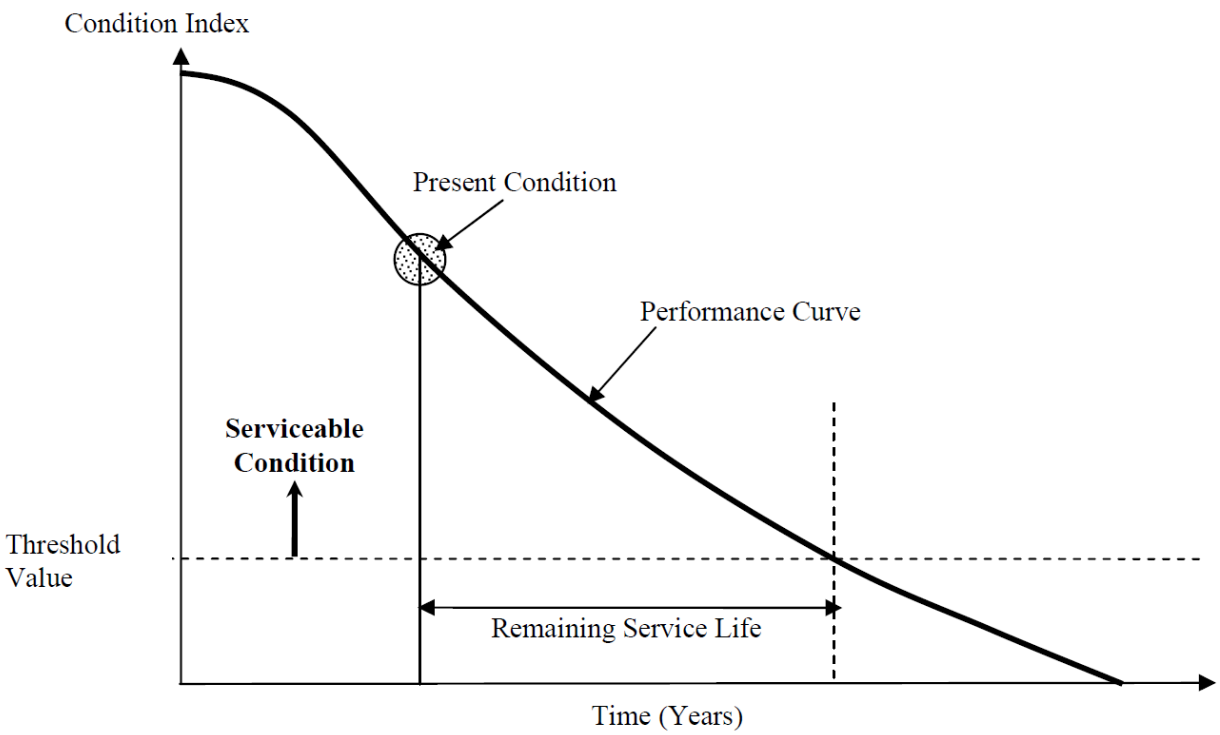


Figure 2.4. Illustration of the remaining service life of a pavement.

The RSL concept can be applied in pavement management systems at all levels: segment, branch, or network. When considering the segment level, the RSL of an individual roadway segment is determined based on the actual pavement condition or the predicted condition based on deterioration models as illustrated in Figure 2.4. At the network or branch level, the RSL of the entire system or subsystem is estimated based on the condition of the individual components of the system. In this case, the pavement manager's goal is to keep the condition of the overall system or network above a particular level (Galehouse and Sorenson 2007).

When implementing the RSL concept in a pavement management system, the goal is to maintain or improve the overall health of the entire network, where the network health is calculated using equation 2.1 and the units are lane-mile-years. The action taken in programming pavement maintenance and construction planning will have a significant impact on the overall health of a network as every maintenance, rehabilitation, and reconstruction activity will improve the remaining service life of a pavement section to a different degree as noted in the example in Table 2.4 (Galehouse and Sorenson 2007).

$$Network\ Health = \sum_{i=0}^{n} (RSL_i \times LM_i) \tag{2.1}$$

where,

RSL_i = Remaining Service Life for category i, years
LM_i = Number of lane miles having RSL of i, lane-miles

The effect of different actions on the overall network health can be visualized in Figures 2.5 through 2.7 where an example network consists of 244 lane-miles of pavement having a present distribution of RSL as indicated in Figures 2.5a, 2.6a, and 2.7a (time = 0) and an overall network heath of 2476 lane-mile-years. The example in Figure 2.5 illustrates the "Do Nothing" scenario where no action (maintenance or construction) is taken on the system. After one year (Figure 2.5b), every lane-mile of pavement loses one year of RSL and the sections that had a RSL of 1 year previously, have been added to the pool of sections having a RSL equal to 0. As a result, the overall network health has decreased to 2243 lane-mile-years. In other words, the overall condition of pavement network has gotten 9.4% worse due to inaction. As the "Do Nothing" action continues, the overall network heath continues to deteriorate as shown by the number of lane-miles having a RSL of 0 (Figures 2.5 c-f) and the network health expressed in lane-mile-years in Figure 2.8.

As seen from this example, "Do Nothing" is not an effective pavement management strategy, therefore, agencies will employ another strategy to address deficiencies in their pavement network. However, not all strategies will improve the overall network health. Some agencies still subscribe to the "Worst First" strategy where all (or most) of the available funds are used to address the pavement sections in the worst condition through reconstruction or major rehabilitation activities. In this case, the pavement sections in poor condition having a low RSL would be rehabilitated or reconstructed, thus increasing their RSL depending on the action taken. If every pavement section in poor condition could be addressed each year, this would be an effective strategy. However, as shown in Table 2.4, the cost of these major activities is high, thus making the possibility of performing major rehabilitation or reconstruction on every lane-mile of pavement in poor condition cost prohibitive. Therefore, the amount of pavement treated using this strategy is limited.

In this example, it will be assumed that the agency has an annual budget of $1,000,000 and will select from the treatment alternatives in Table 2.4. For the "Worst First" scenario, the agency will perform cold in-place recycling with an HMA overlay on 4 lane-miles and mill and overlay on 8 lane miles on pavements having a RSL of 0 each year. As noted in Table 3, CIR with an overlay has a service life extension of 15 years at a unit cost of $112,640/lane-mile and the mill and overlay has a service life extension of 11 years at a cost of $70,400/lane-mile. This strategy addresses only 14 lane-miles of pavement at an annual cost of $1,013,760, which is over budget. This strategy also only addresses 163 lane-mile-years each year—well short of 244 lane-mile-years to maintain the network health. The results of this example are illustrated in Figure 2.6. The results show that, although action is taken, the overall health of the network still continues to decline each year, but at a reduced rate compared to the "Do Nothing" strategy (Figure 2.8). As shown in Figure 2.6f, the network health eventually levels off and will never fall below 1008 lane-mile-years after 20 years. Unfortunately, by this point the network health has decreased 59% over time. It should be noted that this is a simplified example for the purpose of this explanation and there are many factors that need to be considered when determining the course of action to rehabilitate pavements depending on the condition.

The two example strategies previously discussed ("Do Nothing" and "Worst First") resulted in a continuous decline in overall network health because they did not add the minimum number of lane-mile-years per year. In this case, the network consists of 244 lane-miles. Therefore, if the pavement management strategy consists of activities that will equal 244 lane-mile-years per year, the overall network health will remain constant or improve each year depending on the life extension of each activity. The only way to improve the overall health of the network is to devise a strategy consisting of the appropriate mix of activities ("Mix of Fixes") that will equal more than 244 lane-mile-years per year. This can be illustrated in Figure 2.7 where a combination of treatments from Table 2.4 (i.e., fog seal, 3/8-in chip seal, microsurfacing, 1 ¾-in overlay, and CIR with 2-in overlay) were implemented. In the first year, 41 lane miles of pavement having varying present condition ranging from an RSL of 0 to 17 years were treated using appropriate treatments. When considering the life extension of each activity, this strategy addressed 250 lane-mile-years at a cost of $943,712 in this first year. This strategy improved the overall network health as seen in Figure 6b while being under budget. This improvement can be attributed to maintaining pavements in good condition, while improving the condition of pavements in fair or poor condition. Over time, this trend will continue as more and more pavements will be in good condition and fewer will be in fair or poor condition. While the "Mix of Fixes" strategy is an effective solution, there is no single treatment schedule that will repeat year after year. Rather, the number of lane-miles treated using a particular treatment may vary each year depending on the condition and needs of the network.

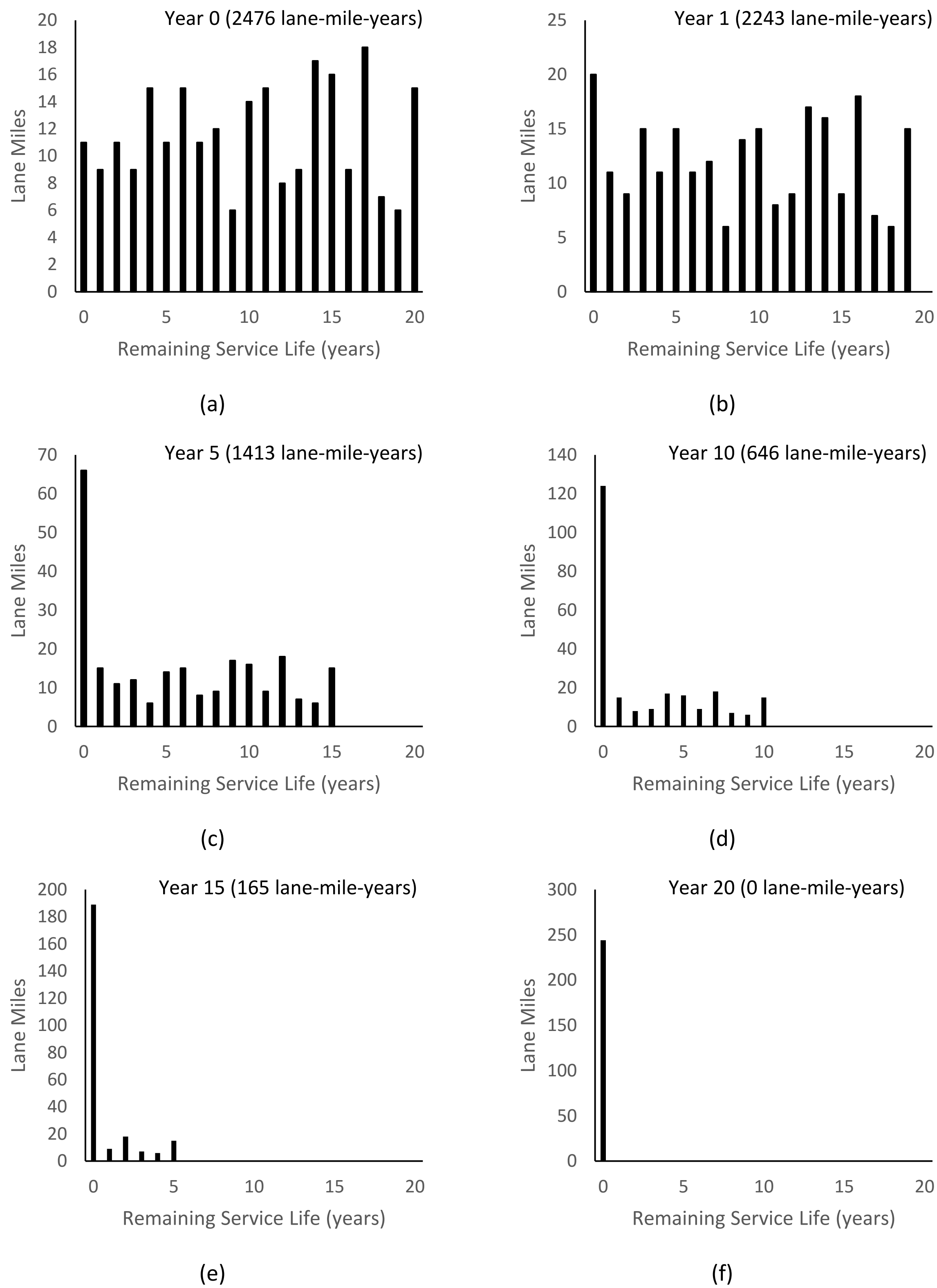


Figure 2.5. Effect of the "Do Nothing" strategy on the RSL of a network.

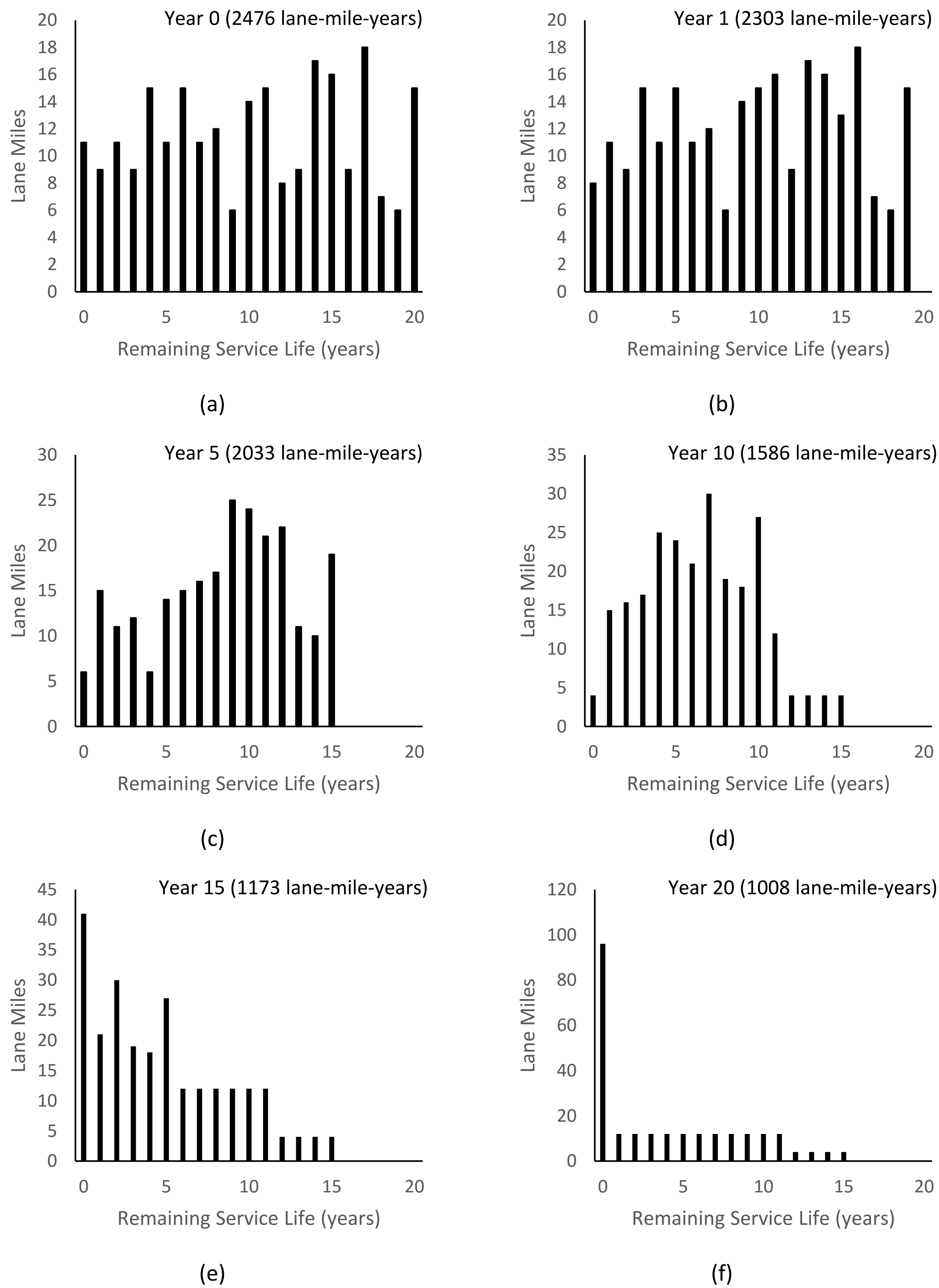
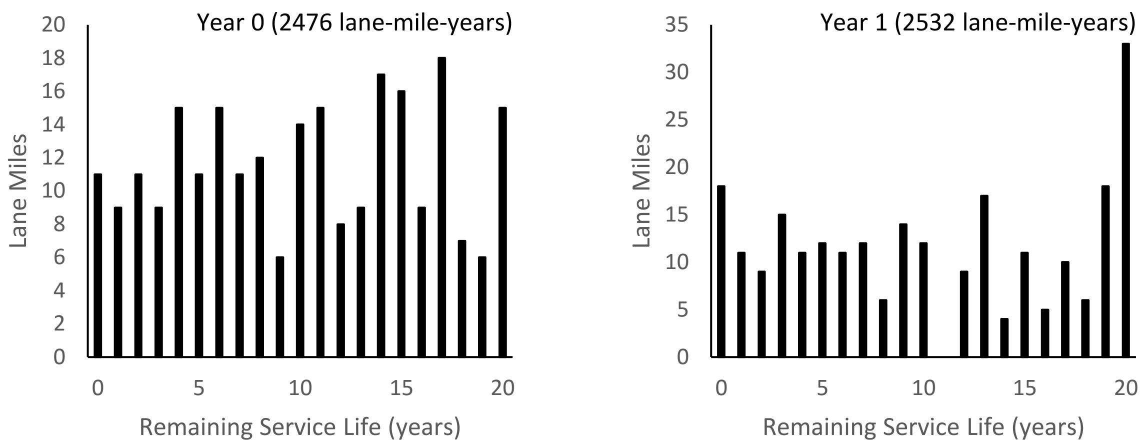


Figure 2.6. Effect of the "Worst First" strategy on the RSL of a network.



(a) (b)

Figure 2.7. Effect of the "Mix of Fixes" strategy on the RSL of a network.

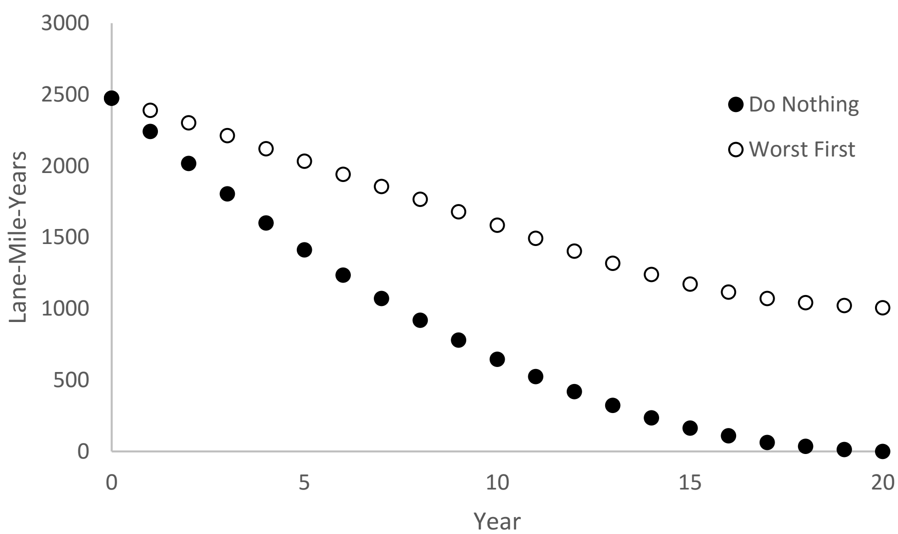


Figure 2.8. Effect of different pavement management strategies on overall network health.

Pavement Preservation in Other States

While some states (i.e., Michigan, New York, and California) have well established preventive maintenance programs that stipulate when and to what condition pavement specific treatments should be applied, others do not (Peshkin et al. 2004). As a result of the differences in the sophistication of pavement preservation programs across the country, there have been varying degrees of success with respect to specific treatments. A survey of transportation agencies in the United States, Puerto Rico, and Canada was conducted in 1999 to identify the status of preventive maintenance programs (AASHTO 1999). This survey indicated that all of the respondents (41) used preventive treatments and 36 respondents had an established preventive maintenance program. Additionally, 17 respondents reported that they have had their preventive maintenance program in place for more than 10 years.

Perhaps the main factor leading to the success or failure of a pavement preservation treatment is the condition of the roadway to which it is applied. These treatments are to preserve the condition of the pavement, not to rehabilitate pavement that has deteriorated to a state of disrepair. In the 1999 survey, 25 respondents reported that preventive maintenance treatments were applied to roadways that were in good condition. However, 22 indicated that pavements receiving these treatments were in poor condition. This supports the variability in the success of pavement preservation programs across the Nation. The survey also revealed that some states applied preventive maintenance treatments to roads in poor condition when reconstruction budgets were limited. The reasoning behind this was that any treatment would provide some benefit to even poor roads (AASHTO 1999). While these treatments may have provided some benefit, that benefit was undoubtedly limited and, therefore, not cost effective.

Michigan

According to the MDOT *Project Scoping Manual,* MDOT is responsible for roads starting with “M,” “I,” or “US,” in what is known as the “trunkline system” which includes 9,700 route miles (2015). MDOT uses the “Mix of Fixes” approach when selecting projects. This approach combines long term fixes, such as rehabilitation and reconstruction, with short-term fixes, like preventive maintenance techniques.

Michigan Department of Transportation established its Capital Preventive Maintenance (CPM) Program in 1992. Its purpose is “to protect the pavement structure, slow the rate of pavement deterioration and/or correct pavement surface deficiencies” (MDOT, 2010). The CPM program looks to prioritize newer pavement with preventive maintenance techniques. Preventive maintenance should be made until repair costs exceed the benefits of the techniques or the pavement structure requires reconstruction or rehabilitation. Projects are selected with the help of the state’s Pavement Management System (PMS). Recommended pavement condition levels are given for each preventive maintenance treatment based on Remaining Service Life (RSL), Distress Index (DI), International Roughness Index (IRI), Ride Quality Index (RQI), and Rut Depth in order to give a statewide consistency to choosing the most cost effective treatment (MDOT, 2010). Michigan uses the following treatments for flexible and composite pavement:

- Non-structural HMA Overlay
- Surface Milling with Non-structural HMA Overlay
- Chip Seals
- Paver Placed Surface Seal
- Micro-Surfacing
- Crack Treatment

- Overband Crack Filling
- HMA Shoulder Ribbons
- Ultra Thin Overlay

The *Capital Preventive Maintenance Manual* provides guidelines to choosing each treatment based on the minimum RSL, DI, RQI, IRI, and Rut Depth. The manual also outlines the life extension each treatment provides.

The Michigan Transportation Asset Management Council has published a guide for assessment management, *Asset Management Guide for Local Agencies in Michigan,* to help with the treatment selection for pavement and bridges. The first step in this guide is to assess current road conditions. The Council adopted the Pavement Surface Evaluation and Rating (PASER) method to measure current pavement condition. PASER uses a visual survey to rate condition on a scale of 1-10 based on the pavement material and type of distress involved. The PASER method ratings are grouped into three categories: routine maintenance, capital preventive maintenance, and structural improvement. Routine maintenance includes PASER ratings 8, 9, and 10 and involves day-to-day activities that prevent water from seeping into the surface. Capital preventive maintenance involves PASER ratings 5, 6, and 7 and is used to "address pavement problems before the structural integrity of the pavement has been severely impacted" (TAMC, 2007). Structural improvement typically involves rehabilitation or reconstruction because the structural integrity of the pavement has been compromised and includes PASER ratings 1, 2, 3, and 4.

The Michigan Transportation Asset Management Council recommends the use of Mix of Fixes concept to find "the Right Fix, in the Right Place, at the Right Time" (TAMC, 2007). The Mix of Fixes approach looks at the remaining service life (RSL), Critical Distress Point (CDP), Extended Service Life (ESL), and risk and cost of deferring maintenance. The remaining service life is the time left before the pavement can no longer be benefited by capital preventive maintenance treatments. The critical distress point is where the pavement changes from capital preventive treatments to structural improvement. The extended service life is the time added to the RSL when a treatment is added. The risk and cost of deferring maintenance is the risk of not performing preventive treatments to good pavement.

The Michigan Transportation Asset Management Council has implemented a two-tiered training structure to help educate agencies. There is an introductory course on asset management and pavement management followed by advanced courses on pavement preservation and asset management (TAMC, 2007).

Virginia

Virginia Department of Transportation has designed decision matrices to determine maintenance needs for interstate, primary, and secondary route pavements. Maintenance activities for secondary pavements are classified into four different categories: Do Nothing (DN), Preventive Maintenance (PM), Corrective Maintenance (CM), or Restorative Maintenance (RM). Table 2.5 breaks down the treatment types associated with each of these categories.

Table 2.5: Maintenance Activities for Secondary Pavements for Different Activity Category (Chowdhury, 2008)

Activity Category	Activities
Do Nothing (DN)	N/A
Preventive Maintenance (PM)	1. Minor Patching (<5% of Pavement Area) • Surface Treatment or Chip Seal Patching • Surface Patching (Depth 2")
	2. Crack Sealing
	3. Surface Treatment (Chip Seal, Slurry Seal, Latex, 'Novachip' etc.)*
Corrective Maintenance (CM)	1. Moderate Patching (<10% of pavement area; Partial Depth Patching; Depth 4")
	2. Partial Depth Patching (<10% of Pavement Area; Depth 2"-4") and Surface Treatment
	3. Partial Depth Patching (<10% of Pavement Area; Depth 2"-4") and Thin (1.5") AC Overlay
	4. 1.5" AC Overlay
	5. 1.5" Milling and 1.5" AC Overlay
Restorative Maintenance (RM)	1. Heavy Patching (<20% of Pavement Area; Full Depth Patching; Depth 8")
	2. ≤4" Milling and Replace with ≤4" AC Overlay
	3. Heavy Patching (<20% of Pavement Area; Full Depth Patching; Depth at least 6") and 1.5" AC Overlay
	4. Heavy Patching (<20% of Pavement Area; Full Depth Patching; Depth at least 6") and 4" AC Overlay

For Virginia, three condition indices are defined: Load-related Distress Rating (LDR), Non-load related Distress Rating (NDR), and Critical Condition Index (CCI). LDR gives an indication of the damage done to the pavement in the wheel path due to wheel loads (McGhee, 2002). New pavement is assigned an LDR of 100, and this index decreases as wheel path damage increases. The distresses that affect LDR include alligator cracking, patching, potholes, delaminations, and rutting (McGhee, 2002). NDR indicates the non-load related distress severity on the pavement such as block cracking, patching and longitudinal cracking out of wheel path, transverse cracking, reflection cracking, and bleeding (McGhee, 2002). These distresses are not a direct consequence of wheel loads and usually can be treated with less drastic treatments (McGhee, 2002). NDR, similar to LDR, is an indicated on a scale from 0 to 100, with 100 being new pavement. For both LDR and NDR, deduct values are calculated using modified PAVER curves developed by VDOT based on the distress types observed on the pavement (McGhee, 2002). CCI is the overall indicator of pavement condition and is defined as the lower value of LDR or NDR. CCI is used as one of the triggers for deciding on the maintenance treatment applied to the pavement section.

Maintenance treatment selection is using the CCI triggers as well as the decision matrices developed (Izeppi et. al, 2015). Figure 2.9 shows the CCI triggers for each route type in Virginia.

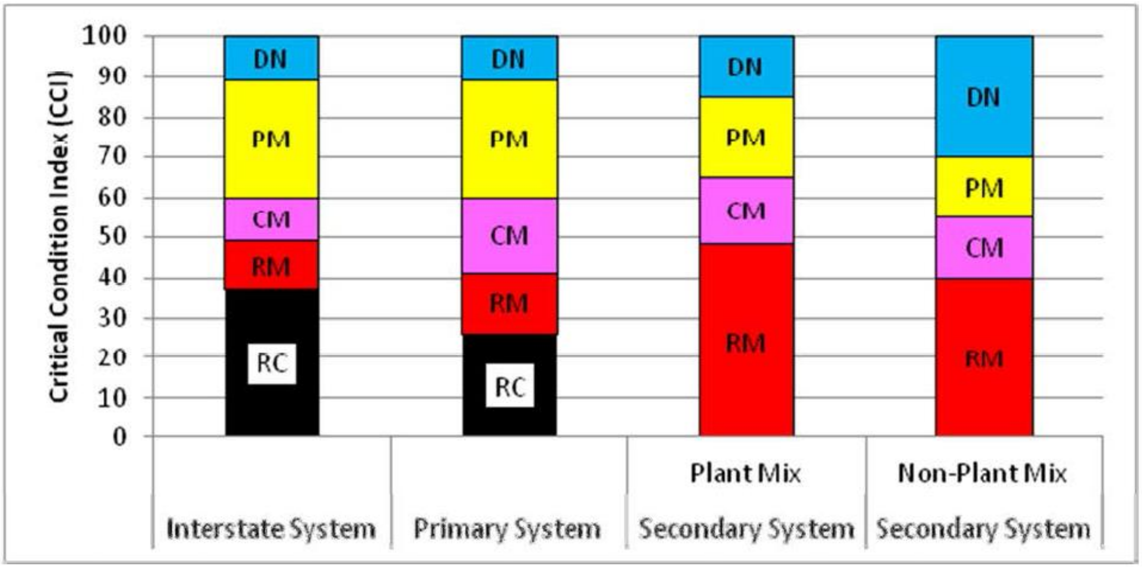


Figure 2.9. CCI Triggers for Each Maintenance Category (Izeppi et. al, 2015)

In addition to using the CCI triggers, VDOT uses a decision matrix that incorporates traffic level, structural condition, and maintenance history of the roadway segment.

California

The California Department of Transportation (Caltrans) has created the *Maintenance Technical Advisory Guide (MTAG) Volume I: Flexible Pavement Preservation Second Edition.* The first edition of this guide was developed in 2003 after Caltrans began a push to "provide technical and uniform guidelines to Caltrans personnel in their pavement maintenance and preservation activities" (Caltrans, 2007). Caltrans also created the Pavement Preservation Task Group (PPTG) to get input on the most current practices from local agencies, the industry, and academia (Caltrans, 2007). The second, and most recent, edition of the MTAG was published in 2007 to make sure the information provided in the guide was up to date with current technology and current information.

According to the MTAG, subgrade soil, pavement material characteristics, traffic loading, and environment all affect the performance of pavement. Subgrade soil must be classified correctly so it can be known how thick pavement should be on it.

The Caltrans treatment selection process begins by assessing the existing pavement conditions. The assessment involves three processes according to the MTAG:

- Visual site inspection and/or inspection of project information from database and/or records
- Testing the existing pavement
- Define the performance requirements for treatment

Caltrans uses the Caltrans Field Distress Manual or the Caltrans Pavement Survey to identify the pavement distresses and their severities. Caltrans recommends having the reviewer of the pavement fill out a well-developed pavement assessment form in order to create uniformity in the process (Caltrans, 2007). Once the pavement condition is identified, Caltrans uses a treatment selection matrix to see feasibility of each treatment for the distress type. Figure 2.10 shows the Caltrans Treatment Selection Matrix.

Caltrans has a Pavement Preservation Program. This program includes the development of the aforementioned Pavement Preservation Task Group. It also includes the publishing of a Maintenance Technical Advisory Guide (MTAG) for flexible pavement and rigid pavement. These MTAGs also include training modules on each chapter to help with education. Caltrans puts on an annual California Pavement Preservation Conference. In these conferences, colleagues are able to present on their usage of different treatments as well as introduce new technology or research in the pavement preservation area.

Preventive Treatments	Raveling	Oxidation	Bleeding	Rutting <1/2"	Rutting >1/2"	Climate Desert	Climate Valley	Climate Coastal	Climate Mountains	Traffic Volumes adt < 5000	Traffic Volumes adt>5000<30,000	Traffic Volumes adt>30,000	Night	Cold	Stop Points	urban	Rural	High Snow Plow use	Cost per lane-mile (Total Project Cost includes traffic control)	Treatment Costs, Cost: $/SQ YD (Treatment Only): Large Projects	Medium Projects	Small Projects	Addtl Premium for night work $/SQ YD	Addtl Premium for Short Work Periods or Work Zones $/SQ YD
Crack/Joint Seal																								
Emulsion	N	N	N	N	N	G	G	G	G	G	G	G	N	N	G	G	G	G	8,000	0.50-0.65	0.60-0.75	0.70-0.85	+0.15-0.20	+0.60-1.00
Modified (Rubber)	N	N	N	N	N	G	G	G	G	G	G	G	G	G	G	G	G	G	8,000	0.55-0.70	0.65-0.80	0.75-0.90	+0.15-0.20	+0.60-1.00
Seal Coats																								
Fog Seal (See note 1)	F	G	N	N	N	G	G	G	G	F	F	N	N	P	F	G	G	F	13,000	0.15-0.30	0.15-0.30	0.15-0.30	+0.05	+0.10
Rejuvenator (See note 1)	G	G	N	N	N	G	G	G	G	G	F	N	N	N	N	G	G	F	15,000	0.20-0.50	0.20-0.50	0.20-0.50	+0.10	+0.20
Scrub Seal (See Note 4)	G	G	N	N	N	G	G	G	G	G	F	N	N	G	N	F	G	P	17,000	2.15	2.15	2.15	N/A	N/A
Slurry Seals																								
Type II (See note 1)	F	G	N	N	N	G	G	G	F	G	G	G	N	N	G	G	G	P	23,000	1.60-2.20	1.75-2.40	1.90-2.60	N/A	+0.30
Type III	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P	24,000	1.60-2.20	1.75-2.40	1.90-2.60	N/A	+0.30
REAS	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P		1.20-1.80	1.20-1.80	1.20-1.80	N/A	+0.30
Microsurfacing																								
Type II	G	G	N	G	F	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00-2.80	2.10-2.90	2.25-3.00	+0.10-0.20	N/A
Type III	G	G	N	G	G	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00-2.80	2.10-2.90	2.25-3.00	+0.10-0.20	N/A
Chip Seals																								
PME - Med. Fine (See Note 4)	G	G	N	F	N	G	G	F	F	G	G	N	N	N	P	P	G	P	27,000	1.80-2.00	2.25-2.75	3.00-3.50	N/A	+0.50-1.00
PME - Medium (See Note 4)	G	G	N	F	N	G	G	F	F	G	N	N	N	N	P	P	G	F	27,000	1.80-2.00	2.25-2.75	3.00-3.50	N/A	+0.50-1.00
PMA - Medium (See Note 3.)	G	G	N	F	N	G	G	G	G	G	G	N	N	G	P	P	G	F	24,000				N/A	
PMA - Coarse (See Note 3.)	G	G	N	F	N	G	G	G	G	G	N	N	N	G	P	P	G	G	24,000				N/A	
AR - Medium	G	G	N	F	N	G	G	G	G	G	G	N	G	G	P	P	G	F	65,000	3.75-4.55	4.00-4.75	4.25-5.00	N/A	+0.50-1.00
AR - Coarse	G	G	N	F	N	G	G	G	G	G	N	N	G	G	P	P	G	G	65,000	3.75-4.55	4.00-4.75	4.25-5.00	N/A	+0.50-1.00
Cape Seals																								
Slurry	G	G	N	F	N	G	G	G	G	G	G	G	N	N	G	G	G	P						
Micro	G	G	N	G	F	G	G	G	G	G	G	G	N	N	G	G	G	P						
PM Alternative to a Seal Coat > 30,000 ADT																								
PBA-O	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	P	65,000	8-12	8-14	10-16		+1.20-4.00
RAC-O	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	60,000	10-14	10-14			+1.50-3.50
RAC-O High Binder (HB)	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	65,000	10-14	10-14			+1.50-3.50
RAC-G	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10-14	10-14			+1.50-3.50
PBA-G	G	G	P	P	N	G	G	G	G	G	G	G	F	F	G	G	G	G	60,000	8-12	8-14	10-16		+1.20-4.00
Thin Bonded Wearing Course (BWC)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10-14	10-14			+1.50-3.50
Thin Bonded Wearing Course Rubber (BWC-RAC O/G)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10-14	10-14			+1.50-3.50
Maintenance Treatments																								
Thin Lifts Overlays																								
Conventional	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	45,000	8-12	8-14	10-16		+1.20-4.00
PBA	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	60,000	8-12	8-14	10-16		+1.20-4.00
RAC	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10-14	10-14			+1.50-3.50
Digouts	P	P	G	N	G	G	G	G	G	G	G	G	G	G	G	G	G	G	125,000					

Last revised 03/22/07

G-Good Performance F - Fair Performance P - Poor Performance N - Not Recommended

Note: 1. Usually limited to shoulders, low volume roads and parking areas.

Note: 2. Generally used on shoulders, parking areas and locations where less aggressive surface is desired.

Note: 3. Under evaluation. Please consider other strategy at this time.

Note: 4. Use of Pass Rejuvenating Seal Under evaluation. Please consider other PME strategy at this time.

Figure 2.10. Caltrans Treatment Selection Matrix (Caltrans, 2007)

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CHAPTER 3. SCDOT Pavement Practices

Current South Carolina Practices

In 2009, the South Carolina Department of Transportation published *Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Pavements*. This manual was published to help with selection of preventive maintenance treatments for flexible pavement preservation in South Carolina. This manual defines five preventive maintenance treatments used in South Carolina: crack sealing, chip seals, microsurfacing, ultra-thin asphalt overlays, and full depth patching. In addition, the manual describes asphalt distresses measured in South Carolina: fatigue cracking, transverse cracking, longitudinal cracking, raveling, rutting, bleeding, and oxidation. The descriptions of the preventive maintenance treatments and asphalt distresses provided in this section below are excerpts from the manual.

South Carolina Pavement Distress Types

Fatigue Cracking

Fatigue cracking is a "series of interconnected cracks enclosing multi-sided pieces, usually less than one (1) foot on the longest side" (SCDOT, 2009). It results from repeated traffic loading or a weakening of the base layers of the pavement. It usually appears as a crack in the wheel paths.

Low severity fatigue cracking may consist of:

1. A single crack in the wheel path
2. Disconnected hairline longitudinal cracks
3. Longitudinal cracks with interconnections just beginning to form
4. Longitudinal cracks combined with horizontal cracks, forming a "net," and commonly referred to as alligator cracking. The alligator cracking may involve all four wheel paths or even the entire road.

Moderate severity fatigue cracking consists of at least three but usually all of the following:

1. Cracks that are not fine or narrow, but rather beginning to widen into widths of appoximately ½ inch
2. Cracking pattern has almost always reached the "alligator" stage
3. The pieces of the alligator cracking usually are beginning to separate and may also be spalled
4. Often associated with old patches
5. The wheel path is often sunken where the moderate fatigue is concentrated

High severity fatigue cracking consists of at least three and usually all of the following:

1. Cracks that are noticeably wider, from ½ inch to an inch or more
2. The cracking pattern has almost always reached "alligator" stage
3. The pieces of the alligator cracking usually are separate, spalled, and breaking up
4. Pieces of the pavement may have broken away entirely, creating holes in the alligator pattern.
5. Often associated with old patches
6. The wheel path is often sunken where the high fatigue is concentrated.

The SCDOT also defines the percentages for the extent of the fatigue cracking.

1. Fatigue in one Wheel Path = 3%
2. Fatigue in two Wheel Paths = 11%
3. Fatigue in three Wheel Paths = 22%
4. Fatigue in four Wheel Paths = 45%
5. Fatigue over entire area = 80%

Transverse Cracking

Transverse cracking occurs relatively perpendicular to the centerline of the pavement. It often occurs as a result of natural shrinkage caused by thermal cycling, high temperature susceptibility of the asphalt mix, or as a result of paving over jointed concrete with asphalt or bituminous mix. Transverse cracking is considered low severity if the cracks are less than ¼ inch in width and have little or no spalling associated with the crack. Moderate severity transverse cracking is identified with a crack of ¼ inch to ½ inch in width with some possible spalling. Transverse cracking is considered high severity if it is greater than ½ inch in width. The extent of transverse cracking is broken down as follows:

1. Transverse Cracks greater than 60 ft. apart = 5%
2. Transverse Cracks between 60 ft. and 30 ft. apart = 15%
3. Transverse Cracks between 30 ft. and 15 ft. apart = 25%
4. Transverse Cracks between 15 ft. and 5 ft. apart = 50%
5. Transverse Cracks less than 5 ft. apart = 99%

Longitudinal Cracking

Longitudinal cracking is cracking that runs relatively parallel to the centerline but is non-load associated, therefore, it is outside the wheel path. It can occur as a result of a poor construction joint, natural shrinkage, or the temperature susceptibility of the asphalt mix. Longitudinal cracking usually occurs between the shoulder and the outside wheel path, between the wheel paths, or on or near the centerline. Low severity longitudinal cracks are less than ¼ inch in width with little or no spalling. Moderate severity longitudinal cracking is identified as between ¼ inch and ½ inch in width. High severity longitudinal cracks are greater than ½ inch in width with spalling often present and severe. The extent of longitudinal cracking is classified as follows:

1. One longitudinal crack = 20%
2. Two longitudinal cracks = 40%
3. Three longitudinal cracks = 60%
4. Four longitudinal cracks = 80%
5. More than four longitudinal cracks = 100%

Raveling

Raveling is the wearing away of pavement surface material by dislodging of aggregate particles and loss of asphalt binder. It affects the entire road. Low severity raveling involves the aggregate or binder wearing away but not to the point where aggregate pops out or the road becomes pitted. The roadway appearance may be grainy or like sandpaper. Moderate raveling involves aggregate and binder worn away causing a rough and pitted texture. The roadway is noticeably noisy and rough on the ride. High severity raveling involves a dramatic wearing away of aggregate and binder making the roadway very rough and pitted. The ride on the roadway is very noisy and very rough. The extent of raveling is defined as follows:

1. Very slight separation of aggregate from asphalt binder; surface still relatively smooth = 3%
2. Enough separation of aggregate and binder for road to become rough = 11%
3. Separation of aggregate and binder quite distinct and noticeably rough = 22%
4. Separation of aggregate and binder very marked; very rough = 45%
5. Separation of aggregate and binder dramatic; very rough = 80%

Rutting

Rutting is a longitudinal surface depression in the wheel path. Low severity rutting is defined as rut depth of less than ½ inch. Moderate rutting is defined as rut depth of ½ inch to 1 inch. High severity rut depth is greater than 1 inch. Extent is not relevant for rutting because instruments measure the rut depth in wheel paths.

Bleeding

Bleeding is excess bituminous binder occurring on the pavement surface, usually found in the wheel paths. It does not have any severity levels because it can be monitored by its extent.

Oxidation

Oxidation is the hardening of asphalt binder due to exposure to oxygen in the air that occurs over time. It causes pavements to loose flexibility and crack easier.

South Carolina Preventive Maintenance Treatments

The SCDOT primarily utilizes five different preventive maintenance treatments: crack seal, chip seal, microsurfacing, ultra-thin lift asphalt overlays, and full-depth patching.

Crack Sealing

Crack sealing is a preventive maintenance treatment designed to keep water from entering cracks in the asphalt where it can weaken the base and subgrade of the pavement. According to the SCDOT Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Pavements, "a good crack sealing candidate will have approximately three linear feet of sealable crack per square yard of pavement" (2009). Crack sealing is usually lower cost compared to other preventive maintenance treatments, but it has a relatively short life span. The manual recommends the treatment be done when the temperatures outside are cooler and cracks are relatively wide. Little quantitative analysis has been performed to show the life extension provided by this treatment, however the estimated life expectancy of treatment is two to five years if the proper timing and treatment is used.

Chip Seals

Chip seals are layers of asphalt emulsion followed by a layer of aggregate. Double treatments involve two layers of chip seal with the first layer containing larger aggregate and higher rate of emulsion than the second layer. According to SCDOT Guidelines, chip seals "do a good job of stopping moisture infiltration and the oxidation that occurs to asphalt pavements from exposure to ultraviolet rays" (2009). The manual recommends that chip seals be used on roads with ADT of less than 1,500 vehicles per day, which puts them mostly on rural roads. The expected life of a chip seal ranges from five to seven years if the proper technique is used when implementing this treatment.

Microsurfacing

Microsurfacing involves a mixture of polymer modified asphalt emulsion, mineral aggregate, mineral filler, water, and other additives that are proportioned, mixed and spread using specialized equipment (SCDOT, 2009). Microsurfacing helps prevent oxidation, water infiltration, and damage to pavement due to ultraviolet rays. Microsurfacing has a life expectancy of approximately five to seven years. However, the SCDOT recommends not using microsurfacing on primary routes with high volume because the SCDOT has limited experience with microsurfacing.

Ultra Thin Asphalt Overlays

Ultra thin asphalt overlays (also called thinlays) are a hot-mix asphalt surface course applied in a lift between ½ and 1 inch thick. It can be placed with or without milling the existing pavement. Moderate or severe working cracks along with non-working cracks should be sealed at least six months in advance to placing ultra thin asphalt overlays. Ultra thin asphalt overlays should have life expectancy of six to eight years depending on how well the overlay bonds to the existing pavement.

Full Depth Asphalt Patch

Full depth asphalt patch is used to repair isolated areas of severe alligator cracking by removing and replacing failed base and sub-grade. It should include a minimum of six inches of asphalt surface course. The average life expectancy of full depth patching is about five years but depends on whether the entire area of failed base and subgrade were replaced properly.

Treatment Usage

As illustrated in Figure 3.1, chip seal is by far the most utilized preventive maintenance treatment employed by the SCDOT. A major reason for this is that several districts within SCDOT have their own chip seal program and perform the work “in-house,” thereby simplifying the contracting process and reducing the treatment cost compared to external sources. However, in recent years, full-depth patching and microsurfacing have been used by more counties as the SCDOT has gained more experience with these methods.

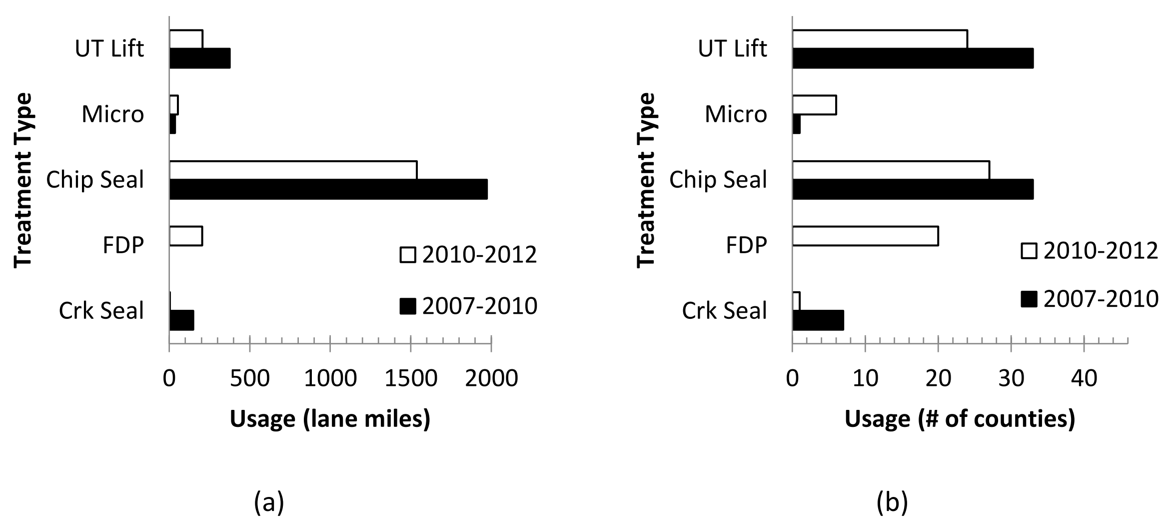


Figure 3.1. Utilization of different preventive maintenance treatments by SCDOT.

Figure 3.2 summarizes the average unit cost ($/lane-mile) and life extension of the preventive maintenance treatments used by the SCDOT. The unit cost is the weighted average of the treatment from projects statewide and does not include the cost of ancillary pay items such as a certain percent of full-depth patching or leveling that typically occurs prior to treatment application.

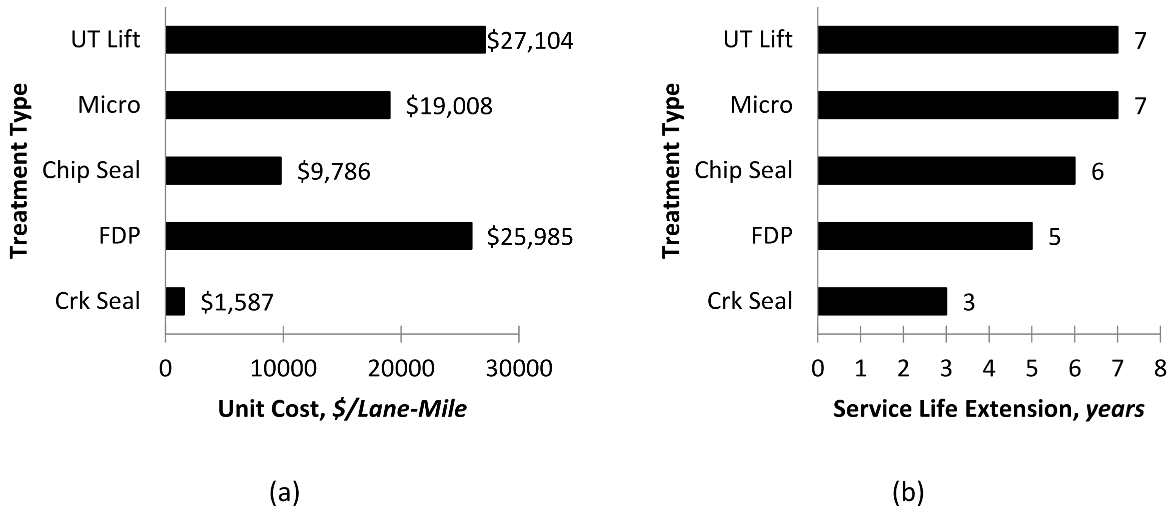


Figure 3.2. (a) average cost and (b) estimated service life extension of preventive maintenance treatments used by SCDOT.

South Carolina Candidate Selection

The South Carolina Department of Transportation received Highway Pavement Management Application (HPMA) index models developed by Stantec in April 2014. The three performance indices used are:

- Pavement Serviceability Index (PSI)
- Pavement Distress Index (PDI)
- Pavement Quality Index (PQI)

Pavement Serviceability Index (PSI)

Pavement Serviceability Index (PSI) is used to represent roughness in the SCDOT HPMA Index models. Roughness is usually measured in the field using devices that calculate the International Roughness Index (IRI) after measuring the longitudinal profile of the roadway (Stantec, 2014). IRI is converted into PSI for the SCDOT by equation 3.1.

$$PSI = 5e^{-0.004(IRI)} \tag{3.1}$$

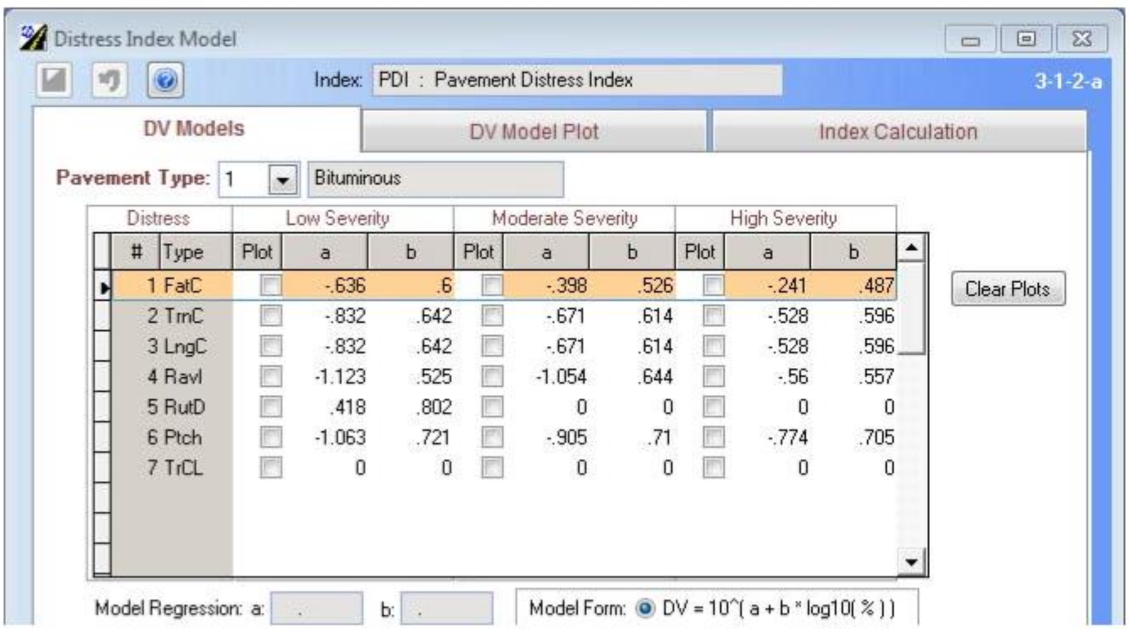
where 5 is the index scale, 0.004 is the local calibration factor, and IRI is the International Roughness Index measured in inches/mile.

Pavement Distress Index (PDI)

Pavement Distress Index (PDI) is used to convert distress measurements into a composite distress index. Distress type, distress severity, and distress extent are important in finding the PDI of the pavement. SCDOT collects distress data in three severity levels (low, moderate, and high) for all bituminous (BIT) pavement distress types previously mentioned, except rutting, which is based only on extent and not severity level (Stantec 2014). The distresses are combined using a deduct value model which "is a modified version of the PCI Method (ASTM D 6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys)" (Stantec, 2014). This modified version has been customized to best suit the SCDOT. Equation 3.2 for the deduct values is given below.

$$DV = 10^{(a+b\log_{10}(PDA))} \tag{3.2}$$

where DV is the deduct value, PDA is percent distressed area (extent value), and a and b are model coefficients. Figure 3.3 provides a display of the model coefficients (a and b) for each distress type for bituminous pavement.



Distress		Low Severity			Moderate Severity			High Severity		
#	Type	Plot	a	b	Plot	a	b	Plot	a	b
1	FatC		-.636	.6		-.398	.526		-.241	.487
2	TrnC		-.832	.642		-.671	.614		-.528	.596
3	LngC		-.832	.642		-.671	.614		-.528	.596
4	Ravl		-1.123	.525		-1.054	.644		-.56	.557
5	RutD		.418	.802		0	0		0	0
6	Ptch		-1.063	.721		-.905	.71		-.774	.705
7	TrCL		0	0		0	0		0	0

Figure 3.3. Model Coefficients for South Carolina HPMA Index Models (Stantec, 2014)

The deduct values (DV) are then summed to get the total. Equivalent Distress (ED) is then calculated for each distress using equation 3.3.

$$ED = \frac{DV_i}{DV_{max}} \tag{3.3}$$

The Number of Equivalent Distresses (NED) is then calculated by putting the sum of the deduct values (TDV) over DV_{max}. Adjusted Deduct Value (ADV) is then calculated by equation 3.4.

$$ADV = 10^{(0.0014-0.3958\log_{10}(NED)+0.9565\log_{10}(TDV))} \tag{3.4}$$

Finally, PDI is calculated by subtracting ADV from the index scale (equation 3.5).

$$PDI = 5 - ADV \tag{3.5}$$

Pavement Quality Index (PQI)

Pavement Quality Index (PQI) is used to "provide a single overall assessment of the pavement quality" by combining PSI and PDI into an overall index (equation 3.6).

$$PQI = PDI^{0.76} \times PSI^{0.20} \tag{3.6}$$

The SCDOT chooses pavement preservation candidates based on the PQI of the roadway section. The trigger values for pavement preservation for each road type in South Carolina are as follows:

- US and SC Routes: PQI greater than or equal to 3.2 but less than 4.0
- Federal-aid Secondary Routes: PQI greater than or equal to 3.2 but less than 4.0
- Secondary Routes: PQI greater than or equal to 3.0

These PQI triggers give SCDOT a set of candidates, then treatment selection is decided based on a number of other factors. According to the SCDOT *Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Pavements,* the following factors are used for treatment selection:

- Traffic volumes
- Location
- Availability of Materials
- Cost effectiveness
- Volume of Work

Figure 3.4 displays the treatment selection matrix created for the SCDOT.

Treatment	Distresses											Parameters						
				Rutting		Cracking						Roughness		Traffic Vol.				
						Fatigue*			Long./Trans.									
	Raveling	Oxidation	Bleeding	< 1/2"	> 1/2" < 3/4"	0 to 2% High	2 to 10% Medium	4 to 25% Low	0 to 2% High	> 2% Medium	> 4% Low	IRI < 170	IRI > 170	Low	Medium	High	Urban	Rural
Crack/Joint Seal																		
Emulsion	NR	NR	NR	NR	NR	F	P	NR	NR	P	G	G	NR	G	G	G	G	G
Modified Rubber	NR	NR	NR	NR	NR	G	F	P	G	G	G	G	NR	G	G	G	G	G
Chip Seal																		
PME - Lightweight Agg.	G	G	G	F	NR	F	F	F	F	F	F	G	NR	G				G
PME - Crushed Granite	G	G	G	F	NR	F	F	F	F	F	F	G	NR	G				G
Microsurfacing	G	G	G	G	F	F	F	F	F	F	F	G	NR	G	G		G	G
Ultra Thin Lift Asphalt Overlay	G	G	G	G	F	F	F	F	F	F	F	G	NR	G	G	G	G	G
Full Depth Patch	NR	NR	NR	NR	NR	G	G	G	NR	NR	NR	NR	NR	G	G	G	G	G

Good Performance G
Fair Performance F
Poor Performance P
Not Recommended NR
Not Used

The quantity and/or severity that are listed for each distress indicate the degree that is considered significant. See Appendix A for a description of these distresses and severity levels.
*Does not include isolated areas that can be repaired with a full depth patch.

Figure 3.4. Treatment Selection Matrix (SCDOT, 2009)

Comparison of SCDOT and Other States' Pavement Preservation Practices

Michigan has had a preventive maintenance program since 1992. It uses five different thresholds on which to base treatment selection. In addition, it is able to estimate the life extension each of these treatments will provide. While South Carolina does develop historic projections of treatment effectiveness, it does not have sufficient detail to standardize selection and the optimization of life extension expected from treatment. Michigan also focuses heavily on the remaining service life (RSL) and the critical distress point (CDP). Michigan wants to implement preservation techniques on roadways that are nearing the CDP to keep them from needing more serious maintenance work. Finally, Michigan has training courses offered to help educate agencies on how to best implement the preservation techniques.

Virginia uses a different set of condition indices from the other states reviewed. The critical condition index (CCI) is used as the trigger to choose what type of maintenance to perform on the roadway segment. Virginia then uses more detailed decision matrices based on traffic level, maintenance history, and structural condition of the roadway to decide on the best treatment type. South Carolina chooses treatments in a similar way. PQI in South Carolina is used as the original trigger before using the decision matrix shown in Figure 3.4 to better decide on the treatment type. However, Virginia boasts much more detailed matrices than South Carolina.

California treatment selection has become more uniform as they have introduced the MTAG as well as a manual and survey to identify pavement distresses. Caltrans has a very detailed treatment selection matrix shown in Figure 2.10. In addition, Caltrans holds an annual California Pavement Preservation Conference to encourage collaboration on this subject.

Distress data collected by each state are similar. Michigan relies heavily on a number of indices used to make decisions on treatment types while South Carolina, California, and Virginia rely on treatment selection matrices. Virginia and California have much more detailed decision matrices than

South Carolina. Virginia has detailed decision matrices to decide on type of treatment by using traffic and location. California also has a section on the treatment selection matrix related to climate. It is important for a large state like California to take into account their climate, but this may also be important for South Carolina as the coastal areas have different climate than farther inland. South Carolina could benefit from a more detailed treatment selection matrix like the ones offered by California and Virginia.

Pavement Management Survey

To gain a better understanding of the current pavement preservation practices in the state of South Carolina, a survey was sent out to all the SCDOT District Maintenance Engineers (DMEs), Resident Maintenance Engineers (RMEs), and Resident Construction Engineers (RCEs) in the state. This survey was created using the website SurveyMonkey, and it was distributed throughout the state by email. The survey was released originally in September of 2013, and re-released in May of 2015. The survey questions included:

1. Please provided your contact information
   - (name, email, and phone number)
2. What is your position with SCDOT?
   - (DME, RME, RCE, other)
3. How many years of experience do you have with pavement maintenance and preservation?
   - (0-2, 3-5, 6-10, 11-15, 16-20, 20+)
4. What process do you use to identify preservation candidates in your area? (e.g., run query in SCDOT data system, or use report generated by district office).
5. Does your area conduct pavement evaluations to supplement the data collected by the van (interstates every year, non-interstate on 3 to 5-year rotation)? For example, do you have a RME or other doing pavement evaluations to select candidates for preservation?
   - (yes, sometimes, no)
6. Do you have a written process for these evaluations?
   - (yes, no)
7. Do you maintain a separate database?
   - (yes, no, other)
8. What is the frequency of these evaluations?
9. What is the coverage of these evaluations? Mileage per year? Or route category?
10. What types of pavement preservation treatments have you used in your area?
    - (asphalt rejuvenators, asphalt sealers, crack sealing, crack filling, scrub seals, sand seals, chip seals, cape seals, slurry seals, microsurfacing, ultra-thin overlays, bonded wearing course, profile milling, ultra-thin overlays (generally ≤ ¾ inch), thin overlays (non-structural, generally ≤ 1½ inch), mill and resurface (nonstructural, generally ≤ 1½ inch), full depth patch, hot in-place recycling, cold in-place recycling, other)
11. How do you decide which preservation treatment to use for a roadway?
12. Is there a specific type of treatment that you prefer to use? Why?
13. Are there preservation treatments that you would rather not use? Why?
14. Are there differences in treatment decisions by county in your district? (yes, no, don't know)
15. Do you have a specific pot of funds for maintenance (specifically pavement preservation)?
    - (yes, sometimes, no)
16. What is the typical funding level? How does this get distributed from district level to county level? Are there any specifications on this money?
17. What obstacles do you face with pavement preservation?
18. If a pavement preservation decision support system were developed for SCDOT, would you want that in a standalone software package or added to the SCDOT RIMS/ITMS data system?
    - (standalone, SCDOT system, other)
19. Do you have any suggestions for improving pavement preservation procedures, decisions, policies?

Survey Results

The Pavement Management Survey distributed to the South Carolina Department of Transportation elicited 98 total responses. The respondents included 10 District Maintenance Engineers (DME), 40 Resident Maintenance Engineers (RME), and 29 Resident Construction Engineers (RCE). Responses came from 3 Assistant RMEs, 2 Assistant RCEs, and 4 Assistant DMEs. The Contracts Engineer for 2 districts also responded.

When asked about years of experience with pavement maintenance and preservation, the responses were distributed as shown in Figure 3.6.

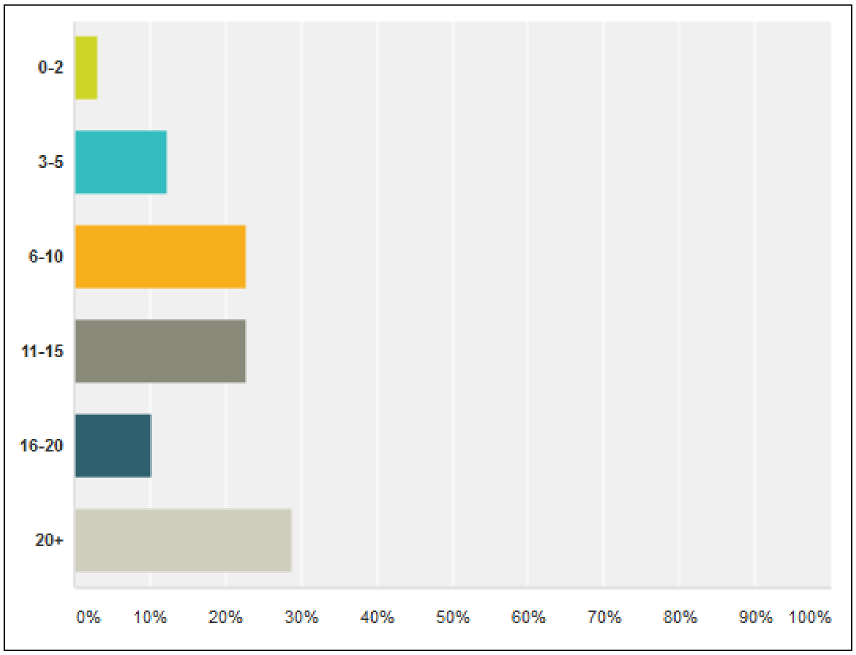


Figure 3.6. Years of Experience with Pavement Preservation

Seventy percent of the DMEs (7) had 20+ years of experience, one had 16-20 years, and the remaining two had 6-10 years of experience. The RMEs varied greatly on years of experience. All RMEs had at least 3 years of experience and over half had at least 11 years of experience. The RCEs also had differing years of experience with most having between 6 and 15 years of experience.

When asked what process they use to identify preservation candidates in their area. Most DMEs reported that the process used to identify preservation candidates in their areas involved using the SCDOT ITMS data system and performing visual inspections in the field. Some reported the use of a state and district ranking system as well as reports from district offices. The RMEs that answered the survey reported a variety of answers to how they identify preservation candidates. However, almost all of the respondents stated they used some combination of district reports, querying the SCDOT data, and field inspections to identify candidates. Some used a personal list of candidates or a plan created for a specific area to help prioritize candidates. The majority of the RCEs that took the survey either did not know how the preservation candidates were identified or stated that the RME or maintenance area chose the candidates.

When the respondents were asked if their area conducts pavement evaluations to supplement the data collected by the van, 28 (29.79%) indicated no supplemental evaluations, 35 (37.23%) stated that their area commonly conducted these supplemental pavement evaluations, and 31 (32.98%) stated that their area did these supplemental evaluations sometimes. Five of the DMEs said their areas did perform the pavement evaluations while 4 said their areas did not. Nine RMEs reported that they did not perform the pavement evaluations and 14 said their area did perform the supplemental evaluations with 17 doing it sometimes. The RCEs that took the survey had 9 state their area performed the supplemental evaluations and 12 state their area did not perform the supplemental evaluations. Seven RCEs reported that their area sometimes did evaluations to supplement the data collected by the van.

Over 75% (46) of the respondents stated that they did not have a written process for these evaluations. Five out of the six DMEs that answered said they have no written process for the evaluations. Twenty-six out of the thirty RMEs that responded said there was no written process. Over half of the RCEs that answered said there was no written process.

Only 18 out of 57 respondents stated that they did maintain a separate database for these evaluations. A few respondents were unsure if a separate database existed or not. Two respondents stated that there was a Microsoft Excel worksheet that showed work done in their area. When asked about the frequency of the evaluations, five DMEs answered this question - four stated it was done annually with the last stating they were done as needed. One DME stated that Act 114 discontinued the practice of these evaluations. Twenty-nine RMEs answered this question - fifteen RMEs said the evaluations were done annually, five RMEs said the evaluations were done as needed, and the rest of the RMEs said the frequency could be daily or vary. Most of the RCEs are not sure about the frequency of evaluations. The coverage of the evaluations also differed. Three DMEs answered this question - one said approximately 100 miles per year while another said 6000 miles, while another response stated that these were done as needed due to upcoming contracts. Eight RMEs said the route category determined the coverage. Others gave certain numbers for miles per year. Over half of the RCEs were not sure about this question.

The survey then asked for the types of pavement preservation treatments used in each respondent’s area. Figure 3.7 shows the responses to this question. Clearly, chip seals, full depth patch, and crack sealing are the three most used treatments in South Carolina, with microsurfacing coming in next.

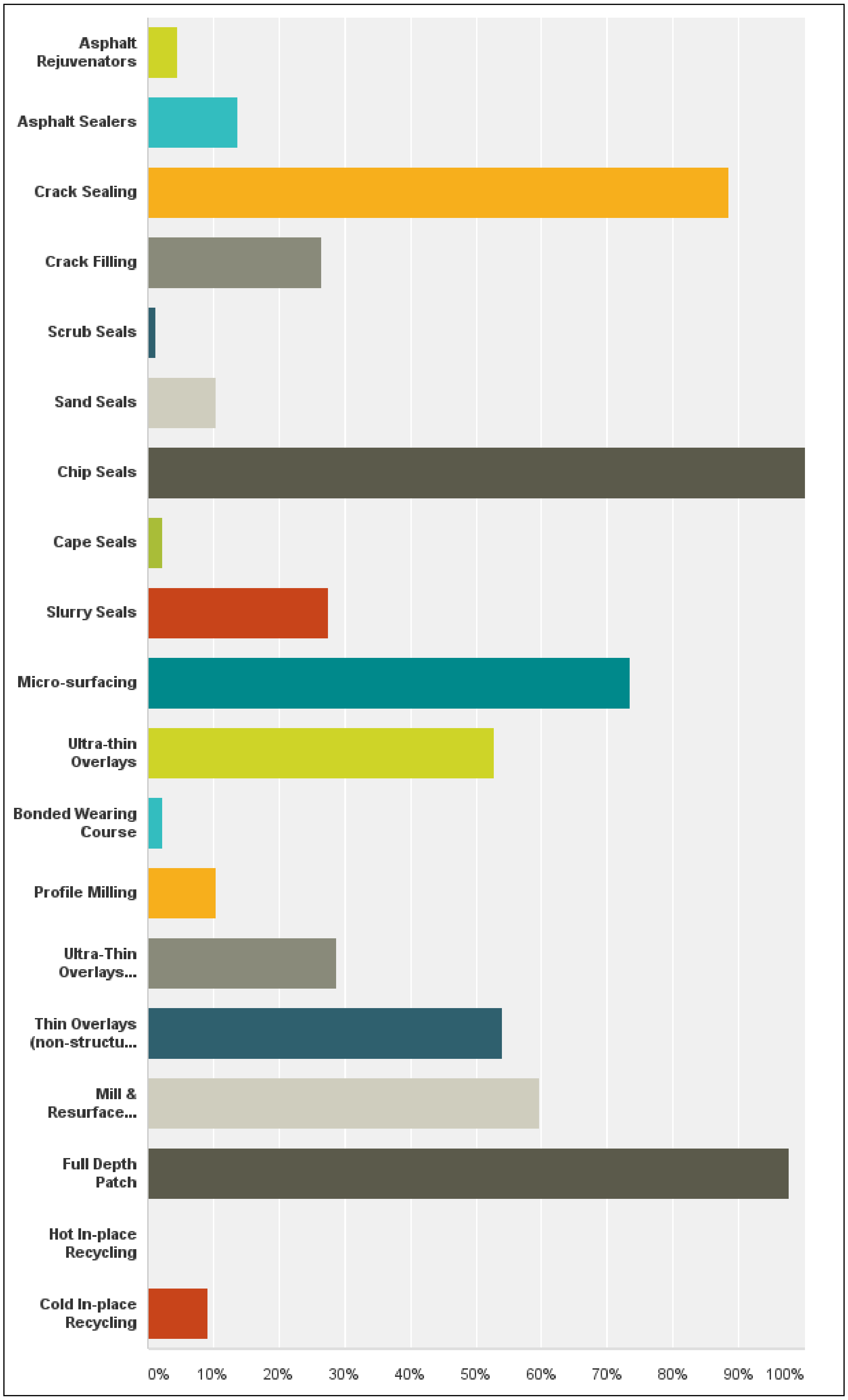


Figure 3.7. Types of Treatments and Frequency of Use in South Carolina

Respondents were also asked how they decide which preservation treatment to use for a roadway. Nine of ten DMEs answered this question - five stated that they use the condition of the pavement and its characteristics, and two stated that the RCE made the recommendations. DMEs also stated that they use past experience when choosing the treatment type. Most of the RMEs stated that the treatments are chosen based on roadway condition, ADT, and location of the road, but three stated the district office makes the decision. The majority of RCEs stated the contract dictated what type of treatment to use.

When asked if there was a specific treatment that was preferred, five of the nine DMEs did not have a specific treatment that they would prefer to use. The DMEs that had preferences stated that they wanted the cheapest and most effective treatments. Eleven RMEs stated that there was no preference on a specific type, but fourteen RMEs stated they preferred chip seals with a couple saying that they are cost effective. RCEs prefer to use thin lift overlays, full depth patching, and mill and resurface.

The survey also asked if there were treatments that the respondents would rather not use. Four of seven DMEs did not have a specific treatment that they preferred not to use, and two DMEs would rather not use thin lifts. Fifteen RMEs did not have treatments they would rather not use. A few others preferred not to use slurry seals, especially in large volume areas. RCEs, in general, don't like to use microsurfacing or slurry seals.

Sixty percent of DMEs (6) said there were no differences in treatment by county in their districts. Sixty one percent of the RMEs did not know with only 6% answering there were differences. Seventy two percent of the RCEs do not know if there are differences.

Sixty percent (6) DMEs stated they do have specific pots of money for maintenance. Forty-six percent of RMEs stated that a specific pot of funds is available sometimes. Forty percent of RMEs said specific pots for maintenance do exist. Fifty-two percent of the RCEs said there was a specific pot while 26% said there was sometimes. When asked about typical funding level, most of the DMEs stated that the district office distributes the funding. These allotments come as Federal Aid or Non-federal Aid. Nine RMEs stated that the district distributes the money, eight stated that the money is split by county based on the size of the county and the total length of roadway in the county, and seven RMEs did not know about the funding. Most of the RCEs did not know the typical funding level.

All 8 DMEs that answered this question stated that funding was one of the main obstacles. One DME stated that public perception of pavement preservation and having the roadways in good enough shape for effective pavement preservation techniques were also important obstacles. Seventeen RMEs stated funding was the biggest obstacle faced. Six other RMEs stated that the roads were not in good enough condition to preserve. Two other RMEs stated that public perception was an obstacle.

When asked whether a pavement preservation support system should be stand alone or added to the SCDOT data system, the majority of respondents wanted it to be added to the SCDOT data system. Figure 3.8 portrays the overall results given by the survey for this question. Two DMEs wanted a stand-alone system while 5 wanted it to be added to the SCDOT data system. One DME said either method would be fine. Fifteen RMEs (43%) want a stand-alone system while 20 RMEs want it to be added to SCDOT system. Sixty three percent of the RCEs wanted it to reside in the SCDOT system.

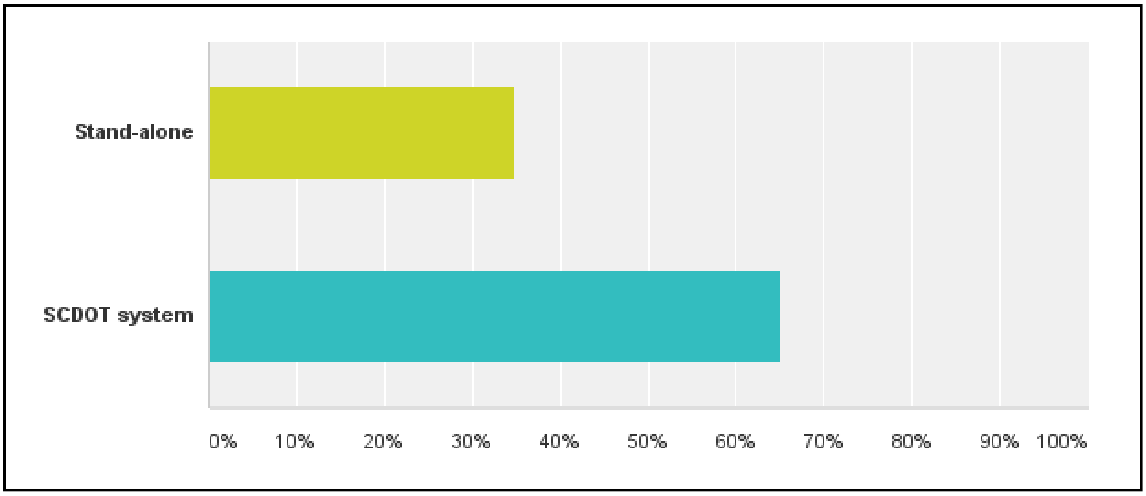


Figure 3.8. Results for Stand-Alone or Integrated SCDOT System

The last question on the survey asked respondents for suggestions for improving pavement preservation procedures, decisions, and policies. Multiple respondents claimed increased funding is desperately needed. Others stated that South Carolina needs to broaden the techniques it uses in order to become more cost effective. One respondent suggested implementing a public awareness program to educate the public on what is actually occurring in pavement preservation. Multiple others suggested that there be additional training as well as local input or checklist implementation when developing a statewide program.

Summary of Survey Results

The pavement management survey distributed to the SCDOT provided a good look into the current pavement preservation practices used in South Carolina. The evidence from the survey showed that currently the SCDOT has little in the way of uniform procedures for implementing pavement preservation. While most areas indicated undertaking pavement evaluations, there does not seem to be a standard process for this evaluation, nor a centralized location to store pre-treatment pavement distress inventories for use in future evaluations of the performance of the preservation treatments. The research team conducted an assessment of the HPMS data collection that is maintained in the ITMS system, and concluded that the data is sufficient for selecting pavement preservation treatments. However, the data collection frequency for lower tier roadways (i.e., state and secondary roads) only occurs once every 4-5 years. This frequency is insufficient to determine which roads should be treated for pavement preservation, and is likely the reason for responses indicating that manual evaluations were undertaken in area offices. Within a four-year period, a preservation candidate roadway left untreated can fall into disrepair and require costlier rehabilitation rather than more efficient preservation. The research team has developed a full data collection protocol for treatment sites (see Chapter 6) as well as a supplemental pavement evaluation protocol for time periods not covered by ITMS data (see Appendix D for evaluation protocols and training needs). These supplemental pavement evaluations are an important source of data for developing decision matrices based on pre-treatment distresses, as well as pavement life extension, and are recommended for inclusion in the statewide data system.

The majority of people who took the survey also wanted a pavement preservation decision support system that could be added to the current SCDOT ITMS. From this suggestion, the research team defined a data analysis process (see Chapters 4 and 5) that could be added to the current SCDOT

ITMS to identify, analyze, and prioritize improvement site and treatments, Chapter 4 reviews a number of available tools for conducting pavement preservation decision support, as well as defining a selection algorithm to identify candidates. Chapter 5 takes the candidates identified in Chapter 4 and uses a cost and life extension optimization to determine the most cost effective mix of treatments for the selected sites.

The survey also pointed out the one glaring problem with pavement maintenance: funding. There was overwhelming evidence that the largest problem with pavement maintenance and preservation is the lack of funding to complete the necessary projects. Support was also suggested for a public education program, as most individuals don't understand why a treatment would be applied to a roadway that is obviously in better condition than the one that has already failed. .

CHAPTER 4. Timing of Pavement Preservation Treatments

The following literature review explores existing pavement management software packages, pavement preservation practices in other states, and the current pavement preservation practices in the state of South Carolina.

Existing Software Packages

Existing pavement management software packages were researched to identify their data requirements and capabilities as well as suitability for use by the South Carolina Department of Transportation for pavement management. Three software packages reviewed: Streetsaver, PAVER 7.0, and OPTime. After completion of the analysis, a matrix was created to compare the three software packages to the current SCDOT ITMS. A matrix comparing the four systems can be found in Table 4.1. A description of the three software packages as well as the SCDOT ITMS is provided in this section.

Streetsaver

Streetsaver is a pavement management software published by the Metropolitan Transportation Commission. It was designed with pavement preservation principles in mind and is the most widely used PMS software on the West Coast (MTC, 2014). Streetsaver seems to be better suited for smaller networks such as those for cities or possibly small counties. Figure 4.1 below displays the inventory data input window for Streetsaver. An inventory is created to identify the roadway section as well as describe the location, area, surface type, functional classification, and construction dates.

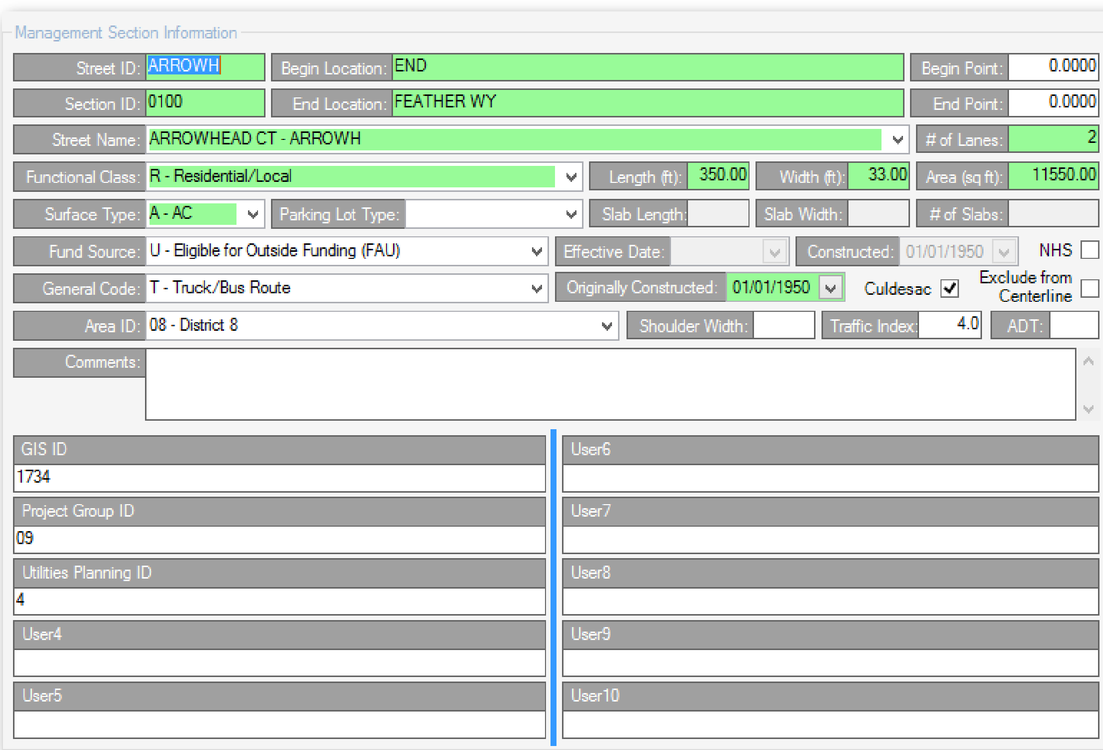


Figure 4.1. Inventory Data Input Window for Streetsaver

Streetsaver uses ASTM Standard D 6433 for condition assessment and offers full PAVER distresses or MTC's 7-Distress (MTC, 2014). MTC's 7-Distress looks at seven distresses at three severity levels for pavements with asphalt concrete and surface treatments. These seven distresses are: alligator cracking, block cracking, distortions, longitudinal and transverse cracking, patching and utility cuts, rutting and depressions, and weathering and raveling. Figure 4.2 displays how inspection data is input into Streetsaver.

Table 4.1. Comparison matrix of data elements included in different software packages. (R = required, O = optional)

	SCDOT	Streetsaver	OPTime	PAVER 7.0
Route Information				
Route ID	R	R		R
Length	R	R		R
Width		R		R
Area		R		R
Begin Point	R	R		
End Point	R	R		
Number of Lanes		R		O
Shoulder Information		O		O
ADT	R	O	R	
% Truck Traffic	R			
Functional Class	R	R		
Pavement Characteristics				
Surface Type	R	R	R	R
Concrete Specific		O		O
Initial Construction Date		R		R
Inspection Date	R	R		R
Distress Type	R	R	R	R
Distress Severity	R	R		R
Distress Quantity	R	R	R	R
Maintenance Data				
Treatment Date	R	R	R	R
Treatment Type	R	R	R	R
Treatment Cost				
Rehabilitation Data				
Rehab Date	R	R		
Rehab Activity	R		R	
Rehab Cost		R	R	
Budget/Other Cost Needs				
Interest/Inflation Rate		R	R	R
Budget Start Date		R		R
Budget Length		R		R
User Delay Cost			O	

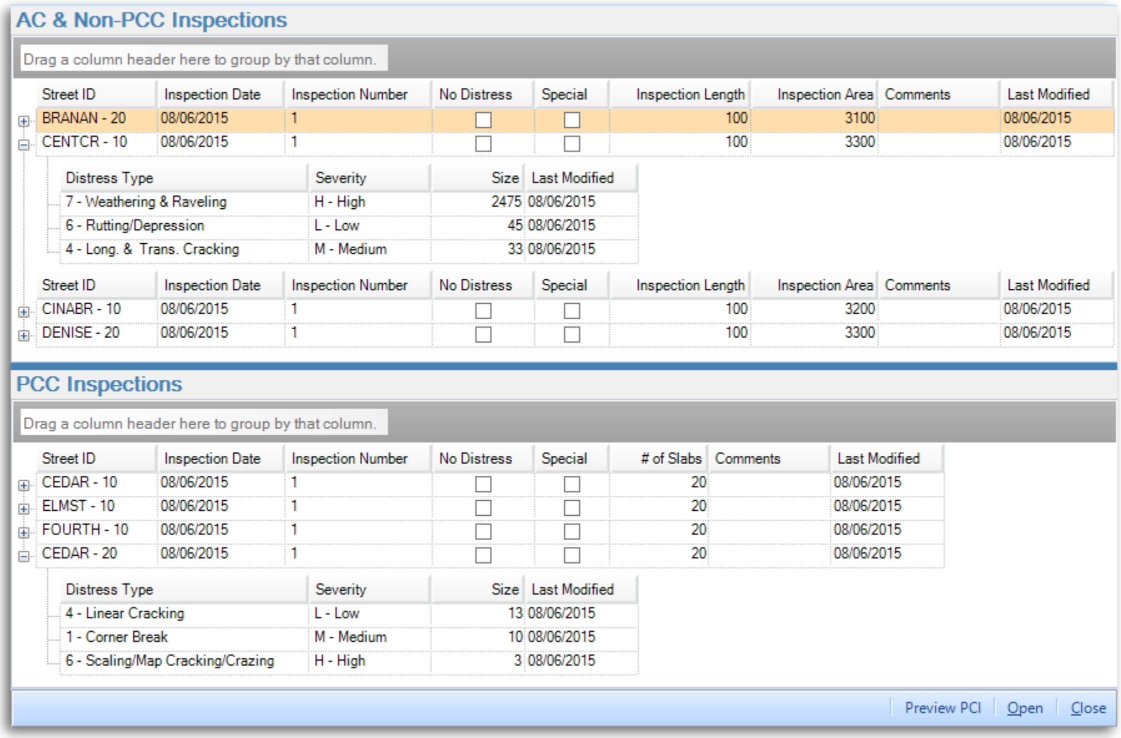


Figure 4.2: Inspection Data Input Window for Streetsaver

Streetsaver uses pavement condition index (PCI) to measure the condition of a pavement segment. The PCI has a scale of 0 to 100, with 100 being the best condition. This inspection data is used to calculate the PCI for the pavement section. The PCI is calculated for the current segment as well as projected for the future. It can be given for the segment or for the entire roadway network.

Streetsaver also provides a GIS toolbox that can link street networks to a GIS base map. Streetsaver also provides a budget analysis feature. It can provide a budget needs calculation to estimate the amount of maintenance work needed to bring the condition of the network to a level that is the most cost effective to maintain. It can also calculate budget scenarios to determine the impact of different funding strategies and can develop a list of pavement sections recommended for treatment within budget constraints specified by the user.

PAVER 7.0

PAVER 7.0, also known as MicroPAVER 7.0, is a maintenance and repair management tool that was developed by the U.S. Army Corps of Engineers and is distributed by the American Public Works Association (APWA). It is used to develop “cost effective maintenance and repair alternatives for roads and streets, parking lots, and airfields” (USACE, 2014). PAVER has the capability to create a pavement network inventory and rate the pavement condition of this inventory. It also allows for development of pavement condition deterioration models, determine present and estimate future pavement condition, and determine maintenance and repair needs. Finally, it allows for analysis of different budget scenarios. PAVER 7.0 also allows the user to create a maintenance and repair plan that can help with budgeting.

PAVER 7.0 gives the user the option to create a new inventory, import a PAVER database created previously (E60, E65, or E70 file), or import a network from GIS. These inventories include a network level, a branch level, and a section level. The networks are divided into branches while the branches are further divided into sections. These classifications of levels allow the user to access pavement condition characteristics of different levels of the network. PAVER 7.0 allows for uploading, saving, and viewing images of roadway sections. The feature is called the EMS™ Image Viewer. This feature allows an image to be attached to the network, branch, or section it is associated with to document the distresses found there. It also allows for multiple images to be stored for the same section to show the section over the time.

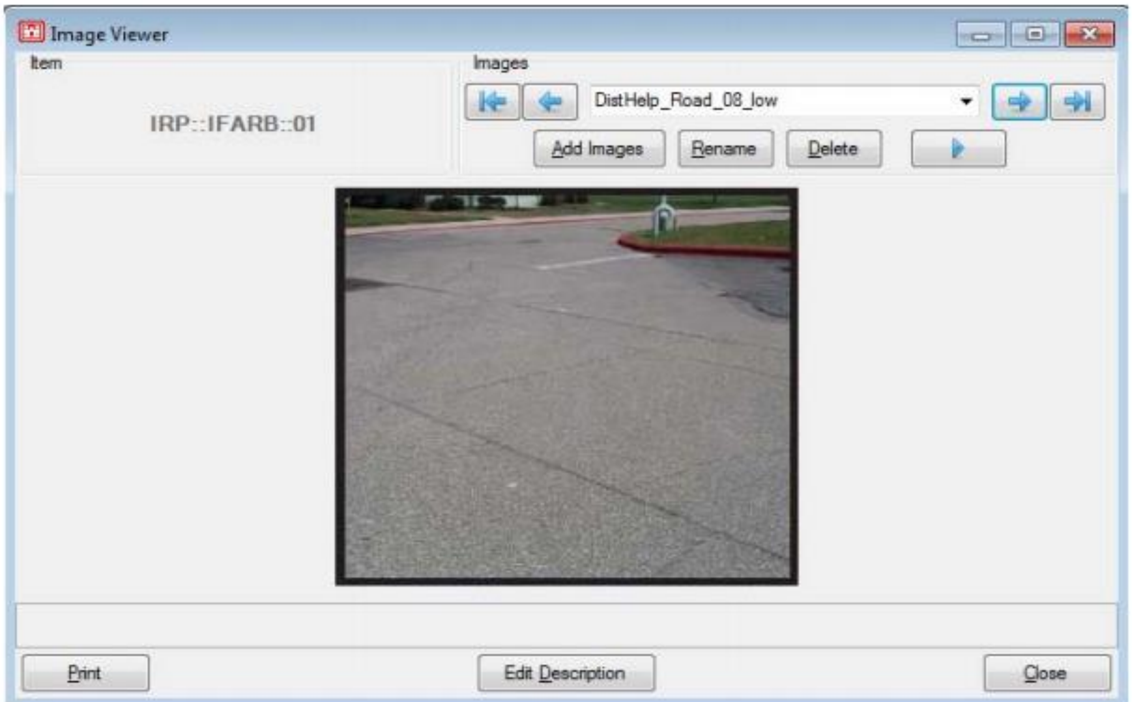


Figure 4.3. EMS™ Image Viewer in PAVER 7.0 (USACE, 2014)

PAVER 7.0 uses pavement condition index (PCI) to rate pavement condition. To calculate the PCI in the program, PAVER 7.0 asks the user to define maintenance and repair (M&R) procedures and costs. The program asks the user to define Localized Stopgap M&R, Localized Preventive M&R, Global Preventive M&R, and Major M&R. For each of these types of maintenance and repair, the user classifies the work type, cost of work type, cost by condition of pavement, and consequence of each maintenance policy. In addition, PAVER 7.0 asks the user to define priority based on branch use and section rank. The user will also define codes and work units for all layer types used as well as the costs associated with each layer type.

PAVER 7.0 "must have an accurate account of the last construction date for each section, in order to accurately predict future pavement performance, maintenance requirements, cost, and inspection schedule" (USACE, 2014). For this reason, it is important for the user to input work history data. The work history data can be entered through GIS or tabular data similar to adding inventory or can be entered through the Work History Wizard shown in Figure 4.4.

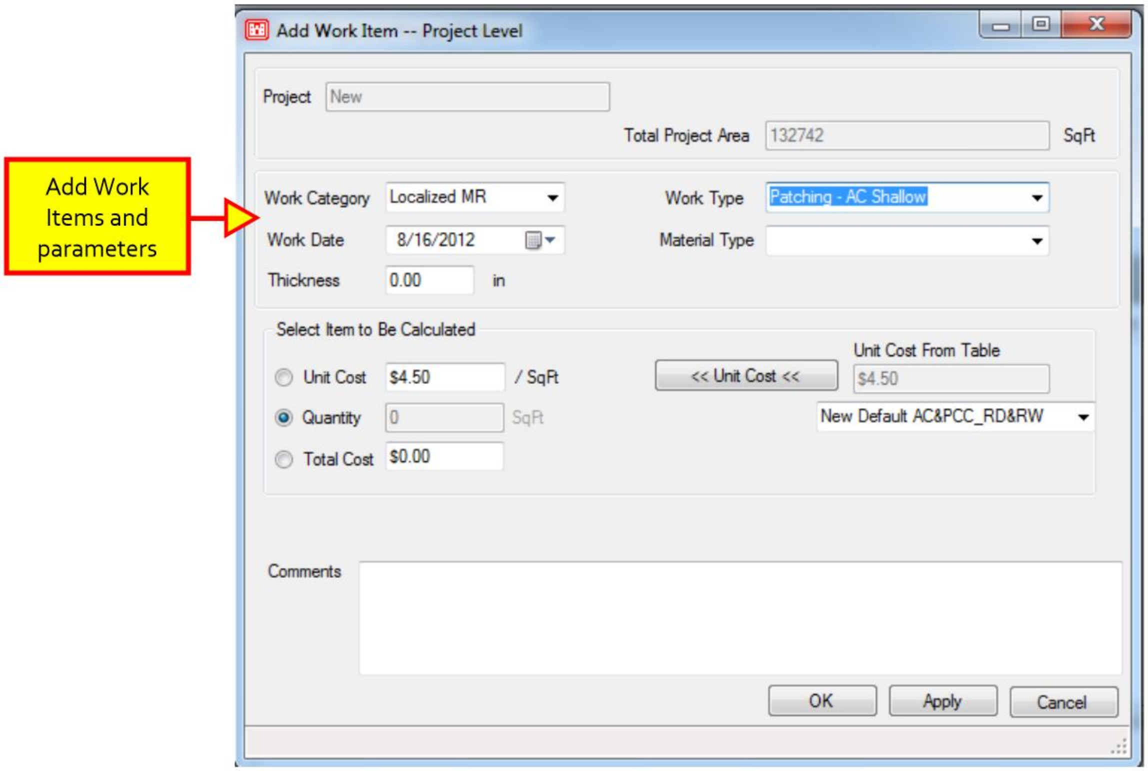


Figure 4.4: Work History Wizard in PAVER 7.0 (USACE, 2014)

Entering inspection data is also an important component to the use of PAVER 7.0. The user must select the section being inspected first. The inspection entry window is shown in Figure 4.5.

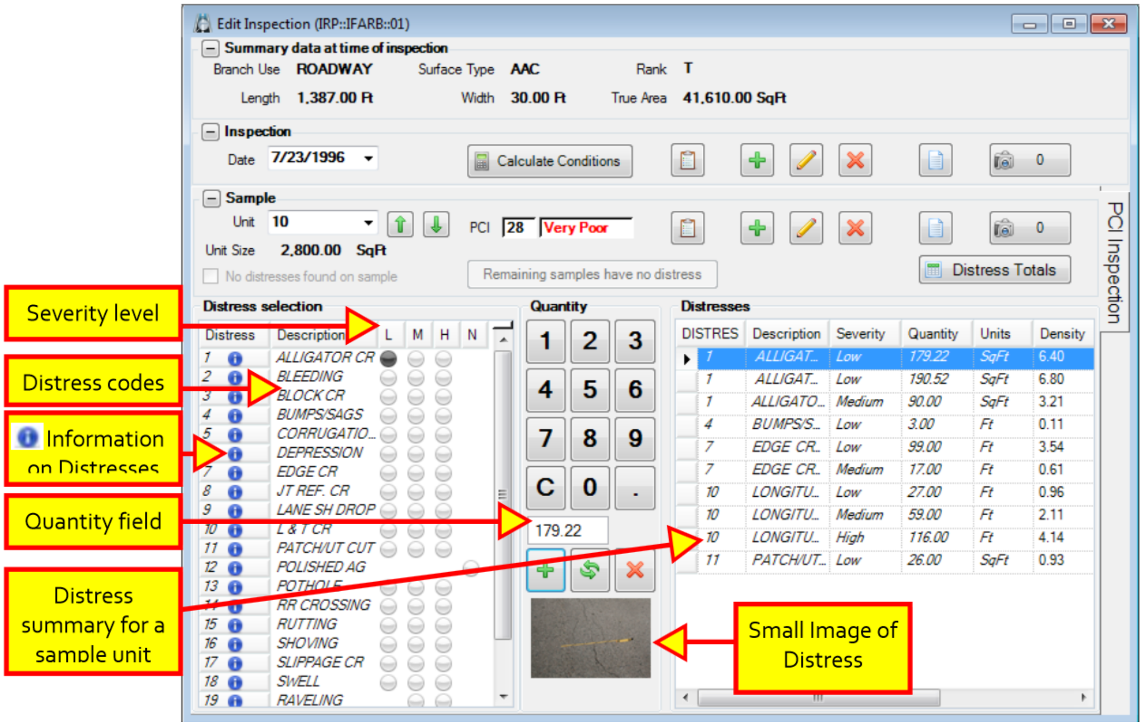


Figure 4.5. Inspection Entry Wizard in PAVER 7.0 (USACE, 2014)

PAVER 7.0 uses a "family modeling" system to group pavement sections together that have similar construction, traffic patterns, weather, and other pavement life affecting factors (USACE, 2014). This method of prediction allows PAVER 7.0 to give more accurate estimates of pavement life. PAVER 7.0 also offers a Condition Analysis tool that will show the condition of the pavement network based on inspection data, interpolated values between previous inspections, and family assignment based projected conditions (USACE, 2014).

PAVER 7.0 produces a number of reports for the user's benefit as well, including GIS reports. Once the inventory has been assigned to GIS as a shapefile, PAVER 7.0 allows the user to view inventory based surface type, branch use, rank, or category. The user can also view the current or latest PCI values for each roadway section in GIS. Lastly, PAVER 7.0 allows the user to view PCI Deterioration, Stopgap M&R, Preventive M&R, Global M&R, and Major M&R Family Assignments in GIS. The GIS reports allow a visual report on the network roadway condition and its maintenance and repair. PAVER 7.0 produces summary charts that can compare any two attributes of the database. In addition, it can produce four standard reports:

- Branch Listing Report: A list of all branches and information on all branches
- Work History Report: Section by section report of all work completed in a section throughout its life
- Branch Condition Report: Shows average and weighted average condition of each branch
- Section Condition Report: Shows average and weighted average condition of each section

PAVER 7.0 also gives the option to display a section history report. This report displays the work and inspection history of the selected section.

OPTime

OPTime is a free analysis tool used "to enable pavement preservation engineers to analyze historical preventive maintenance-related performance and cost data in order to determine the optimal timing of a given preventive maintenance treatment" (Hoerner et. al, 2004). The program gives the option of two types of analyses: detailed analysis and simple analysis. The detailed analysis evaluates observed data taken from monitoring the performance preventive maintenance treatments. The simple analysis gives states that have not implemented preventive maintenance treatments a chance to estimate performance of the treatments without actual performance data from the field. The software gives the option between two pavement types: HMA-Surfaced or PCC-Surfaced. This study was concerned only with the HMA-Surfaced options.

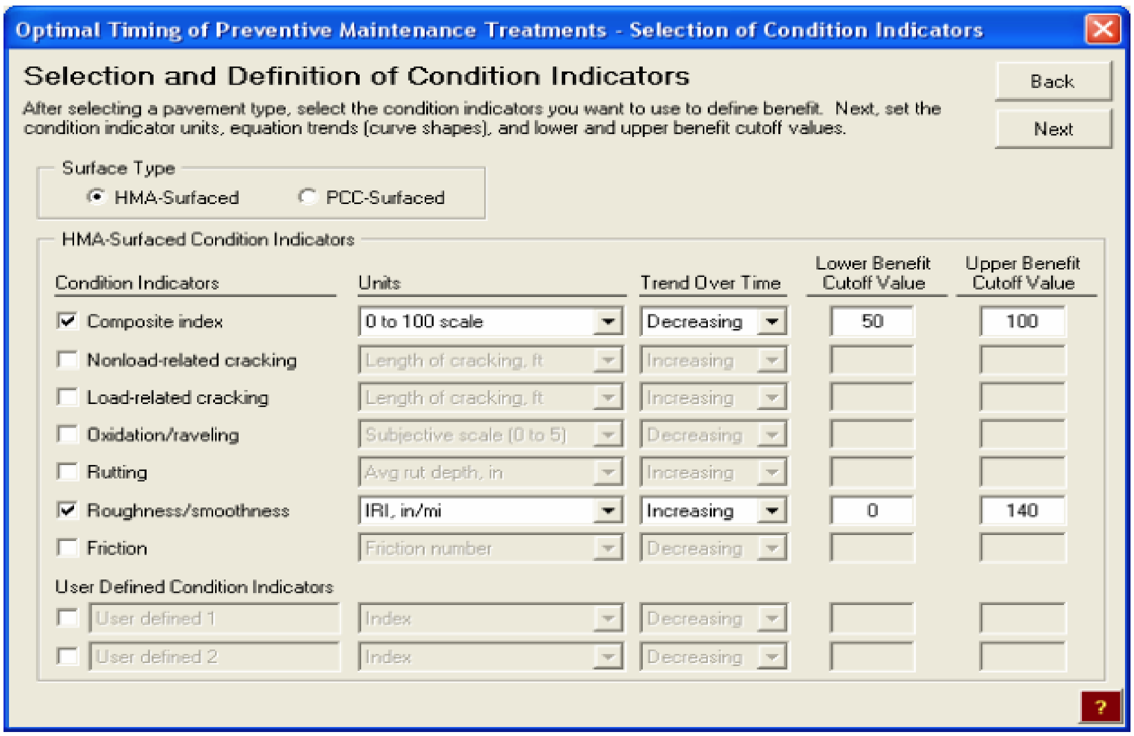


Figure 4.6. Selection of Condition Indicator Screen in OPTime (Hoerner et. al, 2004)

Once the surface type has been selected, the user must select condition indicators. HMA-Surfaced has seven default condition indicators with two user defined condition indicators. A description of these default condition indicators is shown in Table 4.2.

Table 4.2. HMA Condition Indicators Used in OPTime (Hoerner et. al, 2004)

Surface Type	Condition Indicator	Description
HMA	Composite index	Many agencies use composite indices to track pavement performance over time. Examples include a general cracking index or pavement condition index (PCI). Many of these decrease over time and are measured on scales such as a 0 to 100, 0 to 10, or 0 to 5.
	Nonload-related cracking	The sealing or rejuvenating nature of many surface treatments can reduce the development of environmental- or moisture-related cracking. This nonload-related cracking measure reflects that benefit, and would likely be measured in terms of the amount of cracking.
	Load-related cracking	Preventive maintenance treatments such as crack sealing and thin surface seals are effective at keeping the pavement structure free from moisture infiltration, thereby reducing load-related cracking associated with the weakening of the pavement structure. Therefore, the user may want to track the development of load-related cracking over time as a measure of the effectiveness of a particular preventive maintenance treatment. As with non-load-related cracking, load-related cracking would most likely be measured in terms of the amount of cracking.
	Oxidation/Raveling	The sealing or rejuvenating nature of many surface treatments can significantly reduce the occurrence of oxidation and raveling. Raveling is often reported as an area and severity level. Although there is not currently a widely accepted measure of oxidation, the user may want to consider the development of a subjective rating scale (e.g., a scale of 0 to 5).
	Rutting	Several preventive maintenance treatments may be used to correct rutting problems, so rutting may be used as a performance measure. Rutting is typically measured in terms of an average rut depth, which is expected to increase over time.
	Roughness/ Smoothness	*Roughness* typically increases over time and is often measured in terms of International Roughness Index (IRI). Some agencies prefer to characterize the measurement of surface characteristics in terms of *smoothness* instead of roughness. A smoothness measurement is typically expected to decrease over time (e.g., present serviceability index [PSI] is a subjective measurement on a 0 to 5 scale, where 5 represents a perfectly smooth pavement).
	Friction	Maintaining adequate surface friction is an important safety concern. Therefore, the effectiveness of a preventive maintenance treatment may be tracked in terms of its influence on friction. Friction is commonly measured in terms of a friction index or skid number (a characteristic that typically decreases over time).

Units, trend over time, lower benefit cutoff value, and upper benefit cutoff value must all be defined for each condition indicator used. The upper and lower benefit cutoff values are set based on the goals of the agency. For a condition indicator that increases over time, the upper benefit cutoff value represents a failure condition level. With decreases over time, the lower benefit cutoff value represents the failure condition level. Once the condition indicators have been chosen, the software offers an option to choose a treatment from a list of default treatment types. The default treatment types for HMA-Surfaced Pavements are cracking filling/crack sealing, fog seal, slurry seal, scrub seal, microsurfacing, chip seal, thin overlay, and ultrathin friction course. There is also an option to add treatment types. After selecting the treatment, the user selects the treatment application ages to tell the program what years the program will analyze. The program also gives the option to include routine/reactive maintenance in the analysis. This maintenance can be added at a regular interval or at specific years. Figure 4.7 shows the window in the program where the user goes through this process.

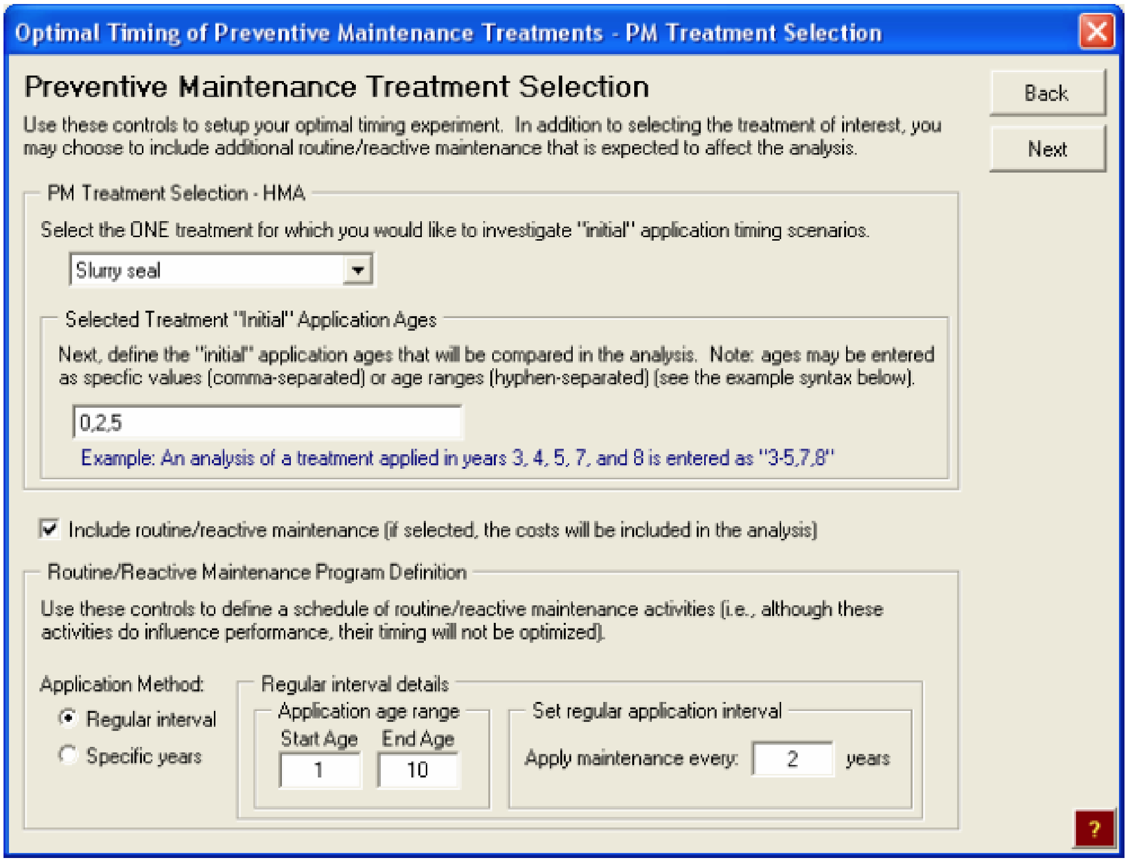


Figure 4.7. Treatment Selection Window in OPTime (Hoerner et. al, 2004)

SCDOT ITMS

South Carolina Department of Transportation currently has an Integrated Transportation Management Suite (ITMS) that allows users to run queries for roadway information, bridge information, sign inventory, daily maintenance work reports, traffic signal information, and pavement information. When querying for pavement information, the user has two options: query by clicking on the roadway on the map given or by launching the pavement viewer on the "Viewers" tab. Figure 4.8 displays the pavement viewer in the SCDOT ITMS. On this main screen, the user has the ability to enter data to specify which route to view. Once the user enters this information, the user can view the route in a screen similar to the one shown in Figure 4.9.

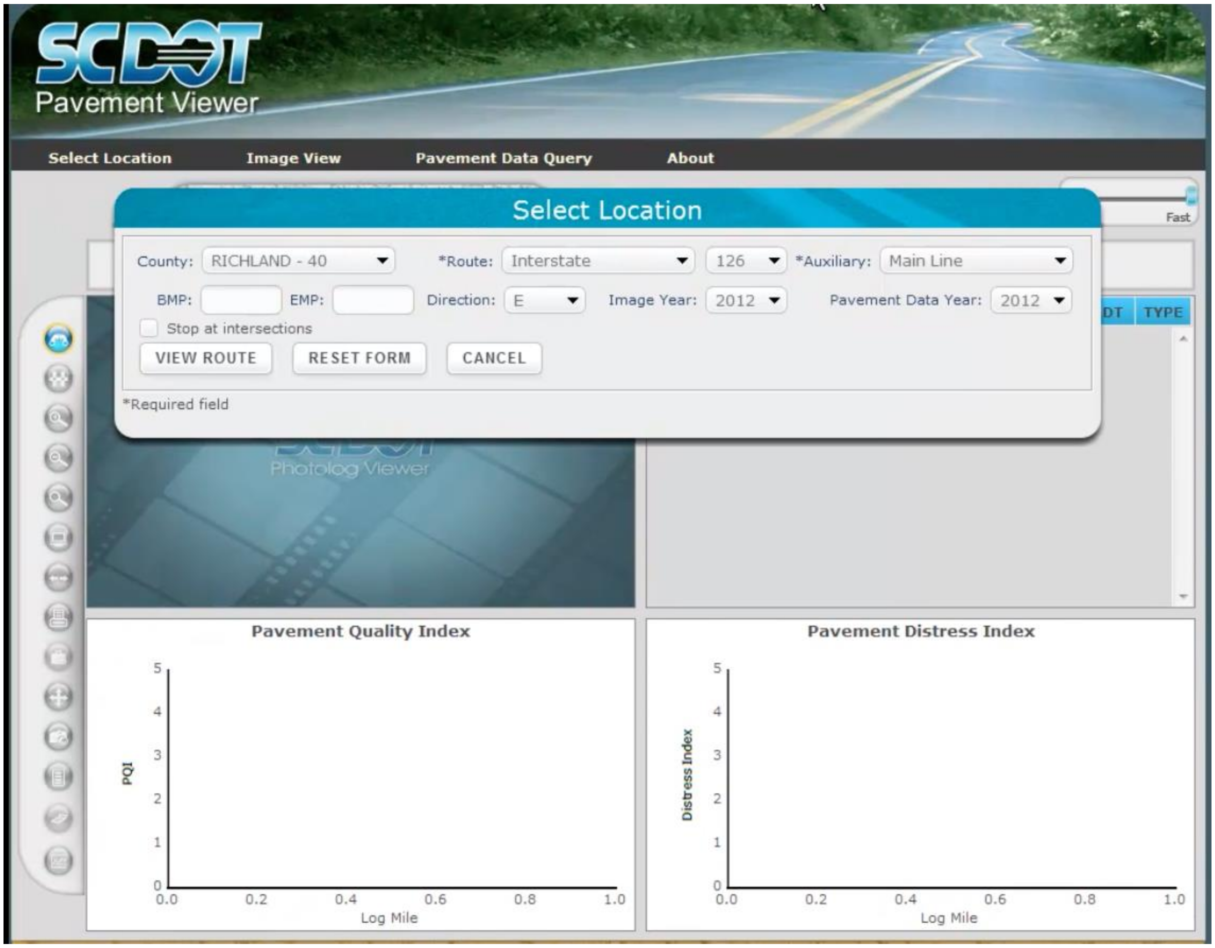


Figure 4.8. SCDOT ITMS Pavement Viewer Main Screen

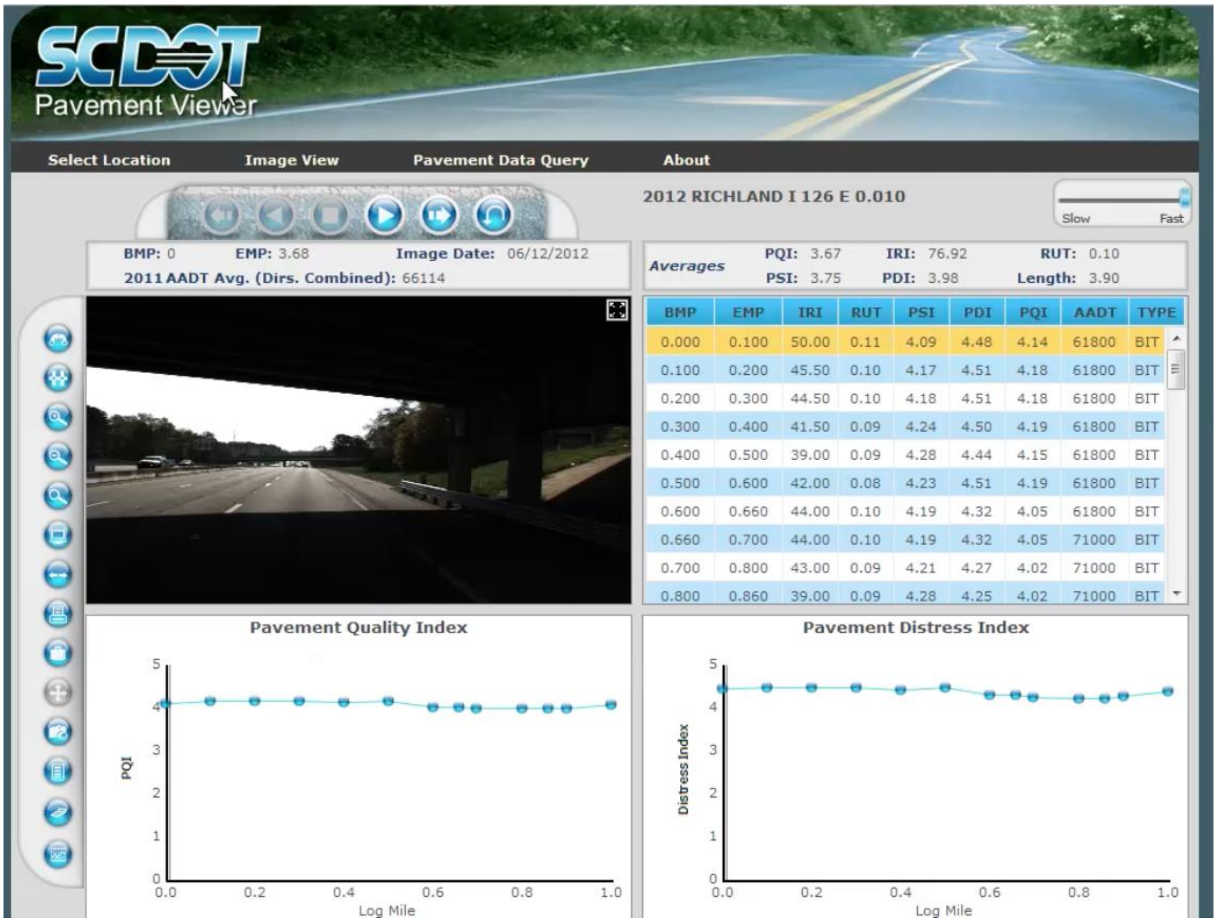


Figure 4.9. SCDOT ITMS Pavement Viewer Information Screen

The screen shown in Figure 4.9 provides vital information about the pavement condition for the route. The screen also provides images taken at specific mile points. The screen portrays the rutting, pavement serviceability index (PSI), pavement distress index (PDI), pavement quality index (PQI), average annual daily traffic (AADT), and type of pavement for each section of the roadway broken up by beginning and ending mile points. An average of each category on the route as well as graphs for the PQI and PDI by beginning and ending mile points are also available. This screen provides the information necessary to identify segment candidates for pavement preservation.

In addition to the pavement viewer, the SCDOT ITMS allows users to view daily work reports (DWR). The DWRs can be seen in a report form or visually on the map. Figure 4.10 provides a view of the visual representation of DWRs.

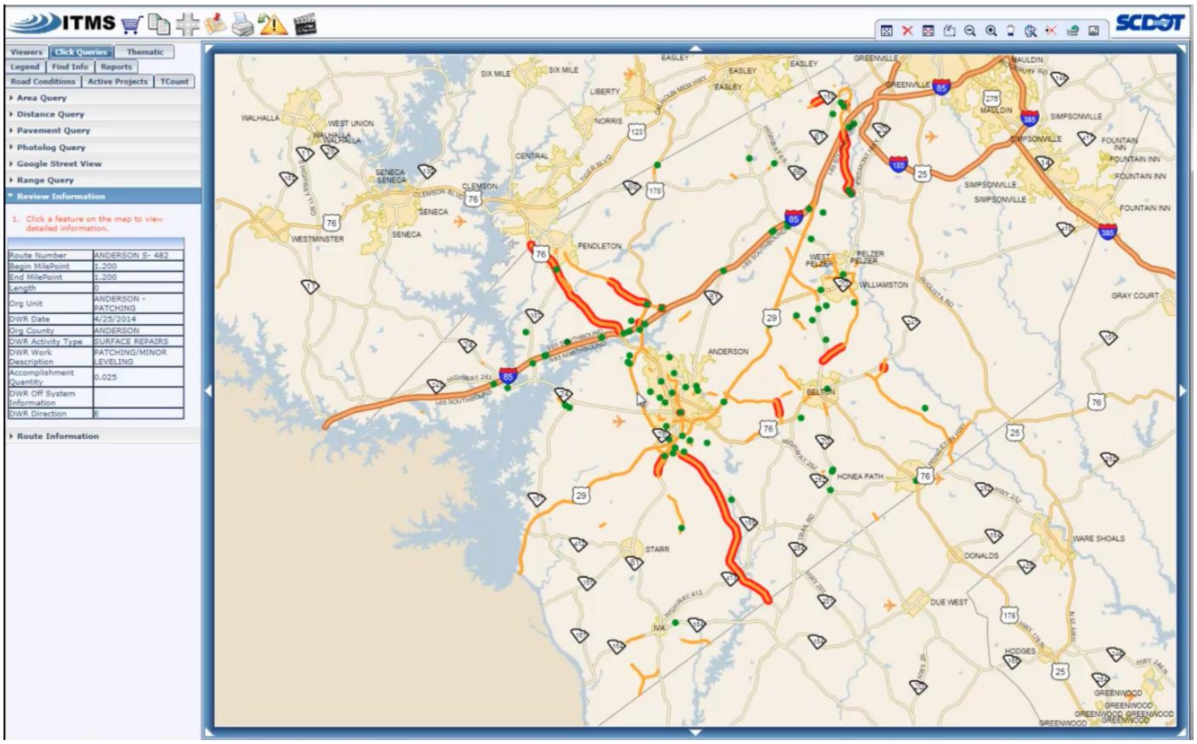


Figure 4.10. SCDOT ITMS DWR Report Visual

To query for specific reports, the user must specify the activity and work description from a drop down menu. In addition, the user will specify which county performed the maintenance work. The user must also specify the date range in which the maintenance activity occurred. The DWRs are provided in a standard report or a detailed report. The detailed report includes the project labor cost, equipment cost, material cost, and total cost, in addition to the information given in the standard report.

Summary of Existing Software Packages

Each of the three existing pavement management software packages analyzed offer different options for pavement management. OPTime is by far the simplest program to use and provides a free management option. However, OPTime may not give the most accurate projection of how treatments will actually behave if historic data is not provided. The program does not require the input of data that could affect treatment selection and performance such as AADT, route type, and route location. Streetsaver is much more detailed than OPTime. It creates an inventory of roadways based on route information and has the ability to create a GIS version of the network. Streetsaver also allows much more detailed reports than OPTime by providing budget scenarios and projected condition of the pavement. The largest drawback for Streetsaver is that it seems to be better suited for smaller networks such as those of cities and small counties because the cost of the program is driven by the number of segments maintained. PAVER 7.0 was the most detailed software analyzed. It allows for the development of the roadway inventory on three separate levels. It also provides a GIS toolbox, like Streetsaver, but it offers a chance to upload images to give a visual of distresses observed. PAVER 7.0 also allows the inputting of inspection data and maintenance of detailed work history like Streetsaver.

The SCDOT ITMS provides detailed information on the current pavement condition, however it does not provide any information on pavement preservation candidates. The daily work reports and pavement viewer provide a foundation on which to build a pavement preservation section of the ITMS.

The ITMS should use the existing software packages as an example for developing models to predict future pavement condition, which treatments are most applicable, and the budget scenarios for the use of those treatments.

The SCDOT collects similar information in their daily work reports found in the ITMS as PAVER 7.0 collects in its work history reports. The PAVER 7.0 system has an input for work type, work category, work date, and cost. The SCDOT ITMS daily work report also allows for inputting information. The detailed DWRs also has cost breakdown in more detail than PAVER 7.0.

Identification of Preservation Candidates

Identifying pavement preservation candidates in the state is the first major step in implementing pavement preservation effectively. South Carolina uses pavement quality index (PQI) to identify those roadway segments that qualify for pavement preservation techniques. For the SCDOT, different route types have different trigger values. These trigger values are shown in Table 4.3.

Table 4.3. SCDOT Preservation Candidate Trigger Values

System	PQI Trigger Values
US and SC Routes	PQI ≥ 3.2 < 4.0
Federal-aid Secondary Routes	PQI ≥ 3.2 < 4.0
Secondary Routes	PQI ≥ 3.0

For this research, two analyses were performed to identify preservation candidates. The first analysis identified segments that were 100% consecutive, while the second analysis identified 80% consecutive segments. The purpose of the second analysis was to identify how many more segments would be eligible if one out of the five consecutive necessary consecutive segments (from the first analysis) did not meet the PQI criteria. The methodology for identifying preservation candidates in this research is given in the steps below.

Step 1: Review SCDOT Data and Identify Important Criteria

For this analysis, pavement preservation candidates were identified for non-federal aid eligible secondary route roadway segments found in a Microsoft Excel worksheet provided by the SCDOT. Based on the route type, the analysis looked for segments that had a PQI greater than or equal to 3.0. This analysis used the Predicted PQI given in the 2014 SCDOT data. The analysis also sought out consecutive segments of at least 0.5 miles in length to make it economical to employ pavement preservation techniques. Each line in the Microsoft Excel worksheet represented a single roadway segment. The roadway segments are identified by the county in which they are located using a county code. They were also identified by route type of secondary (S-). Next, the segment had a route number associated with it as well as a direction (i.e., N, S, E, or W). Usually these segments were 0.1 miles in length, with the only exceptions being the last segments along a roadway that were less than 0.1 miles in length. As a result, roadway sections were identified as candidates if five or more consecutive segments met the threshold value, thus establishing a minimum length of 0.5 mile. The Microsoft Excel worksheet provided by the SCDOT had each roadway segment in order according to its beginning and ending mile point along the roadway. To identify consecutive segments, segments must have the same county code, route type, route number, and direction.

Step 2: Creation of 100% Consecutive Segment Code

The next step in pavement preservation candidate identification was the creation of a code that could identify the candidates from the data. The code was created using MATLAB to scan the Microsoft Excel worksheet for candidates. As stated in Step 1, the code needed to identify roadway segments with identical county codes, route type, route number, and direction. The segments were already sorted in consecutive order by beginning and ending mile points, so the code was able to read down the document without further sorting.

The MATLAB code first looks at Column N (Predicted PQI) in the Microsoft Excel worksheet to determine if the predicted PQI for 2014 is greater than or equal to 3.0. If the predicted PQI is less than 3.0, the code will indicate "FALSE" in a new column it creates at the end of worksheet. If the predicted PQI meets the criteria, the code then moves on to check if five or more segments meeting the predicted PQI criteria are consecutive. To check if the segments are consecutive, the code first checks Column A to see if the county codes for the segments is the same. Next, the code checks Column B to compare the route types of the segments. Then, the code checks Column C to see if the segments have the same route number. Finally, the code looks at Column E to make sure the segments have the same direction. If five or more consecutive rows of segments meet all of these criteria, the code indicates "TRUE" in the newly created column at the end of the worksheet for every segment involved. If all these criteria are not met, the code writes "FALSE" in that column.

Step 3: Extracting Candidates from Original Worksheet

After the code determines whether each segment was "TRUE" or "FALSE," the next step was to separate candidates from non-candidates. To separate these candidates, the Microsoft Excel filter feature was utilized. Using Advanced Filter, the segments with "TRUE" in the last column of the spreadsheet were moved to a new blank spreadsheet. Using the same tool, segments with "FALSE" in the last column were also moved to their own separate spreadsheet.

Step 4: Mapping Candidates in GIS

After the candidates were identified, the final step was to import the data into ArcGIS to create a visual representation of the candidates. To accomplish this step, the Microsoft Excel spreadsheet with the candidates had to be converted to a text file. However, due to route types and numbers being repeated in each county, it was necessary to use a tool to separate Microsoft Excel spreadsheet into multiple text files based on the county code. By extracting based on county code, the candidates were separated into 46 text files, one for each county.

In ArcGIS, the shapefile for the South Carolina counties was added. Next, the secondary routes shapefile for the state of South Carolina was created by using *Select by Attributes* on the shapefile containing all roadways in South Carolina and selecting according to route type (S-). Then this selection was exported as its own shapefile for Secondary Routes. Next, a selection was made in the Secondary Routes shapefile for each county code. These selections were then exported to create a shapefile of secondary routes in each county. Next, each text file for each county was added to the map. A route shapefile was generated for each county's candidates by querying the candidates based on route number and beginning and end point in each county. After creating shapefiles for each separate county's candidates, the candidates were joined into one shapefile for the entire state of South Carolina by selecting all and exporting them as their own shapefile. The process was repeated to include the non-candidates into the map.

Step 5: 80% Consecutive Segment Identification

After completing the analysis for segments that are 100% consecutive, an analysis was performed to see how the number of pavement preservation candidates would change if the analysis included roadway segments that were 80% consecutive. To complete this analysis, the original MATLAB code was edited. The code can be seen in Appendix B. This code searched for segments that were 80% consecutive with the criteria that at least four out of five consecutive segments that met the PQI requirements. This means that even if only one out of five consecutive segments did not meet the PQI requirements, all of those segments were still labeled as candidates with a "TRUE" written in the new column, including the segment that did not meet the PQI criteria. The results of this analysis were then added to ArcGIS through the same procedure described for the 100% consecutive candidates.

Step 6: Comparative Analysis of 80% and 100% Consecutive Segments

After identifying the 100% consecutive segments and 80% consecutive segments, there was an analysis performed to compare the two datasets. The two analyses were performed to find the number of segments left out because one segment in a group did not meet the PQI requirement.

Candidate Selections

100% Consecutive Segment Preservation Candidates

For 100% consecutive segment analysis, 30,615 segments met the criteria. These segments represented 3,006 miles of secondary roadway. In contrast, 189,232 secondary roadway segments, representing 17,613 miles, did not qualify for pavement preservation. Only approximately 14% of secondary non-federal aid eligible roadway segments qualified for pavement preservation treatments. These qualifying segments had an average PQI of 3.60. Table 4.4 portrays the candidate breakdown for each county in the state of South Carolina.

Table 4.4. Candidates by County (100% Consecutive)

County	Number of Candidate Segments (100% Consecutive)	Length for Candidate Segments (100% Consecutive) (miles)	Average Predicted PQI for Candidate Segments (100% Consecutive)	Non-Candidate Segments (100% Consecutive)	Non-Candidate Segment Length (100% Consecutive) (miles)	Non-Candidate Average Predicted PQI (100% Consecutive)	Proportion by Number of Segments	Proportion by Miles
Abbeville	414	40.84	3.50	3124	295.944	2.54	11.7%	12.1%
Aiken	1827	176.785	3.56	6258	566.413	2.42	22.6%	23.8%
Allendale	660	65.479	3.47	2369	223.657	2.24	21.8%	22.6%
Anderson	1045	102.857	3.82	3809	352.149	2.35	21.5%	22.6%
Bamberg	533	52.45	3.52	2562	241.74	2.07	17.2%	17.8%
Barnwell	313	30.33	3.69	2811	258.18	2.51	10.0%	10.5%
Beaufort	337	33.08	3.32	2516	227.84	2.17	11.8%	12.7%
Berkeley	511	49.927	3.68	5236	483.6	2.23	8.9%	9.4%
Calhoun	504	49.49	4.00	2572	246.16	2.21	16.4%	16.7%
Charleston	563	55.33	3.66	6376	564.154	2.16	8.1%	8.9%
Cherokee	515	50.57	3.47	3867	367.414	2.43	11.8%	12.1%
Chester	295	28.82	3.70	4877	458.49	2.24	5.7%	5.9%
Chesterfield	972	95.99	3.45	4846	455.19	1.91	16.7%	17.4%
Clarendon	1114	109.93	3.68	3126	291.91	2.50	26.3%	27.4%
Colleton	897	88.63	3.54	5224	495.31	2.42	14.7%	15.2%
Darlington	1304	127.93	3.48	4644	424.49	2.40	21.9%	23.2%
Dillon	331	32.74	3.48	4060	384.7	2.36	7.5%	7.8%
Dorchester	469	46.26	3.42	3271	304.28	2.09	12.5%	13.2%
Edgefield	501	48.85	3.89	2658	250.93	2.35	15.9%	16.3%
Fairfield	342	33.77	3.42	3140	299.52	2.30	9.8%	10.1%
Florence	1302	128.3	3.43	6002	552.25	2.45	17.8%	18.9%
Georgetown	557	54.46	3.50	3032	278.79	2.10	15.5%	16.3%
Greenville	562	55.31	3.56	4591	430.168	2.25	10.9%	11.4%
Greenwood	476	46.62	3.88	2977	276.88	2.42	13.8%	14.4%
Hampton	663	64.47	3.61	2763	258.59	2.43	19.4%	20.0%
Horry	748	73.61	3.70	4963	464.239	2.25	13.1%	13.7%
Jasper	108	10.59	3.46	2326	220.41	2.31	4.4%	4.6%
Kershaw	487	47.78	3.75	5599	529.76	2.16	8.0%	8.3%
Lancaster	242	23.65	3.84	3985	371.97	1.83	5.7%	6.0%
Laurens	812	79.24	3.76	4510	420.85	2.41	15.3%	15.8%
Lee	462	45.79	3.44	2417	226.68	2.03	16.0%	16.8%
Lexington	1539	151.428	3.43	6854	626.744	2.50	18.3%	19.5%
Marion	580	56.97	3.68	2376	224.24	2.11	19.6%	20.3%
Marlboro	192	18.94	3.63	2886	263.894	2.42	6.2%	6.7%
McCormick	548	54.04	3.82	4178	396.02	1.55	11.6%	12.0%
Newberry	292	28.23	3.97	4118	386.65	2.27	6.6%	6.8%
Oconee	480	47.12	3.42	3708	351.947	2.35	11.5%	11.8%
Orangeburg	1924	189.05	3.48	7439	690.447	2.28	20.5%	21.5%
Pickens	482	47.53	3.67	2050	195.6	2.46	19.0%	19.5%
Richland	819	79.421	3.78	8329	748.438	2.30	9.0%	9.6%
Saluda	369	36.43	3.90	3231	308.1	2.23	10.3%	10.6%
Spartanburg	404	39.8	3.49	4744	447.729	2.18	7.8%	8.2%
Sumter	863	84.79	3.51	5070	463.85	2.19	14.5%	15.5%
Union	294	28.85	3.89	2984	282.2	2.48	9.0%	9.3%
Williamsburg	889	87.13	3.55	4691	446.54	1.77	15.9%	16.3%
York	1074	105.45	3.68	6063	557.582	2.35	15.0%	15.9%
TOTAL	**30615**	**3005.057**	**3.60**	**189232**	**17612.639**	**2.26**		

Figure 4.11 displays the pavement preservation candidates throughout the state of South Carolina.

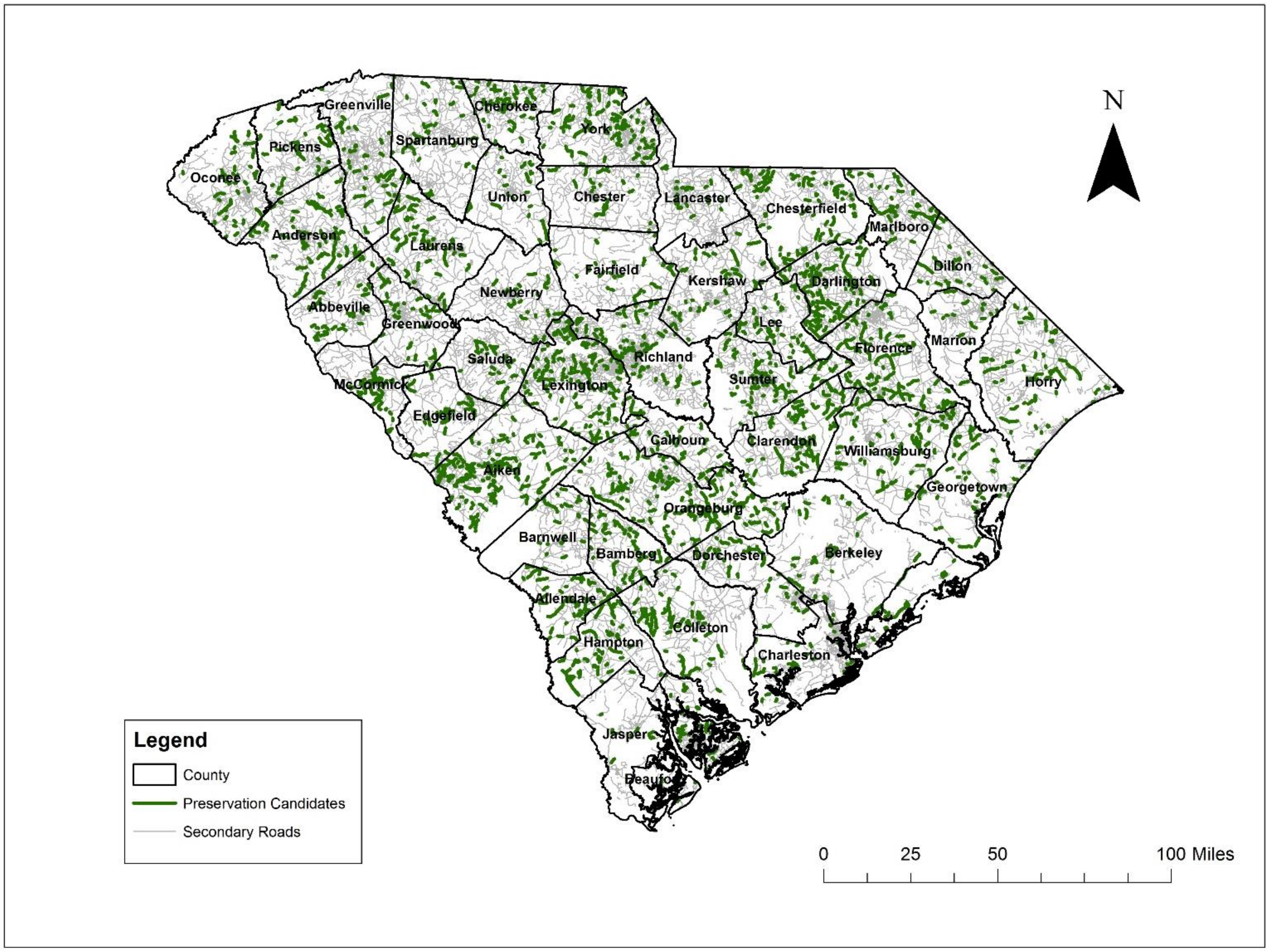


Figure 4.11. Secondary Non-Federal Aid Candidates (100% Consecutive)

Figure 4.12 portrays a color coded map showing the counties in South Carolina. The counties with the largest number of candidates were Aiken, Lexington, and Orangeburg. Each of these counties has over 1,500 candidate segments within the county.

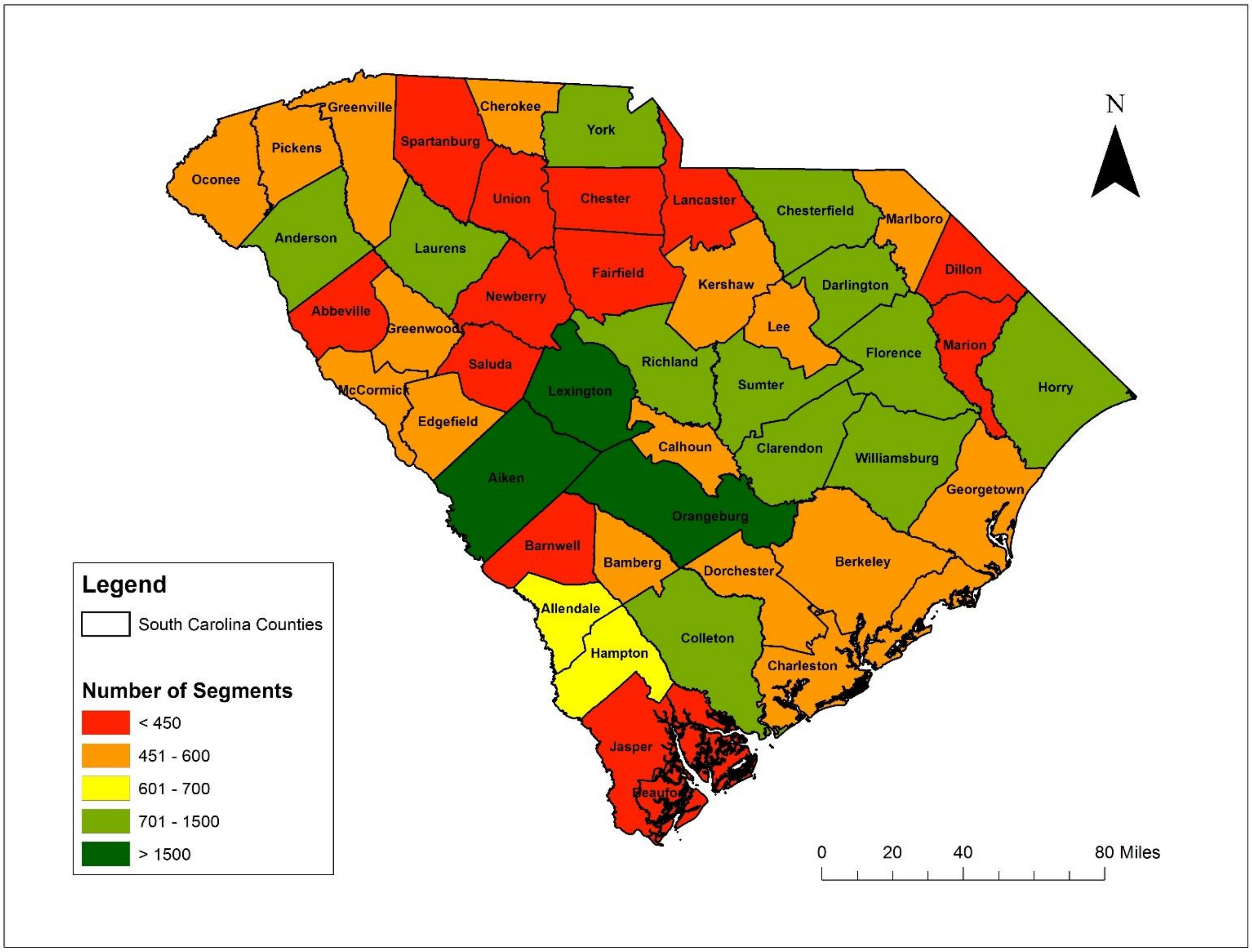


Figure 4.12. Candidate Distribution by County (100% Consecutive)

Figure 4.13 shows seven districts for the state and their number of candidates. District 7 shows the most preservation candidates with over 6,000 candidate segments. This result is not surprising as this district contains two of the three counties with the greatest number of candidates. District 7 contains Aiken, Orangeburg, and Clarendon counties which rank 2nd, 1st, and 6th in number of preservation eligible segments in the state, respectively.

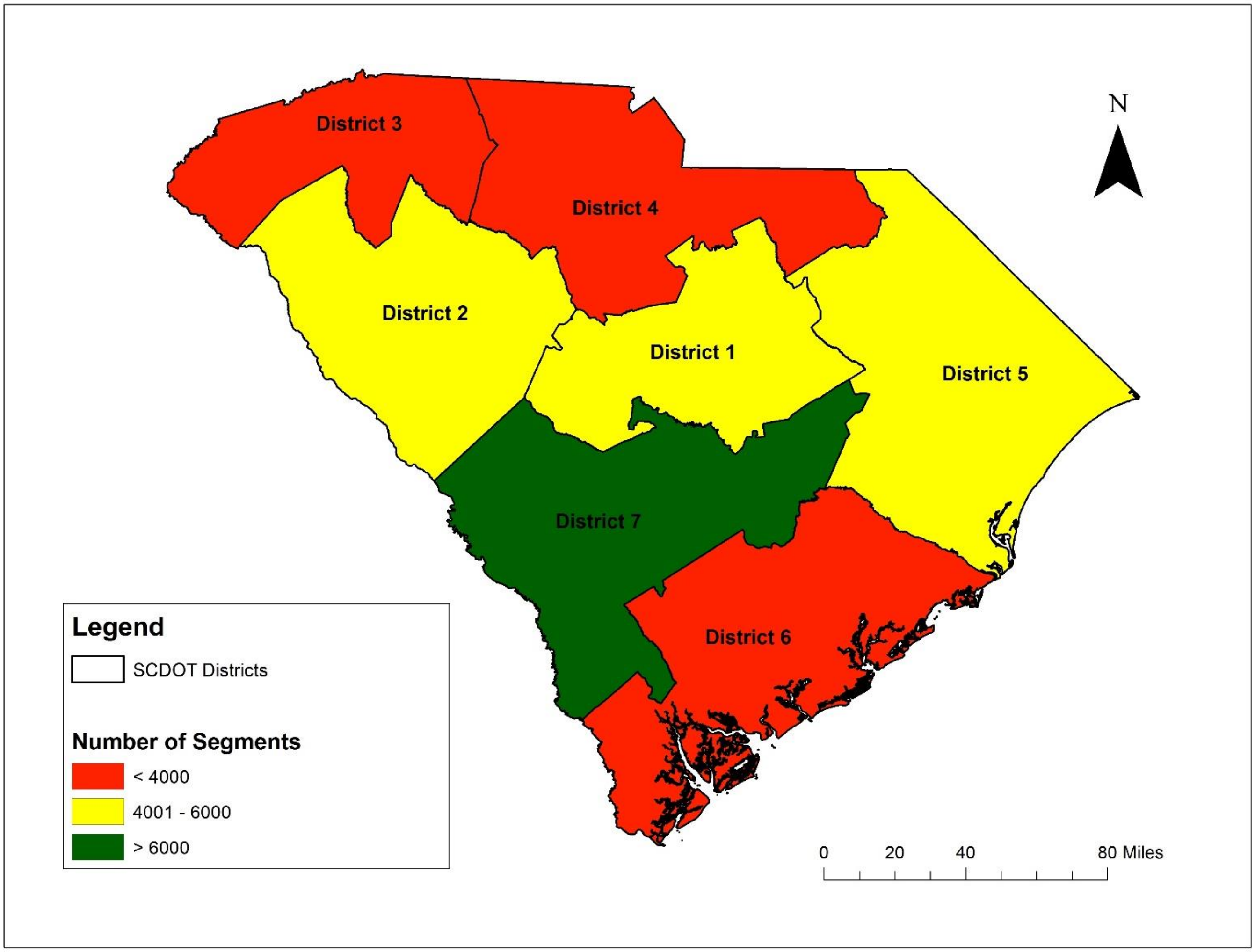


Figure 4.13. Candidate Distribution by District (100% Consecutive)

Figure 4.14 shows a density map for the state based on number of candidate segments. Aiken, Orangeburg, and Darlington counties show the highest density of candidates in the state. The result of the density map is expected with Orangeburg, Aiken, and Darlington counties being three of the four counties with the largest number of preservation eligible segments.

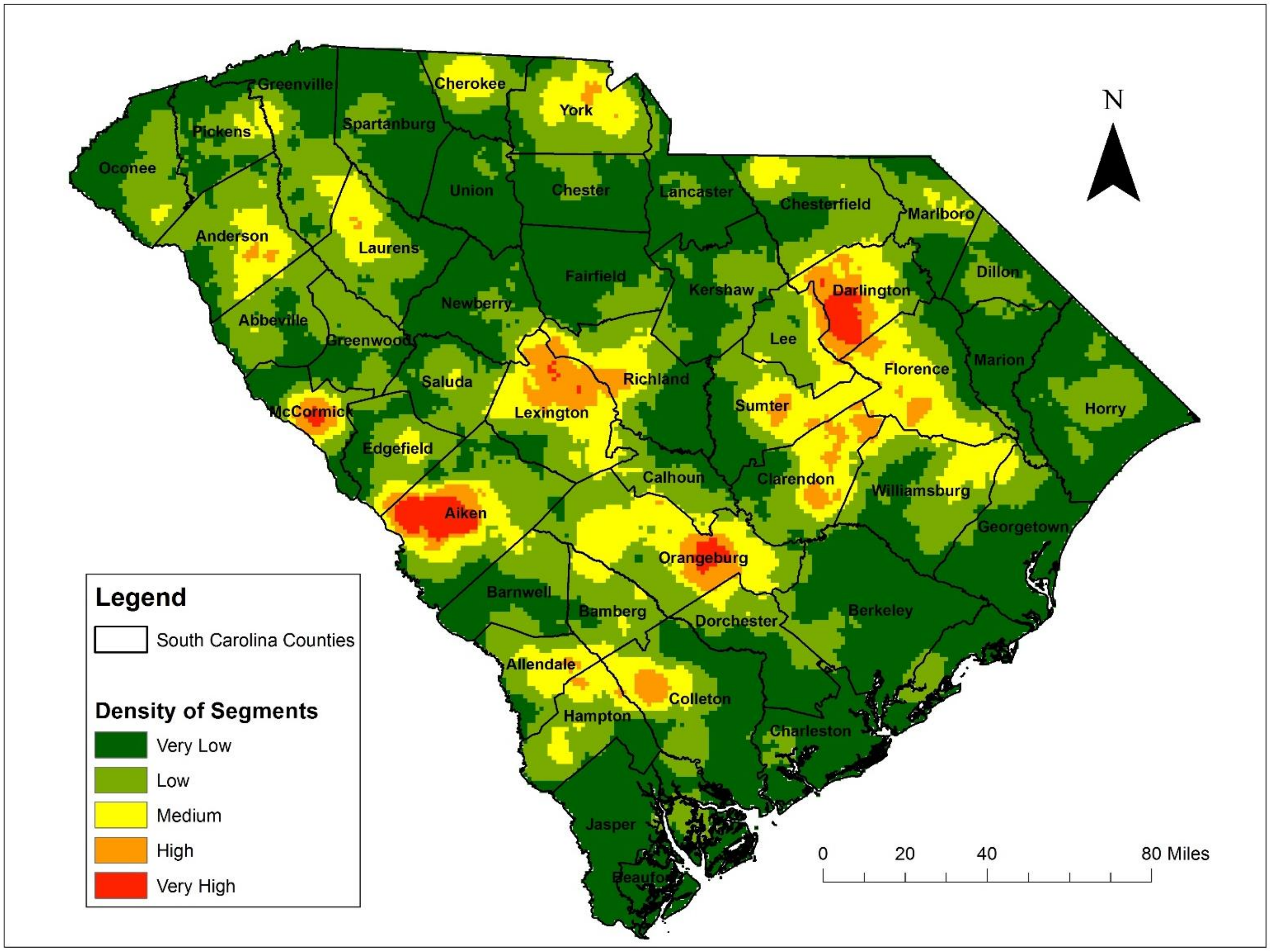


Figure 4.14. Density of Candidates (100% Consecutive)

Figure 4.15 displays the proportion of total miles in each county that met the qualifications to be pavement preservation candidates. Aiken, Orangeburg, and Clarendon counties all have over 20% of their secondary roadway miles as candidate miles. This result could be expected as these counties had large number of candidate segments. In contrast, Marion County had less than 450 candidate segments but that number still consisted of over 20% of the secondary roadway miles in the county.

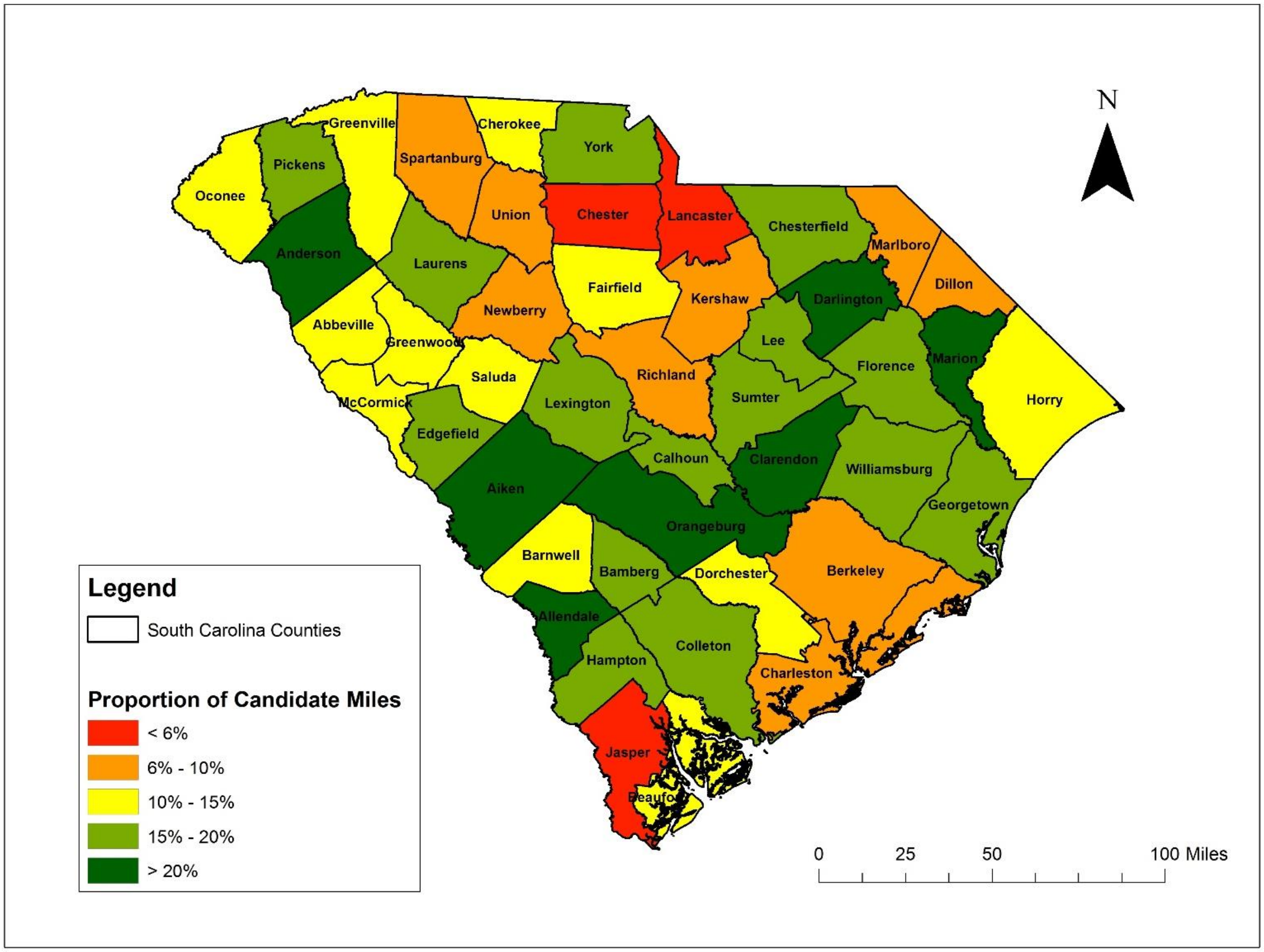


Figure 4.15. Proportion of Total Miles Qualified as Candidates by County (100% Consecutive)

80% Consecutive Segment Preservation Candidates

Another analysis was conducted to find the number of segments that would be preservation candidates if only 80% of the consecutive segments met the 3.0 PQI threshold. This analysis found 39,648 segments that would be preservation candidates. These segments represent approximately 3869.5 miles of roadway in the state. The average PQI represented in these candidates was 3.46. In contrast, there were 180,199 segments that did not qualify as preservation candidates. These segments totaled up to approximately 16,748.2 miles of roadway. Table 4.5 portrays the breakdown of the preservation candidates and non-candidates by county.

Table 4.5. Candidates by County (80% Consecutive)

County Name	Number of Candidate Segments (80% Consecutive)	Length of Candidate Segments (80% Consecutive) (miles)	Average Predicted PQI for Candidate Segments (80% Consecutive)	Non-Candidate Segments (80% Consecutive)	Non-Candidate Segment Length (80% Consecutive) (miles)	Non-Candidate Average Predicted PQI (80% Consecutive)	Proportion by Number of Segments	Proportion by Miles
Abbeville	652	64.11	3.33	2886	272.674	2.50	18.43%	19.04%
Aiken	2407	232.145	3.45	5678	511.053	2.35	29.77%	31.24%
Allendale	946	93.279	3.32	2083	195.857	2.14	31.23%	32.26%
Anderson	1169	114.197	3.73	3685	340.809	2.33	24.08%	25.10%
Bamberg	748	73.22	3.37	2347	220.97	1.99	24.17%	24.89%
Barnwell	393	37.95	3.52	2731	250.56	2.50	12.58%	13.15%
Beaufort	485	46.94	3.23	2368	213.98	2.11	17.00%	17.99%
Berkeley	676	66.157	3.52	5071	467.37	2.20	11.76%	12.40%
Calhoun	579	56.49	3.86	2497	239.16	2.19	18.82%	19.11%
Charleston	686	67.15	3.54	6253	552.334	2.15	9.89%	10.84%
Cherokee	730	70.9	3.31	3652	347.084	2.40	16.66%	16.96%
Chester	359	34.94	3.60	4813	452.37	2.23	6.94%	7.17%
Chesterfield	1325	129.13	3.33	4493	422.05	1.83	22.77%	23.43%
Clarendon	1324	130.21	3.57	2916	271.63	2.47	31.23%	32.40%
Colleton	1280	125.77	3.38	4841	458.17	2.37	20.91%	21.54%
Darlington	1708	167	3.38	4240	385.42	2.34	28.72%	30.23%
Dillon	437	42.96	3.39	3954	374.48	2.34	9.95%	10.29%
Dorchester	702	68.51	3.27	3038	282.03	2.02	18.77%	19.54%
Edgefield	573	55.67	3.75	2586	244.11	2.33	18.14%	18.57%
Fairfield	432	42.34	3.31	3050	290.95	2.28	12.41%	12.70%
Florence	1582	155.16	3.35	5722	525.39	2.42	21.66%	22.80%
Georgetown	716	69.45	3.39	2873	263.8	2.05	19.95%	20.84%
Greenville	678	66.19	3.45	4475	419.288	2.24	13.16%	13.63%
Greenwood	567	55.12	3.75	2886	268.38	2.39	16.42%	17.04%
Hampton	857	83.48	3.49	2569	239.58	2.38	25.01%	25.84%
Horry	949	92.95	3.55	4762	444.899	2.22	16.62%	17.28%
Jasper	135	13.16	3.33	2299	217.84	2.31	5.55%	5.70%
Kershaw	614	59.74	3.60	5472	517.8	2.14	10.09%	10.34%
Lancaster	301	29.42	3.66	3926	366.2	1.81	7.12%	7.44%
Laurens	935	90.7	3.67	4387	409.39	2.39	17.57%	18.14%
Lee	679	66.4	3.31	2200	206.07	1.93	23.58%	24.37%
Lexington	2096	204.798	3.31	6297	573.374	2.46	24.97%	26.32%
Marion	645	63.06	3.60	2311	218.15	2.09	21.82%	22.42%
Marlboro	239	23.29	3.50	2839	259.544	2.41	7.76%	8.23%
McCormick	665	65.24	3.68	4061	384.82	1.50	14.07%	14.50%
Newberry	325	31.16	3.84	4085	383.72	2.26	7.37%	7.51%
Oconee	592	57.95	3.34	3596	341.117	2.33	14.14%	14.52%
Orangeburg	2591	253.29	3.36	6772	626.207	2.21	27.67%	28.80%
Pickens	585	57.15	3.56	1947	185.98	2.42	23.10%	23.51%
Richland	1107	106.351	3.59	8041	721.508	2.27	12.10%	12.85%
Saluda	507	49.89	3.68	3093	294.64	2.19	14.08%	14.48%
Spartanburg	500	48.88	3.40	4648	438.649	2.16	9.71%	10.03%
Sumter	1245	121.7	3.38	4688	426.94	2.12	20.98%	22.18%
Union	382	37.5	3.67	2896	273.55	2.47	11.65%	12.06%
Williamsburg	1182	115.84	3.39	4398	417.83	1.69	21.18%	21.71%
York	1363	132.56	3.53	5774	530.472	2.32	19.10%	19.99%
TOTAL	**39648**	**3869.497**	**3.46**	**180199**	**16748.199**	**2.22**		

Figure 4.16 provides a map view of the preservation candidates for the analysis. Figure 4.17 displays a color coded map of the counties of South Carolina according to the number of preservation eligible segments in each county. The counties with more than 1,500 segments in each county were Aiken, Lexington, Orangeburg, Florence, and Darlington.

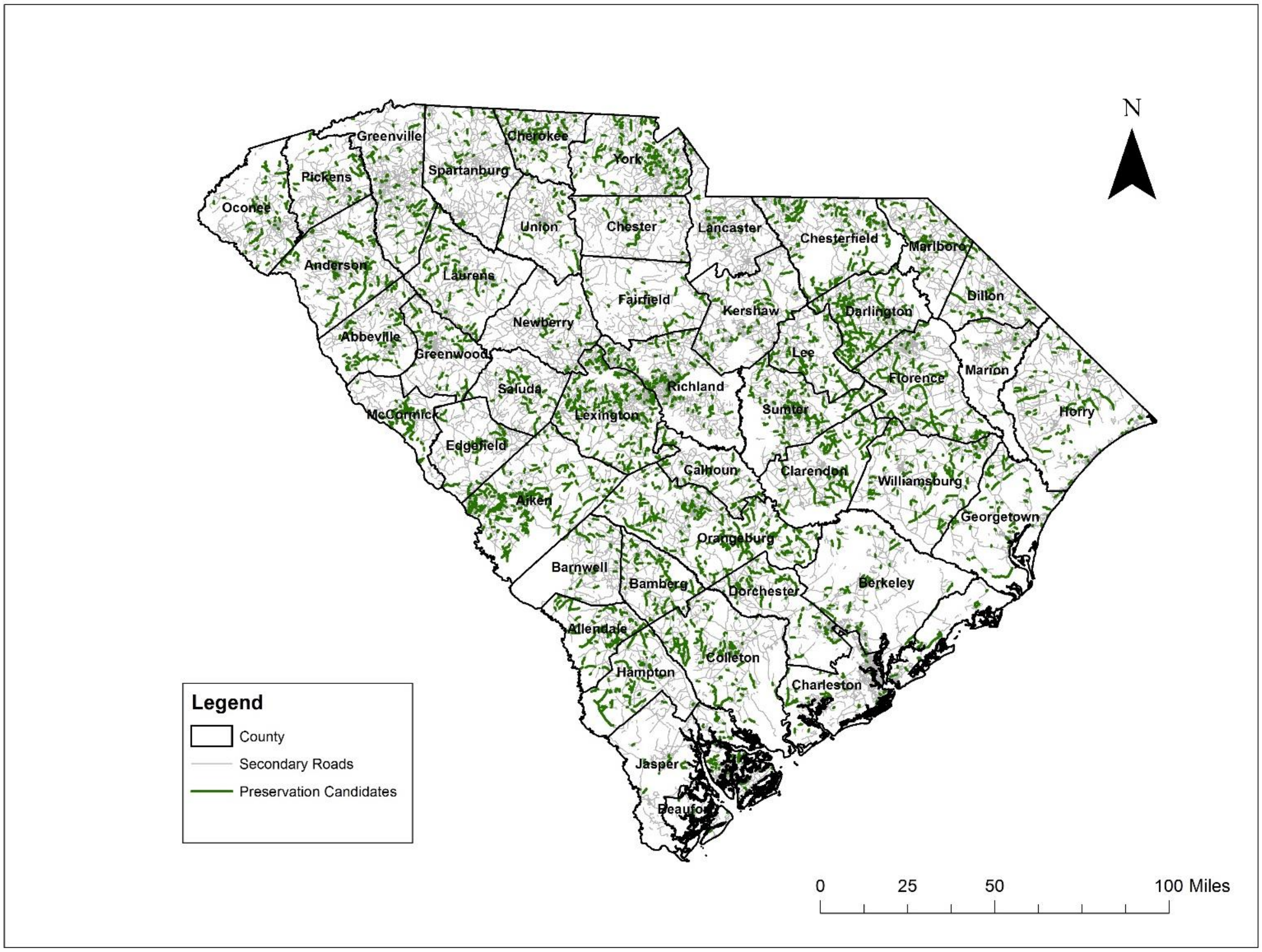


Figure 4.16. Secondary Non-Federal Aid Candidates (80% Consecutive)

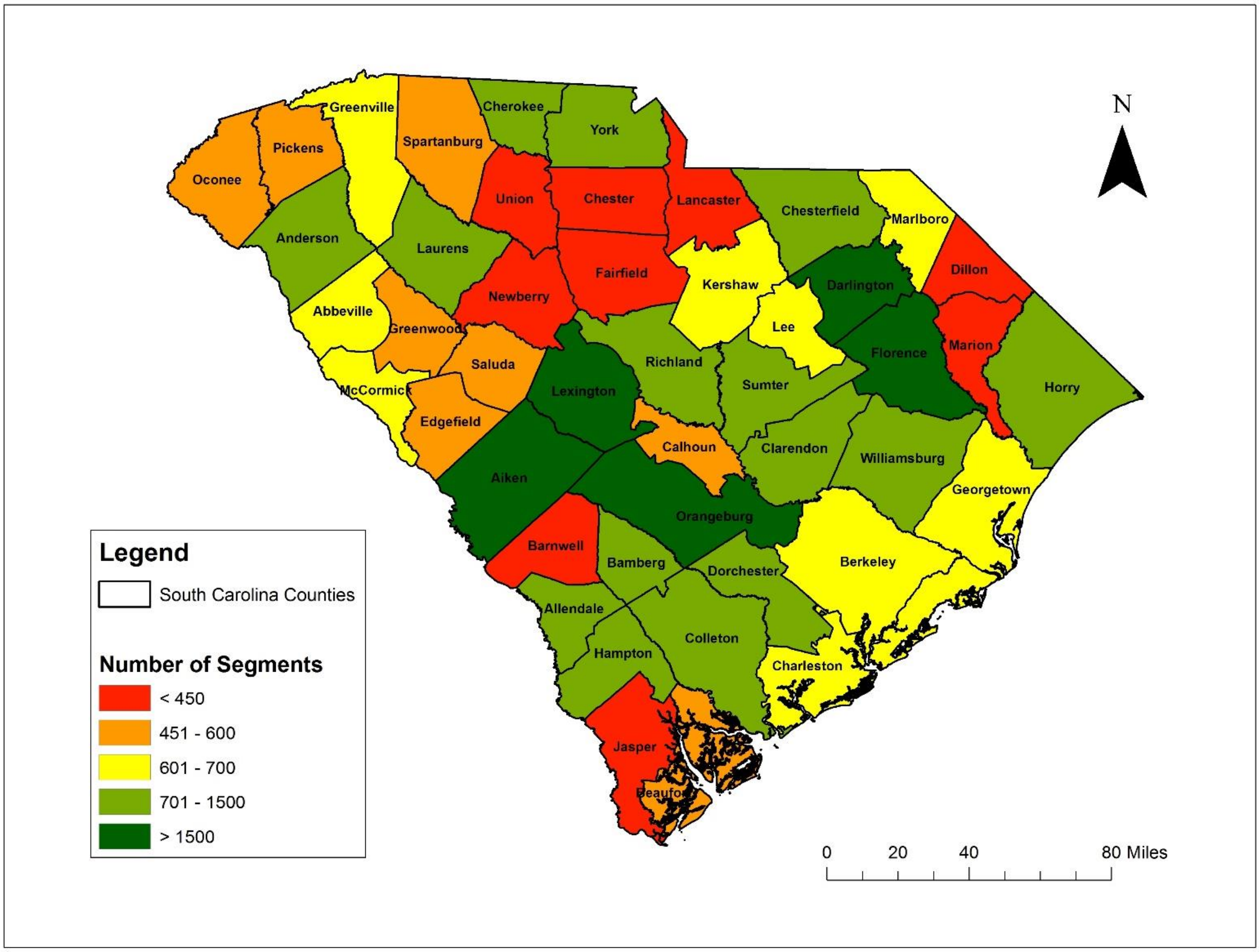


Figure 4.17. Candidate Distribution by County (80% Consecutive)

Figure 4.18 displays the districts for SCDOT color coded according to the number of pavement preservation candidate segments in each. Districts 5 and 7 are the top two districts with each containing over 6,000 preservation eligible segments. This result would be expected as these two districts contain the top 5 counties with the most preservation eligible segments.

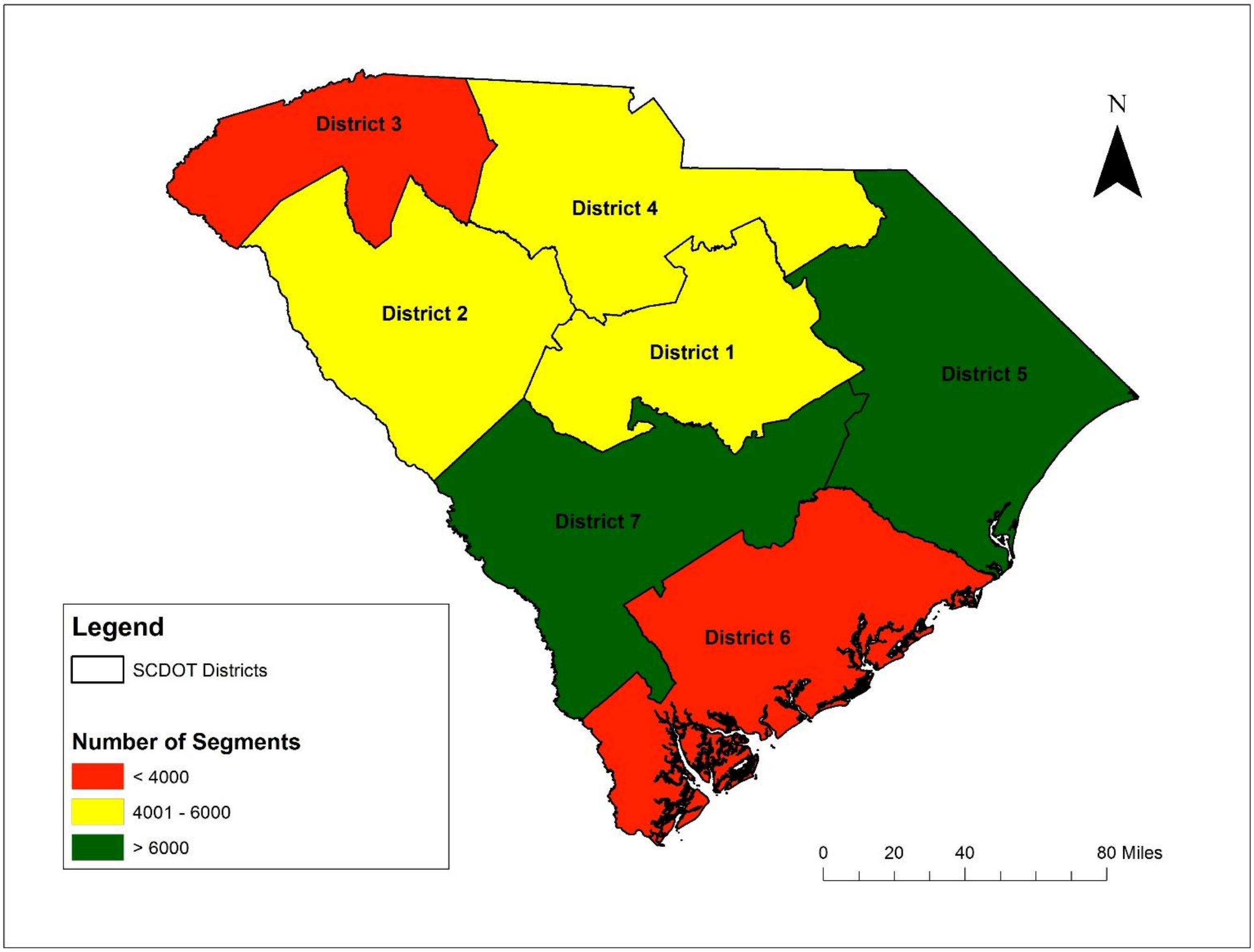


Figure 4.18. Candidate Distribution by District (80% Consecutive)

Figure 4.19 displays a density map created based on the number of preservation candidate segments in the area. The pockets of highest concentration seem to occur in the counties with the most eligible segments like Aiken, Orangeburg, and Darlington. This map also shows a higher concentration in the Columbia area.

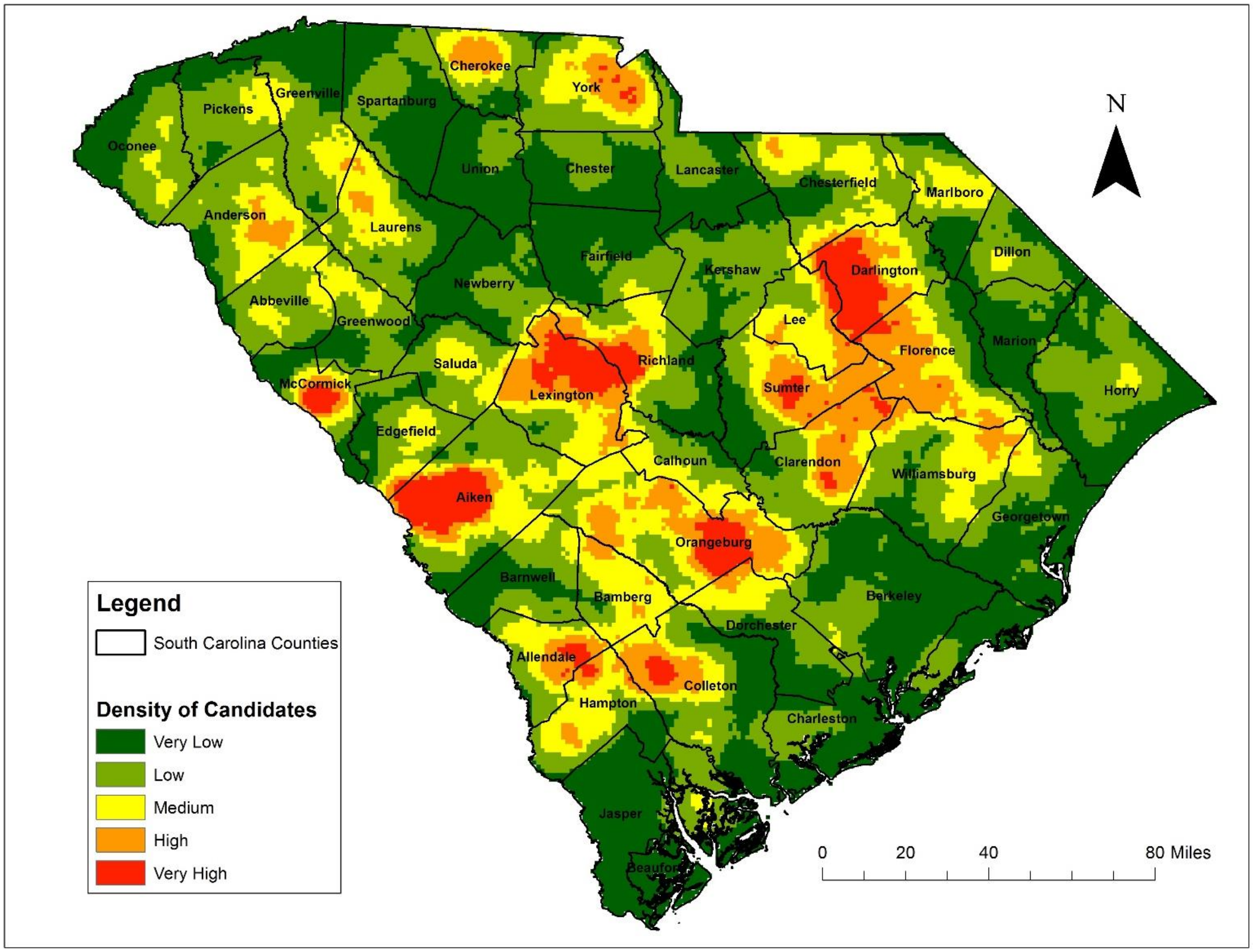


Figure 4.19. Density of Candidates (80% Consecutive)

Figure 4.20 displays the proportion of total miles that are qualified as pavement preservation candidates by county. There are a number of counties that have over 20% of their secondary roadway miles qualified as candidate segments after the 80% consecutive analysis.

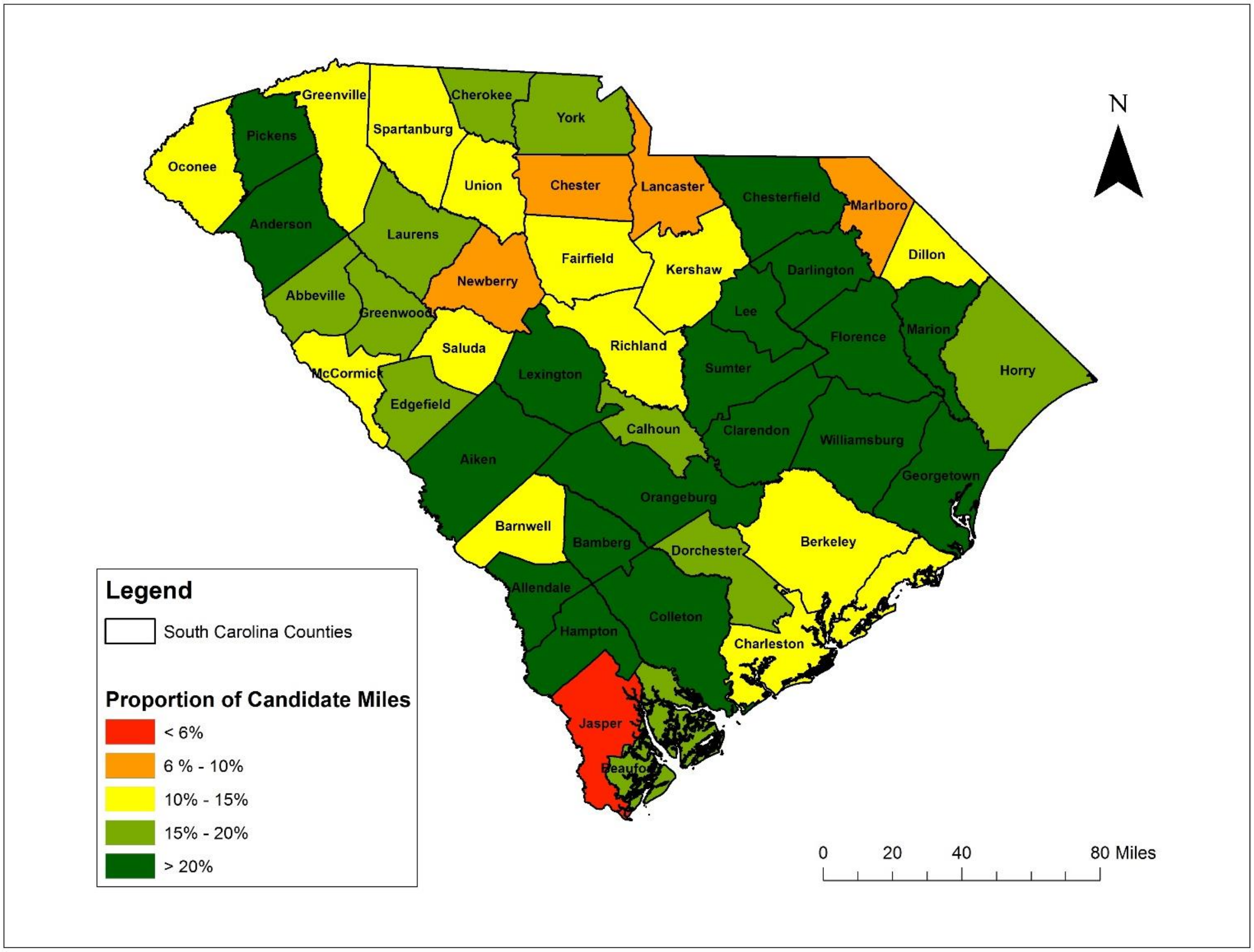


Figure 4.20. Proportion of Total Miles Qualified as Candidates by County (80% Consecutive)

Comparison of 100% and 80% Consecutive Segments

Two different analyses were conducted to compare 80% candidate versus 100% candidate sites. Table 4.6 shows a summary of the data discovered from each analysis.

Table 4.6. Summary Data for 100% and 80% Consecutive Analysis

Percent of Segments Consecutive	Number of Candidate Segments	Length of Candidate Segments (miles)	Average Predicted PQI for Candidate Segments	Non-Candidate Segments	Non-Candidate Segment Length (miles)	Non-Candidate Average Predicted PQI
100	30615	3005.057	3.60	189232	17612.639	2.26
80	39648	3869.497	3.46	180199	16748.199	2.22

The 80% consecutive segment analysis provided 9,033 more preservation eligible segments than the 100% consecutive segment analysis. This difference led to 864.44 more miles of roadway eligible for preservation techniques. The average PQI of candidates is lower for the 80% consecutive segment as would be expected because some of segments included in this analysis would have a PQI lower than the PQI needed to be eligible for pavement preservation. Figures 4.20, 4.21, 4.22, 4.23, and 4.24 display the comparison between the 100% and 80% consecutive analyses for both counties and districts in the state. The maps labeled "A" in each figure display the 100% consecutive analysis results while the maps labeled "B" in each figure display 80% consecutive analysis results. Figures 4.22 and 4.23 portray the results of the proportion of total miles that are preservation candidates in each county or district. Figure 4.24 displays the comparison of the density of candidates throughout the state.

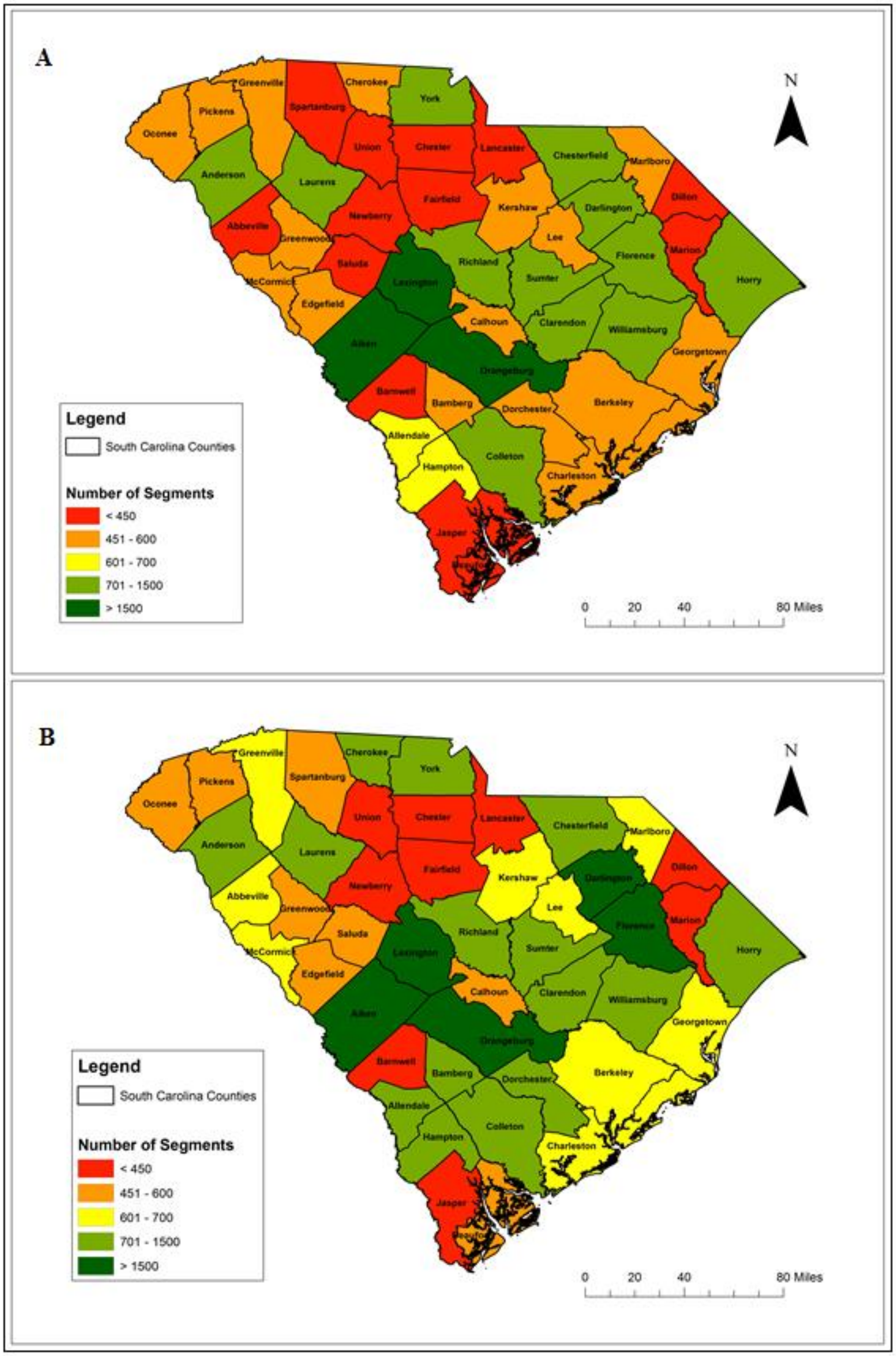


Figure 4.20. Comparison of Number of Candidate Segments by County

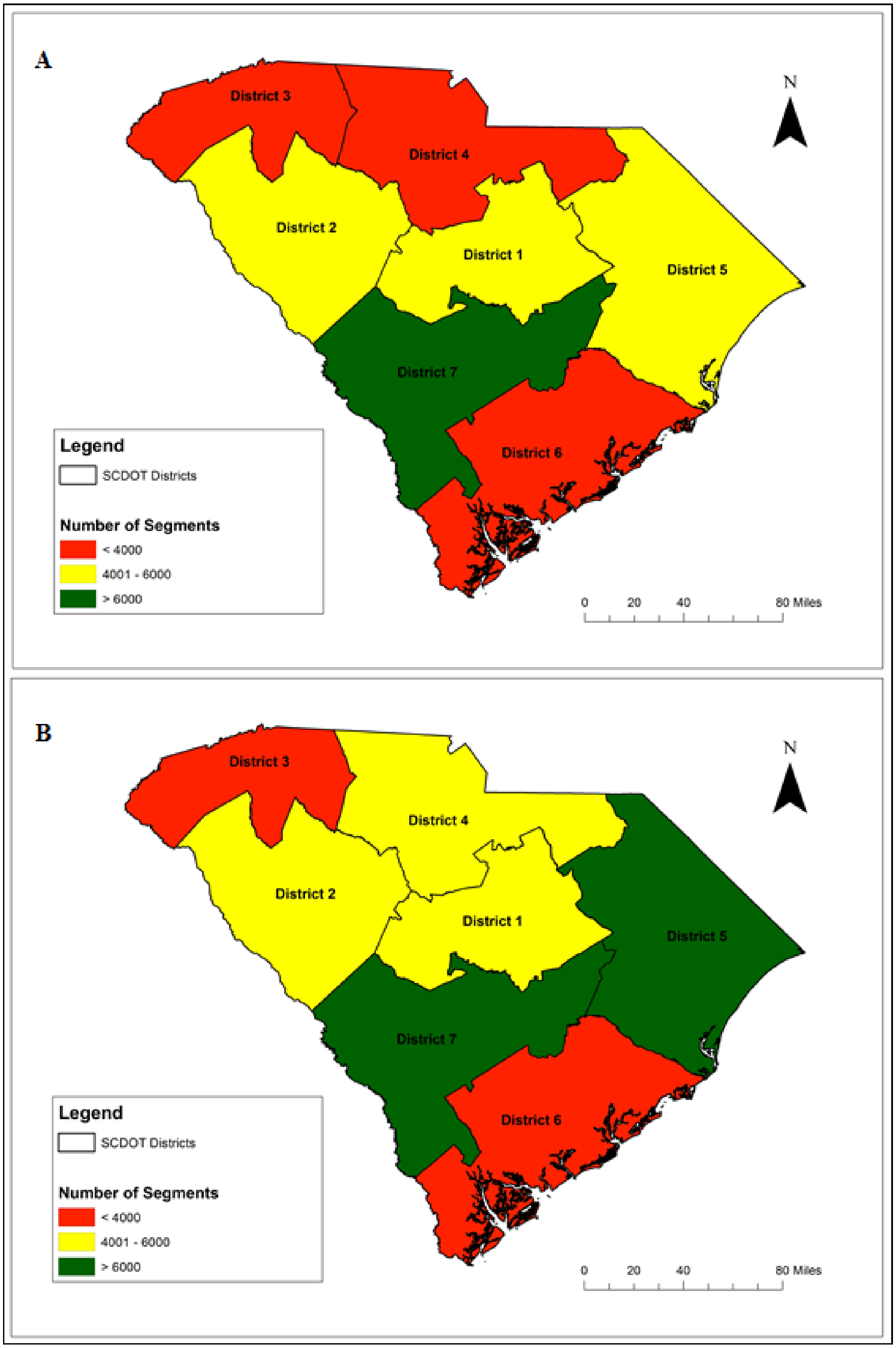


Figure 4.21. Comparison of Number of Candidate Segments by District

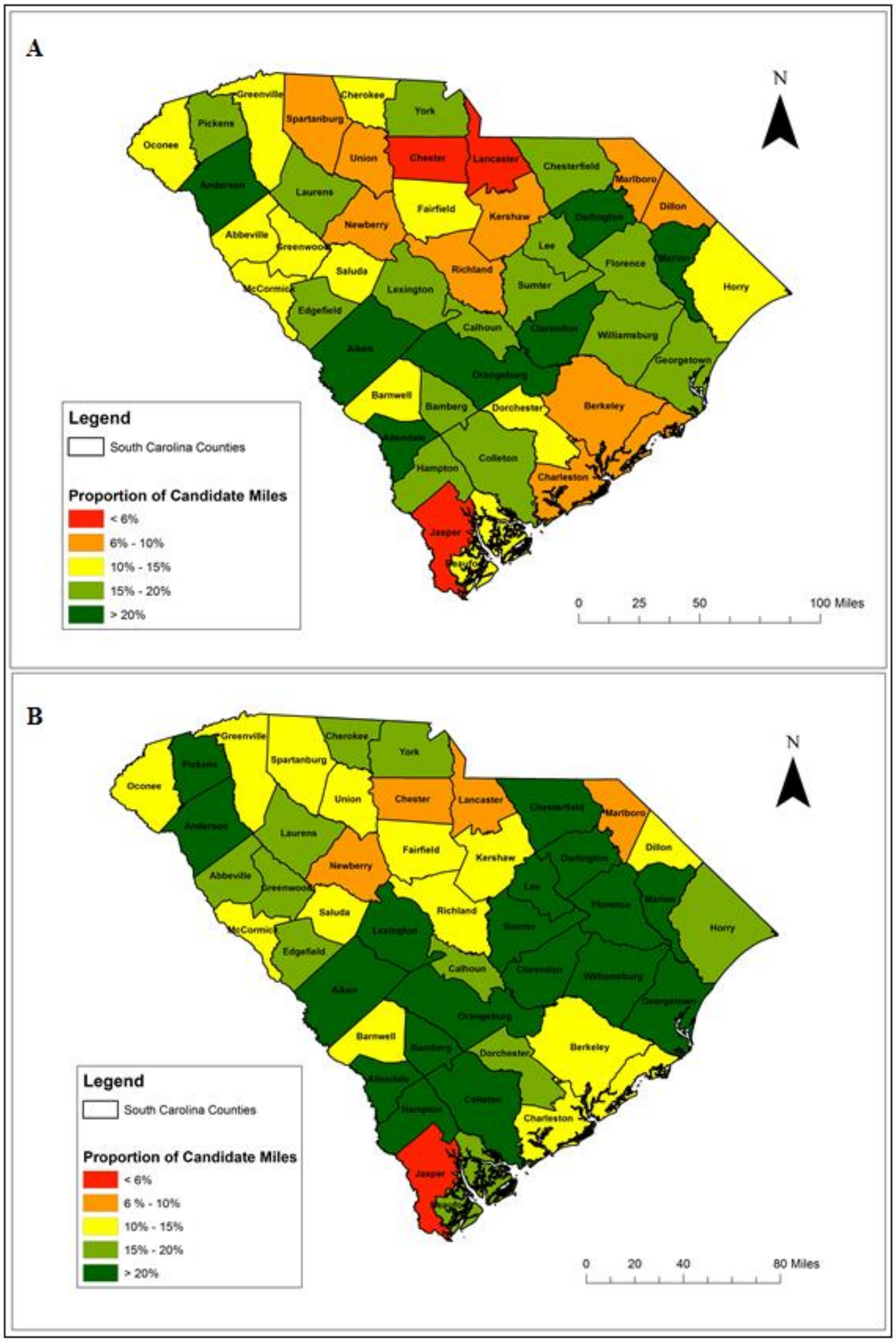


Figure 4.22. Comparison of Proportion of Total Miles Qualified as Candidates by County

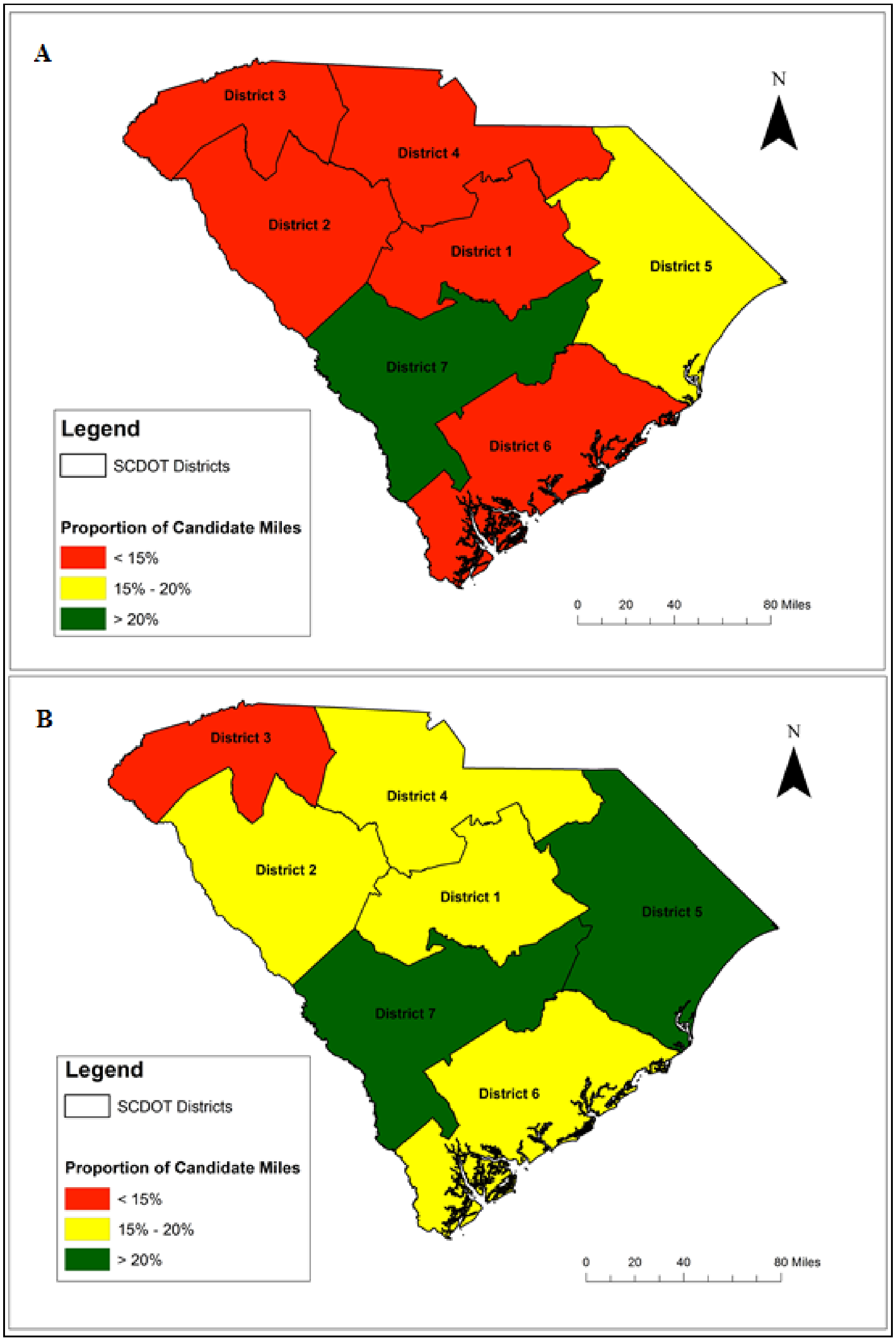


Figure 4.23. Comparison of Proportion of Total Miles Qualified as Candidates by District

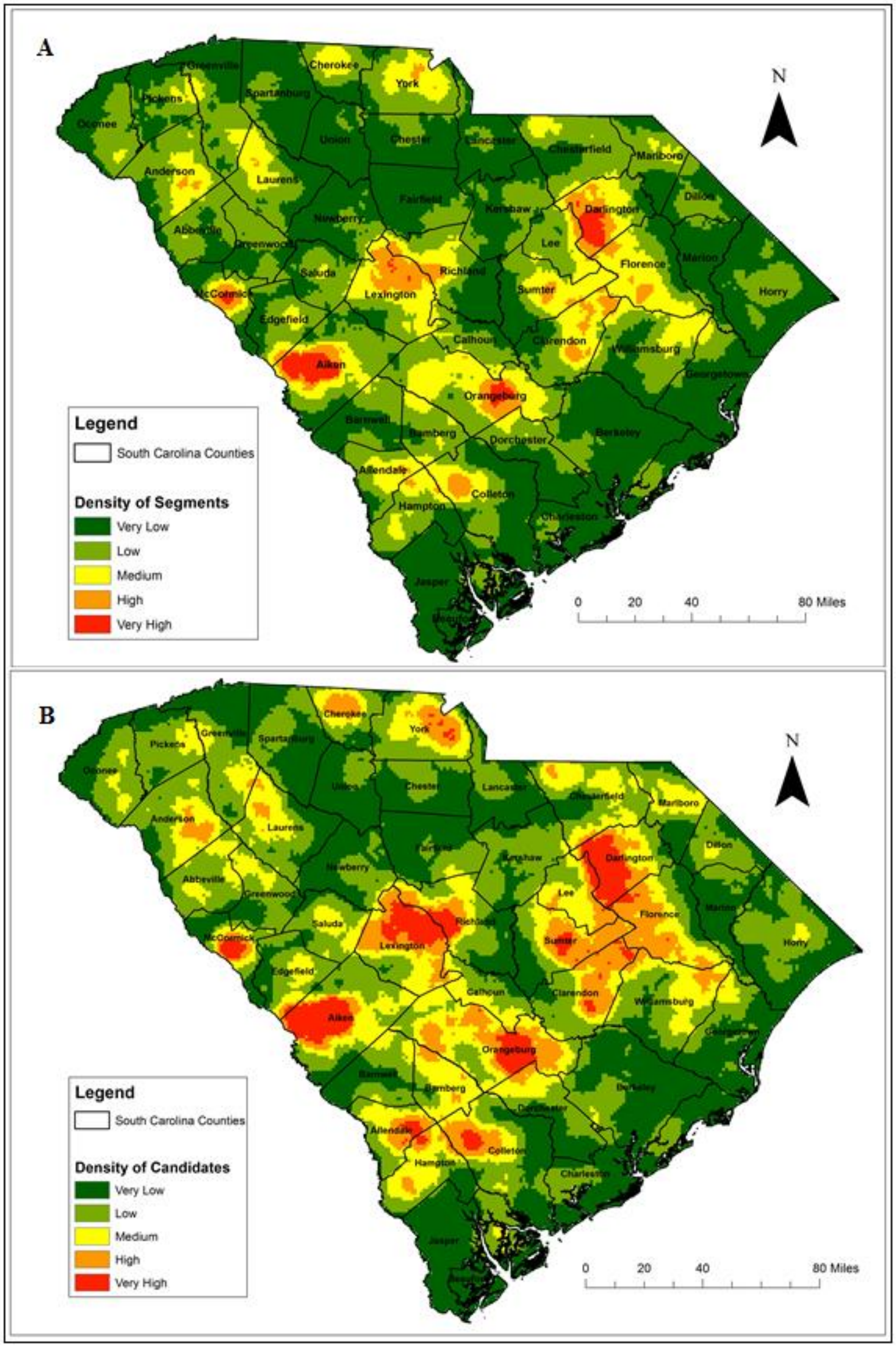


Figure 4.24. Comparison of Candidate Density Statewide

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CHAPTER 5. Treatment Selection and Timing Support

Pavement preservation is critical to highway treatment and essential to US road network maintenance. Related research can be dated back decades. The research team created a pavement preservation decision tool for use by SCDOT. This tool will enable the user to input data specific to a particular pavement segment (e.g., pavement condition information, location, materials information, treatment type(s), treatment cost data, etc.). In addition, the tool provides the user with optimized strategies to assist in selecting the appropriate pavement preservation treatment for a particular pavement segment at the appropriate times to maximize the pavement life and cost-benefit of the pavement in recognition of funding limits. The focus on life cycle and cost benefit requires a re-review of available software packages for handling of these issues. It is important to be able to specify state specific costs as well as adapt life cycle timelines for experience relative to South Carolina conditions. All the acquired information is integrated into the developed optimization modeling framework to prioritize the pavement preservation treatments to the road network. Within the scope of the project, the team assessed existing packages and developed a modeling framework for the SCDOT RIMS/HPMS enterprise system to determine which would best meet the needs of the pavement preservation program.

Literature Review

In early pavement preservation studies, most researchers paid their attention to single segment preservation. Shober and Friedrichs (1998) proposed a pavement preservation strategy for Wisconsin Department of Transportation and they provided clear guidance about the process of pavement preservation in the following order:

1. measure the pavement distress type and distress level
2. determine the pavement problem and problem level based on whether the segment exceed distress threshold
3. determine alternative treatments according to pavement problem
4. select best treatment based on customer's comfort, convenience safety and cost

This was the first time that pavement preservation had a practical procedural order.

Hicks et al (1997) built a framework for selecting appropriate preservation treatments for single segments. They first used decision trees to determine available treatment options based on traffic volumes, distress types and levels, and then use the developed cost evaluation model to make the most cost effective decisions. Hicks et al. (1999) refined their former pavement treatments selection model with a decision matrix and rating factors, which makes the model more accurate while more complicated at the same time.

In addition to the cost of treatment in pavement preservation, other aspects, such as the frequency of applying a preservation treatment, are also of concern in pavement preservation. Mamlouk and Zaniewski (2001) presented a method of optimal timing of specific preservation treatments. Their method relies on an experience-based reference of different treatment applications that feature different frequencies under a specific environment (i.e., pavement type, traffic, and climatic condition). In recent research efforts, impacts on environmental sustainability are more of concern when making decisions on pavement preservation, along with cost and timing considerations. Chan et al. (2011) conducted a study on pavement preservation from the perspective of environmental benefits. Based on the 10-year record of the Ministry of Transportation of Ontario, Canada (MTO), they found that microsurfacing could reduce nitrogen oxide, carbon dioxide, and sulfur dioxide emissions by almost 15%, 6%, and 20%, respectively, compared with the traditional mill and overlay method. In the meantime, both annualized cost saving (Unit Cost/Service Life) and annualized aggregate consumption (Weight/Service Life) can be reduced as well.

The aforementioned studies focused on individual road segments, and neglect the effects of traffic flows and allocation of limited preservation strategies on the network. There is another stream of studies from a network perspective. Abaza and Ashur (1999) proposed a Markovian model to predict road condition and maintenance cost in the future while yielding optimum maintenance plans under budget constraints. The model integrates both deterioration rate and preservation rate. Based on the same model, Abaza et al (2001) designed a pavement management system in a macroscopic scale with three subsystems:

1. A performance prediction module which generates a performance curve
2. A rehabilitation strategy module which provides maintenance treatment options based on the curve
3. An optimum decision module which makes the optimum fractions of preservation road subject to cost constraints

Abaza et al (2004, 2007) conducted simulations with a similar methodology. Rather than selecting treatments, some researchers focused on the allocation of limited funding resources for pavement preservation. Wu et al (2008) combined an analytic hierarchy process and goal programming to create a multi-objective optimization model. The results demonstrated how the funding was allocated to each district and what appropriate treatments should be deployed in different districts. All these studies are based on the prediction of future road network conditions.

Decision Making Strategy

As noted in previous chapters, the cost of pavement preservation activities is significantly lower than rehabilitation and reconstruction. Additionally, pavement preservation maintains the condition of good pavements instead of letting them fall into fair or poor condition. Therefore, it would be more cost effective to continuously increase the number of lane-miles of pavements that are candidates for pavement preservation (i.e., good condition). The threshold for pavement preservation for Secondary, Non-Federal Aid pavements defined by the SCDOT is a PQI of 3.0—pavements having a PQI ≥ 3.0 are considered to be candidates for pavement preservation. As previously discussed, the PQI of a pavement decreases each year due to a number of factors and pavements will eventually fall out of the pool of pavement preservation candidates if no action is taken to preserve the condition.

The overall objective of the development of a decision support tool for pavement preservation strategies was to consistently improve the overall health of the pavement network using aspects of the remaining service life concept discussed in Chapter 2. This was accomplished by selecting treatment strategies to improve overall network health by increasing the number of lane-mile-years each year. In doing this, the total number of pavement segments having a PQI ≥ 3.0 should also increase each year as pavements having a PQI < 3.0 receiving rehabilitation or reconstruction activities will move into this pool of preservation candidates having a PQI ≥ 3.0.

Model Formulation

Modeling Assumption

This project focused on deploying a network level cost-effective set of strategies to meet performance expectations. The objective of this decision tool is to minimize preservation cost while fulfilling the life extension requirement. The framework used to accomplish this goal was based on a model that considers different distress types:

1. Low severity fatigue cracking
2. Moderate severity fatigue cracking
3. Low severity transverse cracking
4. Moderate transverse cracking
5. Low severity longitudinal cracking
6. Moderate severity longitudinal cracking

Depending on the type and severity of distress, there are strategies that can be applied (e.g., Crack Sealing, Chip Seal, Microsurfacing, Ultra Thin Asphalt Overlay), according to the *SCDOT Program Procedure - Pavement Improvement and Preservation Project Development*. Each strategy was assumed to have a specific severity range for different distress types. If the distress severity falls in the range under the same distress type, the treatment was considered as an option for the segment. With this methodology, every possible strategy for a segment can be calculated. Then, considering both lane-mile-year (LMY) requirement and total cost, the model will select the most effective combination for the whole road network.

Mathematic Formulation

Table 5.1. Notation table

Parameters
R: index i, set of road segments which need preservation;
S: index s, set of the strategy available for road segments;
D: index h, set of the distress type which could happen on the road segment;
C: the total cost ($) of the preservation strategy plan
l_i: the length (mi) of segment i;
e_s: the life extension(yrs) of strategy s;
c_s: the cost($) of strategy s;
d_{ih}: the distress severity (%) of road segment i under distress h;
$avail_{ish}$: the available strategies s for segment i under distress h;
$lower_{sh}$: the lower bound for available strategies s under distress h;
$upper_{sh}$: the upper bound for available strategies s under distress h;
LMY: the Lane Mile Year (ln*mi*yrs) requirement.
Decision Variable
x_{ish}: = 1 when strategy s is applied on road segment i when distress h happened; =0 otherwise.

The complete mathematic formulation of the proposed model is below:

Minimize:

$$C = \sum_{i,s,h} l_i * x_{ish} * c_s \tag{5.1}$$

The objective function (5.1) is to minimize the total cost of preservation plan of the current year.

Subject to constraints:

$$\sum_{s,h} x_{ish} = 1, \forall i, \tag{5.2}$$

$$\sum_{i,s,h} l_i * e_s * x_{ish} \geq LMY. \tag{5.3}$$

$x_{ish} \in \cup_s \{avail_{ish}\}, \forall i, h$ (5.4)

Constraint set (5.2) assures that only one strategy s can be applied to a road segment i when h distress is observed on that segment. Constraint (5.3) enforces the life extension requirement to be satisfied. Constraint (5.4) states that the pavement preservation strategies for each segment i given distress type are chosen from the merger set of eligible strategies, which is provided by:

If $lower_{sh} \leq d_{ih} \leq upper_{sh}$, then $avail_{ish} = 1$. Otherwise, $avail_{ish} = 0$.

Case Study: Pavement Preservation Plan for Pickens County, SC

Model Inputs

There are three major model inputs:

1. System setting

According to *SCDOT Program Procedure - Pavement Improvement and Preservation Project Development,* Pavement Quality Index (PQI) as the criterion for segment condition and the trigger value for pavement preservation is 3.0. Based on this trigger value, 748 candidates were selected from 2,654 segments in Pickens County as eligible segments for pavement preservation while the remaining segments should be treated by other applicable rehabilitation or reconstruction method. The total length of available candidates is 72.34 miles.

2. Strategy related data

The *SCDOT Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Pavements* also provides cost and life expectancy data as shown in Table 5.2. In the baseline study, the upper bound of life expectancy was adopted in the model.

Table 5.2. Strategy cost and life expectancy

Treatment Strategies	**Cost/LM**	**Life Expectancy (Years)**
Do Nothing	$0	0
Crack Sealing	$2,395	2-3
Chip Seal	$12,354	5-7
Microsurfacing	$25,588	5-7
Ultra Thin Asphalt Overlay	$30,628	6-8

3. Treatment selection matrix

The lower and upper bounds of distress severity (assumed for the purpose of this analysis) for different treatment strategies are provided in Table 5.3.

Table 5.3. Treatment selection matrix

Treatment Strategies	**Low Fatigue**	**Moderate Fatigue**	**Low Transverse**	**Moderate Transverse**	**Low Longitudinal**	**Moderate Longitudinal**
Do Nothing	(0,5)	(0,5)	(0,5)	(0,5)	(0,5)	(0,5)
Crack Sealing	(0,15)	(0,10)	(0,15)	(0,10)	(0,15)	(0,10)
Chip Seal	(5,15)	(5,10)	(5,15)	(5,10)	(5,15)	(5,10)
Microsurfacing	(5,20)	(6,10)	(5,20)	(6,10)	(5,20)	(6,10)
UTAO	(5,20)	(6,10)	(5,20)	(6,10)	(5,20)	(6,10)

Result and Analysis

In this case study, the life expectancy was set to be 150 LMY. The model was programmed in AMPL and solved by an off-the-shelf solver CPLEX. The minimized total cost was $119,750. For illustration purpose, Table 5.4 shows the optimal treatment strategies for the first 26 of 746 segments. In the table, "1" indicates a strategy is applied to a particular segment; zero otherwise. For example, segment #15 receives "crack sealing" treatment.

Table 5.4. Treatment strategies for different segments

Segment ID	DO Nothing	Crack Sealing	Chip Seal	Micro-surfacing	UATO
1	1	0	0	0	0
2	1	0	0	0	0
3	1	0	0	0	0
4	1	0	0	0	0
5	1	0	0	0	0
6	1	0	0	0	0
7	1	0	0	0	0
8	1	0	0	0	0
9	1	0	0	0	0
10	1	0	0	0	0
11	1	0	0	0	0
12	1	0	0	0	0
13	1	0	0	0	0
14	1	0	0	0	0
15	0	1	0	0	0
16	0	1	0	0	0
17	0	1	0	0	0
18	1	0	0	0	0
19	1	0	0	0	0
20	1	0	0	0	0
21	1	0	0	0	0
22	1	0	0	0	0
23	1	0	0	0	0
24	1	0	0	0	0
25	1	0	0	0	0
26	1	0	0	0	0

The results indicate that as the goal is to minimize the total cost, least costly strategies will be adopted as long as they can meet the LMY requirement collectively. When LMY is set low, many segments, depending on their distress condition, may not need treatment at all as suggested in Table 5.4. However, the treatment strategy will be enhanced with the increase of LMY.

A sensitivity analysis was conducted to better understand how strategy and the total system cost will be impacted by a change in the LMY requirement. The results are plotted in Figure 5.1.

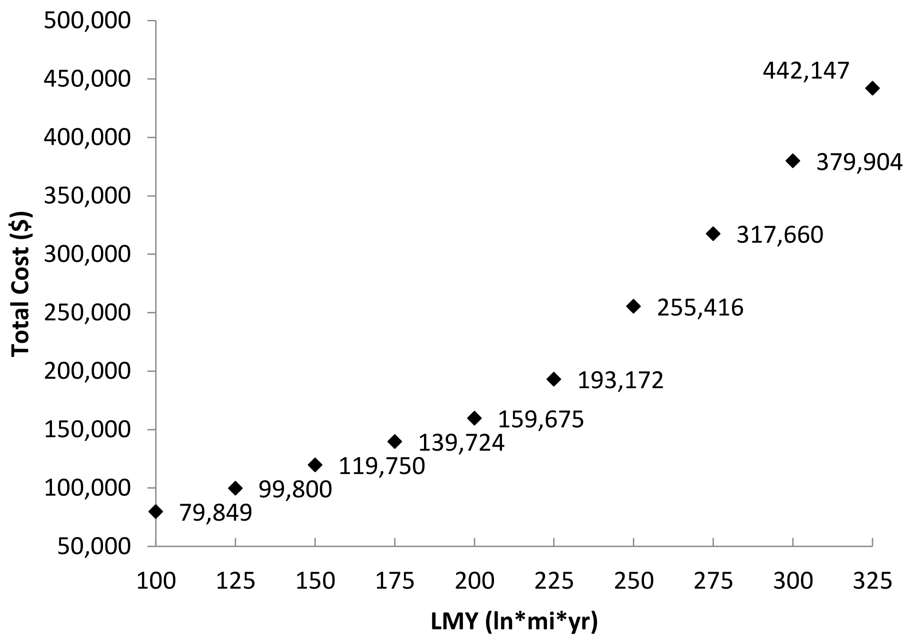

Figure 5.1. Total cost value under different LMY settings

Table 5.6. Treatment strategies when LMY = 325

Segment ID	DO Nothing	Crack Sealing	Chip Seal	Micro-surfacing	UATO
1	0	0	1	0	0
2	0	0	1	0	0
3	0	0	1	0	0
4	0	0	1	0	0
5	0	0	1	0	0
6	0	0	1	0	0
7	0	0	1	0	0
8	0	0	1	0	0
9	0	0	1	0	0
10	0	0	1	0	0
11	0	0	1	0	0
12	0	0	1	0	0
13	0	0	1	0	0
14	0	0	1	0	0
15	0	1	0	0	0
16	0	1	0	0	0
17	0	1	0	0	0
18	0	0	1	0	0
19	0	0	1	0	0
20	0	0	1	0	0
21	0	1	0	0	0
22	0	0	1	0	0
23	0	0	1	0	0
24	0	0	1	0	0
25	0	0	1	0	0
26	0	0	1	0	0

When comparing the treatment strategies, the strategy to meet a higher LMY requirement (i.e., LMY=325) requires more enhanced strategies (e.g., shifting from Do Nothing to Chip Seal), thus resulting in higher total cost.

Previous analyses were based on the use of upper bounds of life expectancy, which may underestimate the need of treatment strategies. Another analysis was conducted using the lower bounds of life expectancy, given the same LMY of 150. The optimal strategies in Table 5.7, compared with Table 5.4, show the shifts to enhanced strategies. As a result, the total cost goes up to $190,957, which presents a 60% increase. As before, the solution strategies for only the first 26 segments are shown in Table 5.7.

Table 5.7. Treatment strategies with lower bounds of life expectancy

Segment ID	DO Nothing	Crack Sealing	Chip Seal	Micro-surfacing	UATO
1	0	0	1	0	0
2	0	0	1	0	0
3	0	0	1	0	0
4	0	0	1	0	0
5	0	0	1	0	0
6	0	0	1	0	0
7	0	0	1	0	0
8	0	0	1	0	0
9	0	0	1	0	0
10	0	0	1	0	0
11	0	0	1	0	0
12	0	0	1	0	0
13	0	0	1	0	0
14	0	0	1	0	0
15	0	0	1	0	0
16	0	0	1	0	0
17	0	0	1	0	0
18	0	0	1	0	0
19	0	0	1	0	0
20	0	0	1	0	0
21	0	0	1	0	0
22	0	0	1	0	0
23	0	0	1	0	0
24	0	0	1	0	0
25	0	0	1	0	0
26	0	0	1	0	0

Decision Support Adaptation

To simplify this process for the user, a Microsoft Excel worksheet was created to assist SCDOT decision makers in developing preventive maintenance and preservation strategies at the county level. This procedure is outlined in Appendix E.

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CHAPTER 6. Treatment Tracking

Defining treatment tracking data items was another major objective of this research. The first step in defining these data elements was to analyze and define the data already collected by the South Carolina Department of Transportation. As shown in Chapter 3, the SCDOT ITMS has a section where pavement quality data can be accessed. After reviewing a tutorial for this section of the ITMS, it was noted what information the SCDOT currently allows users to view. Microsoft Excel worksheets were also received from the SCDOT that showed an example of the type of data collected. After noting the current SCDOT data elements, the existing software packages' data elements were also analyzed. After comparing the data needed by all these programs, a data matrix, shown in Table 6.1, was created to provide SCDOT with data that should be included in an ITMS treatment tracking program.

Table 6.1. Sample data matrix for treatment tracking.

Data Elements	Description	Type of Data	Example
Location			
District	SCDOT District where work is completed	Number	2
County	County where work is completed	County code	Abbeville (1)
Route Type	Route type for roadway where treatment is implemented	Route Type Code (US, SC, S, L)	S
Route Number	Route number for roadway where treatment is implemented	Number	579
Begin Mile Point	Beginning mile point for section where treatment is implemented	Number (1 decimal)	0.5
End Mile Point	Ending mile point for section where treatment is implemented	Number (1 decimal)	0.6
Length (miles)	Length of section where treatment is implemented (End MP - Begin MP)	Number (1 decimal)	0.1
Direction	Direction of section where treatment is implemented	Direction Code (N, NE, E, SE, S, SW, W, NW)	N
Site Selection Triggers - Traffic Volume and Condition Data			
Pavement Type	Indicate the existing type of pavement used for this section of roadway	Pavement Type Code (A, H, P)	H
Last Rehab Year	Year when section was last rehabilitated, prior to this treatment being performed	Number (YYYY)	2002
AADT	Traffic data, preferably at the treatment year	Number	1550
% Trucks	% Trucks for corresponding AADT	Number	5
Year of AADT/% Trucks	List the data collection year for AADT/% Trucks		2015

Table 6.1 (continued). Sample data matrix for treatment tracking.

Data Elements	Description	Type of Data	Example
ITMS Distress Data			
PQI Prior	Most recent Pavement Quality Index (PQI) taken prior to treatment	Number (1 decimal, Range 1-5)	3.2
IRI Prior	Most recent International Roughness Index (IRI) taken prior to treatment	Number (1 decimal, Range 1-5)	4.1
PQI/IRI Year	Year that most recent PQI and IRI data was collected	Number (YYYY)	2014
Predicted PQI	If PQI/IRI Year is not current, include the predicted PQI for the current year based on degradation charts	Number (1 decimal, Range 1-5)	3.1
Predicted IRI	If PQI/IRI Year is not current, include the predicted IRI for the current year based on degradation charts	Number (1 decimal, Range 1-5)	3.9
Fatigue Cracking	% low, % mod, and % high	%L/%M/%H	90L/7M/3H
Transverse Cracking	% low, % mod, and % high	%L/%M/%H	90L/7M/3H
Longitudinal Cracking	% low, % mod, and % high	%L/%M/%H	90L/7M/3H
Raveling	% low, % mod, and % high	%L/%M/%H	90L/7M/3H
Patching	% low, % mod, and % high	%L/%M/%H	90L/7M/3H
Manual PSR Distress Data (for local roads and sections not on HPMS)			
Date of Survey *	Date that manual pavement evaluation data was collected	Date (DD/MM/YYYY)	11/3/2015
PSR Prior *	Pavement Section Rating (PSR) evaluated prior to treatment	Number (Range 1-10)	6
PSR Factor 1 *	For each rating, there are up to 6 visible distress factors that can be selected to further describe the pavement section prior to treatment. This is a binary data - either the factor was or was not present.	Binary Number (1 - present, 0 - not present)	1
PSR Factor 2 *	"	"	0
PSR Factor 3 *	"	"	1
PSR Factor 4 *	"	"	1
PSR Factor 5 *	"	"	0
PSR Factor 6 *	"	"	0

Table 6.1 (continued). Sample data matrix for treatment tracking.

Data Elements	Description	Type of Data	Example
Treatment Information			
Treatment Type *	Pavement preservation treatment implemented in the field	Treatment Name or Code (Crack Sealing, Chip Seals, Microsurfacing, Ultra-Thin Asphalt Overlay, Full Depth Patch)	Chip Seal
Treatment Quantity *	Amount of Treatment Implemented (volume)	Number	1
Treatment Description *	Brief description of work completed	Text	Patching/minor leveling and chip seal
Treatment Date *	Date treatment is implemented	Date (DD/MM/YYYY)	1/10/2016
Contractor Name *	Name of contractor that implemented treatment	Text	ABC Construction Company
Cost Information			
Labor Cost *	Cost of labor on the project	Number	2650
Unit Cost of Treatment *	Unit cost of the treatment Implemented ($/lane-mile)	Number	3500
Total Units of Treatment *	Number of treatment units implemented	Number	0.1
Total Material Cost *	Unit Cost x Total Units	Number	350
Total Cost *	Total cost of the treatment project	Number	4000
Post Treatment Rating			
PQI After *	Pavement Quality Index (PQI) taken after treatment	Number (1 decimal, Range 1-5)	4.1
IRI After *	International Roughness Index (IRI) taken after treatment	Number (1 decimal, Range 1-5)	4.4
PSR After *	Pavement Section Rating (PSR) taken after treatment	Number (Range 1-10)	9

The following list of data elements are currently maintained in the SCDOT ITMS database: County

- Route Type
- Route Number
- Auxiliary
- Direction
- Begin Mile Point
- End Mile Point
- Length
- AADT
- % Truck Traffic
- Most Recent IRI
- Predicted IRI
- Most Recent PQI
- Predicted PQI
- Most Recent Year of Distress Collection
- % Low, Moderate, and High Severity for Fatigue, Transverse, and Longitudinal Cracking
- % Low, Moderate, and High Severity Raveling
- Low, Moderate, and High Severity Tran Crack Length
- % Low, Moderate, and High Severity Patching
- Maintenance Activity (Assuming Pavement Preservation Maintenance)
- Maintenance Year
- Rehab Activity
- Rehab Year
- Pavement Type
- Functional Class

As discussed in Chapter 3, the SCDOT uses a formula to calculate the pavement quality index (PQI) of a roadway to find its condition. This formula was developed by Stantec specifically for the SCDOT. The pavement serviceability index (PSI) is a value based on the IRI collected by a vehicle in the field. The SCDOT collects the distress data for each distress defined in Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Treatments. The collected distress data is used to create a deduct value used in calculating pavement distress index (PDI). The PSI and PDI are used to calculate the PQI to give the overall pavement condition. The PQI is used as a trigger value to decide on maintenance treatments for the roadways. The SCDOT currently collects all data necessary to compute PQI and identify pavement preservation candidates.

Comparing the elements above with the listing of sample variables in Table 6.1. Sample data matrix for treatment tracking, there are a number of items that need to be added to the enterprise database. For convenience, these are indicated with a (*) beside the data element name in the table. Several of the data elements (see data elements under Manual PSR Distress Data) would be generated by manual pavement evaluations as defined in Appendix D. The pre-treatment distress levels are important variables in the selection of treatments and the life extension of the pavement. The maintenance of these variables in the state data system will allow for much more detailed degradation models to be developed for decision support in the future.

In general, the SCDOT lacks in information to determine which treatments are working the best throughout the state. The inability to identify treatment sites, treatment types, and cost remains the biggest factor. While the SCDOT ITMS does currently allow for users to query daily work reports (DWR) to see what activity has been completed on a roadway segment, the information is not complete (covering only internal SCDOT work) and the user interface does not easily support preservation specific queries. The DWRs do provide a detailed look into maintenance activities and provide the project labor cost, equipment cost, material cost, and total cost. This DWR query feature in the ITMS provides a good starting point to creating a successful treatment tracking program for pavement preservation in South Carolina. In addition to DWRs, similar reports would be needed for contracted pavement work. From the DWRs and contract work, the treatment tracking program should collect the following data:

- Location of the treatment
- Treatment type
- Treatment description
- Volume of treatment implemented
- Cost breakdown of treatment
- Date of treatment (Month/Year)
- Contractor name

To better implement the different treatments throughout the state, collecting data on their actual performance in the field is crucial. Knowledge on the location of the treatment implementation is important as certain treatments may be more successful in some parts of the state in comparison with other parts. County name, route type, route number, beginning mile point, ending mile point, direction, length, and AADT are all data elements needed to identify the location of the treatment. Treatment type and treatment description are needed for obvious reasons. The application rate of the treatment applied is also necessary to give an accurate picture of treatment performance. The cost breakdown of the treatment, such as labor cost, equipment cost, and material cost, is important to display the cost effectiveness of implementing certain treatments. The date of treatment implementation is also important to accurately show the performance period and life extension of the treatment. Weather as well as the season in which the treatment was applied could affect the overall performance of the treatment and show a treatment as ineffective. The name of the contractor or work performing group should also be included. This data could have two advantages: allowing better distribution of work by location and identifying if any one contractor is not performing work up to standard repeatedly.

Finally, a pavement evaluation should be conducted and maintained after the treatment is put into place to determine the new PQI or PSR value. This information should also be included in the statewide data system as a means of further assessing the contractor performance, as well as a basis from which to determine the expected pavement life extension. This in combination with the pre-treatment distress information is useful for establishing the effectiveness of the treatment.

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CHAPTER 7. Treatment Costs and Life Extension

Literature Review

"Pavement Preservation is a systematic approach to employing a network level, long term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations (CTDOT)." Falls and Tighe state that life cycle cost analysis (LCCA) is an economic tool used to evaluate the economic worth of infrastructure projects. The LCCA includes two different types of costs: agency and user costs. Agency costs are those such as initial construction, maintenance, reconstruction, rehabilitation, and resurfacing of the pavement. User costs are those such as vehicle operating costs, crash costs, and user delay costs (Falls and Tighe, 2004).

When a pavement preservation strategy is used correctly with a LCCA, three separate groups can benefit: Road user (reduced travel time, vehicle operating, accidents), agency (timely and appropriate maintenance and rehabilitation), and public (objective, consistent, transparent, and repeatable decision making) (Falls and Tighe, 2004). Perpetual pavements, also known as long life pavements (LLP) will be economically viable if they result in lower overall costs over their lifetime, such as lower whole life costs compared to the whole life costs of determinate designs. Economic evaluation of LLPs seem to be the most appropriate of the available tools, however, the tool does not have the capability to evaluate the environmental costs (Cheneviere and Ramdas, 2006).

Smith et al. 2005 conducted research on the cost benefit analysis of continuous pavement preservation design strategies versus reconstruction. Only pavement sections with complete traffic records were selected for analysis. The following steps were taken to complete the LCCA on the different pavement preservation strategies (Smith et al. 2005):

1. The rehabilitation treatments evaluated were defined according to (a) depth of removal (milling) of existing pavement, and (b) treatment application thickness
2. Cost Database: (2% inflation rate was used) Unit costs used in LCCA
3. Breakdown as Pavement Type, Facility Type (Interstate), Climate (Hot-Dry, Moderate, Cool-Wet), using revised matrix, survival functions were developed: Survival Age (years) and Survival Life (number of trucks-millions)
4. Mechanistic Based Analysis→ Life Cycle Cost Analysis

Results showed a consistent reduction in total life-cycle cost corresponding to an increase in the number (from 0 to 2) of rehabilitations between initial construction and the first reconstruction. There is an economic value in performing at least one to two sequential rehabilitation treatments prior to reconstruction (Smith et al. 2005).

A new optimization model and priority programming for pavement network maintenance and rehabilitation management was conducted by Li et al. (1997). A time related Markov Modeling of Pavement Deterioration was conducted. A Markov process is a probabilistic based deterioration model in terms of its properties and prediction outputs. The following steps were taken to pick the pavement preservation treatment that would be most cost effective (Li et al. 1997):

1. Sections of road were determined (length of section, lane-km)
2. Pavement Condition Index (PCI) was determined for each section
3. A minimum PCI was chosen (PCI=4.5)
4. Treatments are chosen based on PCI
5. Different alternatives are calculated

Shober and Friedrichs stated that an effective pavement management system requires a comprehensive pavement preservation strategy (PPS). The benefits of a PPS are as follows: better quality transportation, longer pavement service lives, reduced life cycle costs, improved decision making for transportation planning, and more efficient use of transportation funds. First, for each pavement section, determine the specific pavement distresses from field measurement and categorize each specific pavement distress into one distress level. Then use the pavement distress levels to determine the treatment alternatives for each problem. The final step is to determine the proper treatment option based on LCCA. A summary of the process can be seen (Shober and Friedrichs, 1998):

1. Defined the problem
2. List of acceptable treatments
3. Pavement problem severity matrix
4. Treatment alternatives
5. LCCA of applicable treatments

Zimmerman et al. 2000 applied economic concepts from LCCA to pavement management analysis. The LCCA included both equivalent uniform annual cost (EUAC) and present-worth methods. In order to conduct an LCCA, one must convert all future costs that are expected to occur over the analysis period to present day cost. As reported by Wall and Smith (1998), the costs that are associated with a LCCA can be reported in terms of either nominal or real dollars. Real dollar values reflect dollars that have the same or constant level of purchasing power over time. Nominal dollar values reflect dollars whose purchasing power fluctuates over time (Walls and Smith, 1998).

The Federal Highway Administration (FHWA), in its Technical Bulletin, supports the use of real dollars and real discount rates on the basis of their analysis of best practice. Zimmerman et al. suggest the following when conducting a LCCA (Zimmerman et al. 2000):

- Use a present worth analysis in the incremental benefit cost analysis with real treatment costs and a real discount rate
- Inflated budget values must be discounted back to the analysis year to eliminate the effects of inflation on their value
- To conduct the incremental benefit cost analysis, the costs for any treatments being recommended must be discounted back to the analysis year
- To have the project list from the incremental benefit cost analysis match the budget values after they have been inflated, the cost of the treatment in the recommended program listing must be inflated. This adjustment, made by applying an inflation rate to the baseline costs, allows nominal budgets to be matched with nominal costs.

Stroup-Gardiner suggests fixing all local pavements in one area at one time, if possible, to save money. The larger the paving job, the more money that can be saved instead of doing several smaller jobs. She also suggests that the following steps be included into a pavement preservation manual (Stroup-Gardiner, 2009):

1. The low and high prices of different preventative treatments were calculated for large, medium, and small projects.
    a. A Large project requires the contractor to be on site for more than one week.
    b. A medium project take about three to five days to complete the work
    c. A small project lasts for about one to two days
2. Estimated upper cost for each type of preservation treatment for small size projects.
3. Reduction in treatment cost achieved by increasing the size of treatment project.

4. Influence of existing pavement condition on anticipated treatment life. (PCI=80, good. PCI=60, fair. PCI=40, poor).
5. A PCI of 80 is the most desirable time to place a pavement preservation treatment.
6. Significant cost savings can be achieved by organizing pavement preservation work so that the contractor will have several projects in one geographic area.

Wang et al. stated that a cost benefit analysis was performed to select the most economical alternative among various pavement preservation choices using LCCA analytical technology. The impact of pavement conditions on the performance of the specific treatment were investigated in terms of pavement performance curves, which were developed for the treatments under varying pavement condition levels at each traffic network based on the PennDOT Overall Pavement Index (OPI) data. A relationship between pavement life extension and pavement condition prior to the treatment was established. Lastly, LCCA was conducted to quantify the impact of the pavement condition on the performance of the preservative treatments in terms of benefit cost (B/C) ratio and net equivalent uniform annual cost (∆EUAC). Equations of how these were calculated are below (Wang et al. 2013):

∆EUAC = EUAC (do-nothing) – EUAC (treatment)

B/C= ∆EUAC/ EUAC (pvc)

EUAC (do-nothing) = computed equivalent uniform annual cost due to do nothing

EUAC (treatment) = computed equivalent uniform annual cost with application of a treatment

EUAC (pvc) = computed equivalent uniform annual cost due to the cost of preservation

The main question that needs to be answered is when it is best to apply maintenance treatments to a road that is undergoing pavement preservation. The difficulty lies in establishing performance curves based on treatment application at different pavement conditions. Pavement management information in the form of OPI from the PennDOT pavement management database has been used to make this evaluation. The OPI was developed by PennDOT to measure overall pavement condition, which is on a 0 to100-point scale, where 0 = complete failure of the pavement and 100 = undamaged pavement with no distresses (Wang et al. 2013).

Over a 10-year period (1998-2008) the OPI data was grouped into four traffic network levels:

1. ADT Less than 2000
2. ADT greater than 2000
3. National Highway System (NHS)
4. Interstate Highways

Once the life benefit was determined, the next step was to analyze the benefits and costs computed for each OPI value to determine the most cost effective OPI scenario that provides the largest B/C factor or net benefit ∆EUAC. A simple three step LCCA was conducted to evaluate the cost effectiveness of the preservation activities under different pavement conditions. First, the net present value (NPV) (at year zero) of each OPI scenario was calculated. Then the computed NPV was converted into an equivalent uniform annual cost (EUAC). Lastly, ∆EUAC and B/C factor were calculated (Wang et al. 2013).

Another type of LCCA is realistic Life-Cycle Cost Analysis. Abdollahipour and Jeong state that association analysis is the identification of items that occur together in a given event or record and is also known as market basket analysis. Association rules are based on the number of times items occur alone and in combination in the transaction records. An association rule can be expressed as “if item A is part of an event, then item B is also part of the event” with a probability value. The original data structure needs to be modified before association and sequence analyses can be used. In the new data structure, each control section is divided into smaller sections based on the following factors: Original pavement type, original pavement construction year, and treatment history (Abdollahipour and Jeong, 2012).

There are two types of LCCA: Deterministic LCCA and Stochastic. Pittenger et al. 2012 state that deterministic LCCA is the use of discrete input values (point estimates) that result in single output values (traditional LCCA mostly used in transportation decision making). Stochastic LCCA is more robust than the deterministic approach involves modeling uncertainty with probabilities. Pittenger et al. 2012 primary objective was to study the stochastic LCCA approach specifically for a pavement preservation treatment strategy (Pittenger et al. 2012).

Step one of a stochastic approach requires the analyst to identify which input values have associated uncertainty and will have a material effect on the outcome. Those values should be treated probabilistically, while all others are treated deterministically to simplify the analysis. As far as the service life (analysis period) and discount rate, this study uses the triangular distribution to describe the one-inch HMA pavement treatment service life, with a minimum value of 8 years, maximum of 12 years, and most likely value of 10 years. This study uses the previous 30 years of discount rate data from the Federal Reserve, fitted to the appropriate probability distribution (Pittenger et al. 2012).

Second step of a stochastic analysis is to "fit" a given data set to the "best" theoretical probability distribution. The "fitting" process is enabled by statistically based goodness-of-fit tests such as Anderson-Darling (A-D) and chi-squared tests. The third step of a stochastic approach is risk analysis, which is based on probability theory and can be defined as a "Systematic use of available information to determine how often specified events may occur and the magnitude of their consequences" (Pittenger et al. 2012).

Cost and Benefit of Pavement Preservation in South Carolina

Understanding the benefits and costs of pavement preservation treatments in South Carolina is important for making data-driven decisions related to pavement preservation as part of pavement management activities and resource allocation. However, to truly understand the value of individual pavement preservation treatments, it is of critical to have the appropriate data. This data includes:

1. Detailed cost breakdowns of individual preservation projects
2. Detailed pre-treatment pavement condition
3. Routine detailed post-treatment pavement condition.

The combination of these pieces of information will provide the cost of the treatment and the life extension (benefits) on the project level. To appropriately quantify the benefit of any preservation treatment, it takes several years of detailed and deliberate assessment on a project, thus sufficient data was not available (especially for secondary roadways) during the duration of this study to quantify the benefits, or life extension of individual pavement preservation treatments. The data that was available is provided in Table 7.1.

Table 7.1. Pavement preservation treatment cost and life extension estimates reported by the SCDOT.

Treatment	**Average Unit Cost *(per lane-mile)***	**Estimated Life Extension *(years)***	**Equivalent Uniform Annual Cost* *(per lane-mile)***
Crack Seal	$1,587	3	$550
Full Depth Patching	$25,985	5	$5,513
Chip Seal	$9,786	6	$1,747
Microsurfacing	$19,008	7	$4,188
Thinlay	$27,104	7	$5,244

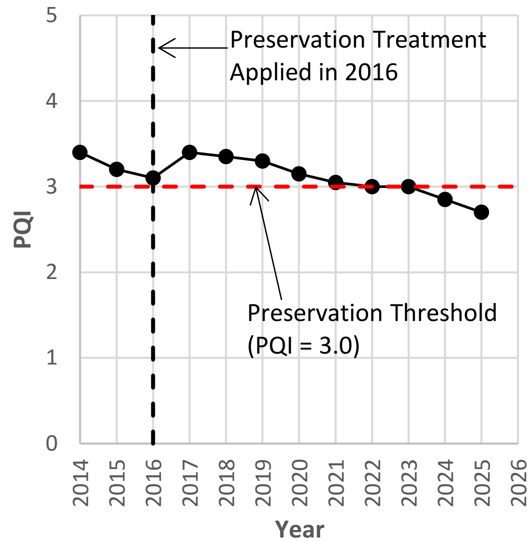
** EUAC calculated using an interest rate of 2%*

While the data in Table 7.1 provides a general representation of the cost and life extension of treatments in South Carolina, more data (i.e., project specific cost and performance) is required to quantify the benefit-cost ratio of pavement preservation treatments on an individual project basis. With this in mind, the research team focused on defining a long-term evaluation protocol to determine the life extension and benefit-cost ratio of future treatments used by SCDOT. The resulting data will then be available to better understand the actual benefit of different treatments in different conditions.

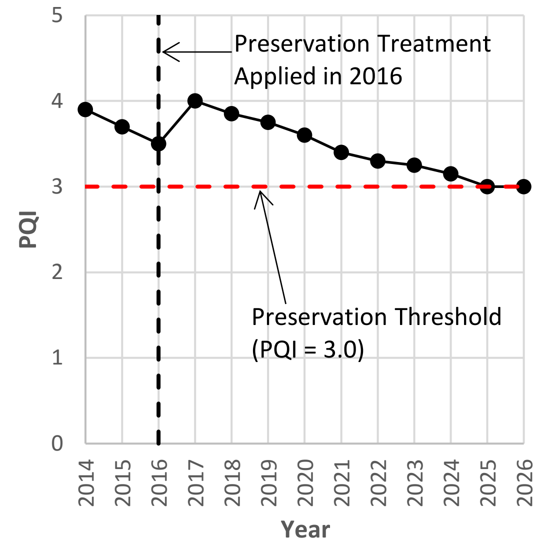
Methodology

The methodology proposed by Hajj et al. (2010) was an effective method to quantify the benefit-cost ratio of pavement preservation treatments for the Nevada DOT while also being simple to implement given the appropriate information. Therefore, this method has been adapted for proposed use by the SCDOT.

1. Determine the condition of the pavement prior to application of the preservation treatment. If possible, the condition should be quantified by PQI, however, this must be a measured PQI instead of a predicted PQI. If the PQI cannot be determined due to resource limitations, the surface condition rating should be determined using the guidelines provided in Appendix D.
2. Apply the appropriate treatment to the pavement and document the actual cost of the application and calculate the unit cost per lane-mile.
3. Measure the pavement condition within a short period of time after the treatment application using the same procedure from Step 1.
4. Regularly measure the pavement condition on an annual basis to establish a pavement condition deterioration curve similar to the examples in Figure 7.1.



(a)



(b)

Figure 7.1. PQI curves for pavements receiving preservation treatments.

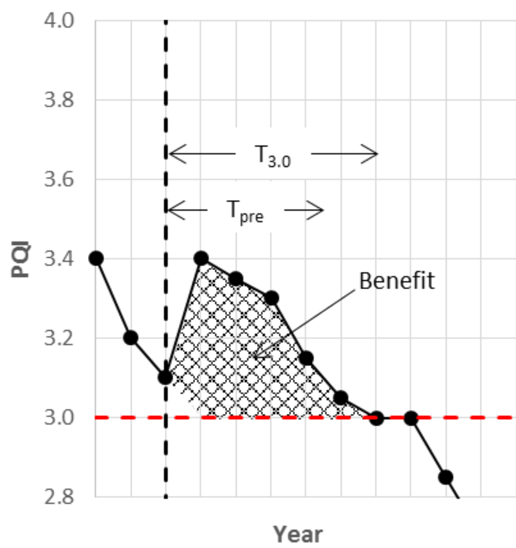
With the data shown in Figure 7.1 available for a section of pavement that has received a preservation treatment, the pavement life extension and benefit-cost ratio can be calculated using Equation 7.1 and the elements described in Table 7.1 and Figure 7.2.

$$Benefit/Cost\ Ratio\ = \frac{Benefit}{Cost} \times 10^5 \tag{7.1}$$

where, Benefit is as explained in Table 7.2 and Figure 7.2 (PQI·years) and Cost is the total treatment cost ($/lane-mile).

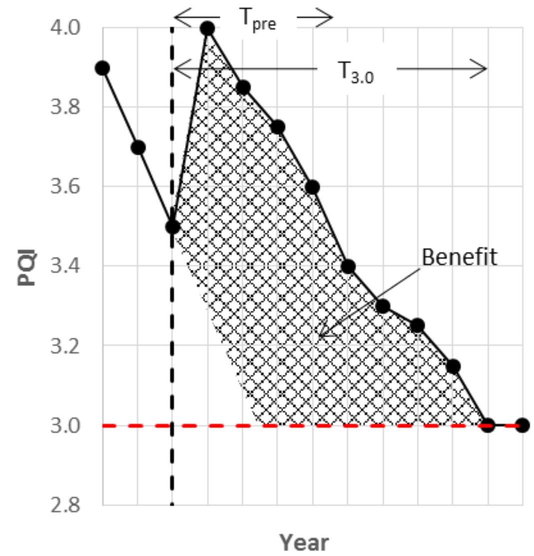
Table 7.2. Elements of the determination of benefit-cost ratio for pavement preservation treatments (adapted Hajj et al. 2010).

Data Element	Description	Units
PQI_{pre}	PQI of pavement before treatment.	
PQI_{post}	PQI of pavement immediately after treatment.	
PQI_{recent}	Most recent PQI on record	
T_{pre}	Number of years to reach PQI_{pre}	years
$T_{3.0}$	Number of years to reach PQI of 3.0, which is the threshold for pavement preservation.	years
Performance Range	Range of time from T_{pre} to $T_{3.0}$.	years
Benefit	Area under the PQI curve from the time of treatment to $T_{3.0}$.	PQI·years
Cost	Total cost of the treatment including labor, materials, and equipment.	$/lane-mile



T_{pre} = 4.5 years
$T_{3.0}$ = 6.0 years
Performance Range = 4.5–6.0 years
Benefit = 1.25 PQI·years

(a)



T_{pre} = 4.5 years
$T_{3.0}$ = 9.0 years
Performance Range = 4.5–9.0 years
Benefit = 4.13 PQI·years

(b)

Figure 7.2. Example calculations of data elements required for proposed benefit-cost analysis.

Having quantitative benefit-cost data as described in this section, the SCDOT can more accurately track the influence of several variables on the effectiveness of different pavement preservation treatments. These variables can include geographic area (by district or county), pre-treatment PQI, traffic volume, treatment variables, and construction variables, to name a few. A spreadsheet based tracking tool has been developed using this method and is included in Appendix F.

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CHAPTER 8. Conclusions and Recommendations

The most effective method for maintaining pavement serviceability is to implement a pavement preservation program, which is a planned system of pavement surface treatments designed to extend the life of a pavement using the fewest resources (money, materials, energy, and time). To sum up the objective of a pavement preservation program, it is deciding on "***the right treatment on the right pavement at the right time.***" Pavement preservation techniques provide the opportunity for state departments of transportation to use their budgets efficiently to keep the greatest number of roadways at an acceptable condition.

Conclusions

Currently, the South Carolina Department of Transportation does not have a pavement preservation component that is part of their Integrated Transportation Management System (ITMS) that is used to maintain comprehensive network information. From surveying those involved in pavement maintenance throughout the state, it became clear that the procedure for implementing pavement preservation needs to improve. The first step to being able to implement such changes was to assess the current practices by the SCDOT through the survey and investigation of the SCDOT ITMS. Comparing SCDOT current practices to other states with established pavement preservation programs revealed that the distress identification and treatment options in the South Carolina are comparable to other states. After looking at existing pavement software packages, it became clear the SCDOT was lacking in its ability to predict future pavement condition, identify which treatments to implement, and accurately budget for those treatments.

For the SCDOT to have the improved abilities to implement pavement preservation, this research developed a process to identify the candidates for preservation from current SCDOT data. This procedure can be utilized to not only identify candidates, but through GIS, it can also provide the decision maker with a visual representation of the proximity of candidates within a network which can be useful when developing contracting plans or strategies for pavement preservation. Identifying the candidates can allow the SCDOT to allocate funding to appropriate counties or districts based on the need. It can also help track the overall progress of the pavement preservation program in increasing the number of lane-miles in good condition throughout a network.

Treatment selection for pavement preservation is typically the task of Resident Maintenance Engineers (RME) within a district and is frequently based on the experience of the decision maker with particular treatment types. Additionally, some districts have an in-house chip seal program, therefore, chip seals are commonly the treatment of choice in these areas. Another major factor that affects these decisions is available funds. In the survey, many respondents noted that there are not enough funds available to maintain or improve the network they manage. In an effort to address the need to make informed decisions, the research team developed a treatment decision support tool that accounts for life extension, treatment cost, available funds, and the current health of the network in terms of the number of lane-miles considered to be pavement preservation candidates. This tool will enable the decision maker to identify network level strategies that will maximize the available budget while improving the overall network health based on the Remaining Service Life concept.

Post-treatment tracking and evaluation was found to be limited in South Carolina and the performance of most treatments is frequently anecdotal. A likely cause for this gap is the limited resources (equipment, personnel, and funds) available to maintain such a large inventory of pavements, especially in the secondary roadway system. To address this, the research identified a simplified procedure to monitor the condition of select roadways within a local network (e.g., county level).

The SCDOT maintains data related to all pavements that can lay the groundwork for supporting a pavement preservation treatment tracking system, however, there is still more data that needs to be included in this record keeping. By adding to the data collected, decision makers will be armed with all of the necessary information to make more data-driven decisions related to pavement preservation.

There is very limited information related to the benefits and costs of pavement preservation treatments in South Carolina. In most cases, the benefit (pavement life extension) of individual treatments is assigned a single value regardless of the condition of the pavement that it is applied to or the location or traffic conditions. While these values are within the typical ranges of preservation treatments experienced by DOTs throughout the US, there should be a more specific range of benefit for South Carolina that accounts for the pre-treatment pavement condition. This limitation was addressed by the research team with the adaptation of a method to quantify the benefit-cost ratio of pavement preservation treatments that accounts for the actual life extension of the pavement based on pavement condition as measured by PQI or some other metric based on distress evaluations at the local level (e.g., PCI).

The practices outlined in this research are designed with the South Carolina Department of Transportation current practices in mind. This system should allow for an efficient use of funds to improve the roadway network health in South Carolina and increase the number of pavement sections in good condition over time.

Recommendations

Based on the results of this research, the following recommendations have been developed to help the SCDOT increase the effectiveness of its pavement preservation program.

1. Include more educational opportunities for decision makers related to pavement preservation to focus on long-term network preservation and planning.

2. Consider implementing the decision support concept based on Remaining Service Life to continuously increase the number of lane-mile-years included in the pavement preservation candidate pool (i.e., PQI ≥ 3.0).

3. Document additional information on preservation treatments to adequately track pavement preservation treatments.

4. Implement a more detailed pavement condition evaluation protocol to monitor the actual life extension of pavement preservation treatments. This process should include pre- and post-treatment condition assessment followed by routine evaluations on an annual basis.

5. Consider implementing the system to quantify the benefit-cost ratio of pavement preservation treatments to better understand the effectiveness of different treatments in particular situations.

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APPENDIX A. SCDOT Pavement Management Survey

SCDOT Pavement Management Survey

1. Please provide your contact information.

Name:

Email Address:

Phone Number:

2. What is your position?

- DME
- RME
- RCE

Other (please specify)

3. How many years of experience do you have with pavement maintenance and preservation?

- 0-2
- 3-5
- 6-10
- 11-15
- 16-20
- 20+

4. What process do you use to identify preservation candidates in your area? (e.g., run query in SCDOT data system, or use report generated by district office)

5. Does your area conduct pavement evaluations to supplement the data collected by the van (interstates every year, non-interstate on 3-5 year rotation)? For example, do you have a RME or other doing pavement evaluations to select candidates for preservation?

- ◯ Yes
- ◯ Sometimes
- ◯ No

SCDOT Pavement Management Survey

6. Do you have a written process for these evaluations?

- ◯ Yes
- ◯ No

7. Do you maintain a separate database?

- ◯ Yes
- ◯ No

Other (please specify)

8. What is the frequency of these evaluations?

9. What is the coverage of these evaluations? Mileage per year? or route category?

SCDOT Pavement Management Survey

10. What types of pavement preservation treatments have you used in your area?

- [ ] Asphalt Rejuvenators
- [ ] Asphalt Sealers
- [ ] Crack Sealing
- [ ] Crack Filling
- [ ] Scrub Seals
- [ ] Sand Seals
- [ ] Chip Seals
- [ ] Cape Seals
- [ ] Slurry Seals
- [ ] Micro-surfacing
- [ ] Ultra-thin Overlays
- [ ] Bonded Wearing Course
- [ ] Profile Milling
- [ ] Ultra-Thin Overlays (generally ≤ ¾ inch)
- [ ] Thin Overlays (non-structural, generally ≤ 1½ inch)
- [ ] Mill & Resurface (non-structural, generally ≤ 1½ inch)
- [ ] Full Depth Patch
- [ ] Hot In-place Recycling
- [ ] Cold In-place Recycling

Other (please specify)

11. How do you decide which preservation treatment to use for a roadway?

12. Is there a specific type of treatment that you prefer to use? Why?

13. Are there preservation treatments that you would rather not use? Why?

14. Are there differences in treatment decisions by county in your district?

- Yes
- No
- Don't Know

15. Do you have a specific pot of funds for maintenance (specifically pavement preservation)?

- Yes
- Sometimes
- No

SCDOT Pavement Management Survey

16. What is the typical funding level? How does this get distributed from district level to county level? Are there any specifications on this money?

SCDOT Pavement Management Survey

17. What obstacles do you face with pavement preservation?

18. If a pavement preservation decision support system were developed for SCDOT, would you want that in a stand alone software package or added to the SCDOT RIMS/ITMS data system?

- ◯ Stand-alone
- ◯ SCDOT system

Other (please specify)

19. Do you have any suggestions for improving pavement preservation procedures, decisions, policies?

Thank you for your time to fill out this survey!

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APPENDIX B. Matlab Code for Preservation Candidate Identification

Matlab Code for Identifying 100% Consecutive Preservation Candidates

```
% Look for consecutively large PQI

% Logan Reed
% 6/9/2015


clear
clc

% Excel file information
FileName = 'Secondary_NonFedAid Eligible1.xlsx';
Worksheet = 'All';
SaveTo = 'True or False';

% Preliminary work
% Load the worksheet
[Num,Txt,Data] = xlsread(FileName, Worksheet);
% Get the length of the sheet
R = length(Num);

% Write falses
for t = 3:R+1
    Data{t,41} = 'False';
end

% Increment the rows
i = 1;
for step = i:R-4
    Headers = step+2;
    % Check for the conditions
    % Check for 5 cells in a row that are greater
    if Num(step,14) >= 3.0 && ...
       Num(step+1,14) >= 3.0 && ...
       Num(step+2,14) >= 3.0 && ...
       Num(step+3,14) >= 3.0 && ...
       Num(step+4,14) >= 3.0
        %Check to make sure county is the same
        if Num(step,1) == Num(step+1,1) && ...
           Num(step,1) == Num(step+2,1) && ...
           Num(step,1) == Num(step+3,1) && ...
           Num(step,1) == Num(step+4,1)
        %Check to make sure the route numbers are the same
        if Num(step,3) == Num(step+1,3) && ...
           Num(step,3) == Num(step+2,3) && ...
           Num(step,3) == Num(step+3,3) && ...
           Num(step,3) == Num(step+4,3)
            % Check to make sure the route names are the same
            if strcmp(Data(Headers,2),Data(Headers+1,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+2,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+3,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+4,2)) == 1
```

```
                % Check to make sure the direction is the same
                if strcmp(Data(Headers,5),Data(Headers+1,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+2,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+3,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+4,5)) == 1
                     Data{Headers,41} = 'True';
                     Data{Headers+1,41} = 'True';
                     Data{Headers+2,41} = 'True';
                     Data{Headers+3,41} = 'True';
                     Data{Headers+4,41} = 'True';
                end
             end
         end
         end
     end
end

% Save the Data in a new worksheet
xlswrite(FileName, Data, SaveTo);
```

True-False Matlab Code

```
function [Binary] = TrueFalse(Cell)
% Return a 1 if Cell is greater than or equal to 3.0
% Return a 0 if Cell is below 3.0

if Cell >= 3.0
    Binary = 1;
else
    Binary = 0;
end
```

Matlab Code for Identifying 80% Consecutive Preservation Candidates

```
% 80% consecutive PQI

% Logan Reed
% 6/10/15


clear
clc

% Excel file information
FileName = 'Secondary_NonFedAid.xlsx';
Worksheet = 'All';
SaveTo = 'True or False';

% Preliminary work
% Load the worksheet
[Num,Txt,Data] = xlsread(FileName, Worksheet);
% Get the length of the sheet
R = length(Num);

% Write falses
for t = 3:R+1
    Data{t,42} = 'False';
end

% Increment the rows
i = 1;
for step = i:R-4
    Headers = step+2;
    % Check for the conditions
    % Check for 5 cells in a row that are greater
    if TrueFalse(Num(step,14)) + ...
       TrueFalse(Num(step+1,14)) + ...
       TrueFalse(Num(step+2,14)) + ...
       TrueFalse(Num(step+3,14)) + ...
       TrueFalse(Num(step+4,14)) > 3
    % Check if the same county
    if Num(step,1) == Num(step+1,1) && ...
       Num(step,1) == Num(step+2,1) && ...
       Num(step,1) == Num(step+3,1) && ...
       Num(step,1) == Num(step+4,1)
        % Check to make sure the route numbers are the same
        if Num(step,3) == Num(step+1,3) && ...
           Num(step,3) == Num(step+2,3) && ...
           Num(step,3) == Num(step+3,3) && ...
           Num(step,3) == Num(step+4,3)
            % Check to make sure the route names are the same
            if strcmp(Data(Headers,2),Data(Headers+1,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+2,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+3,2)) == 1 && ...
               strcmp(Data(Headers,2),Data(Headers+4,2)) == 1
```

```
                % Check to make sure the direction is the same
                if strcmp(Data(Headers,5),Data(Headers+1,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+2,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+3,5)) == 1 && ...
                   strcmp(Data(Headers,5),Data(Headers+4,5)) == 1
                     Data{Headers,42} = 'True';
                     Data{Headers+1,42} = 'True';
                     Data{Headers+2,42} = 'True';
                     Data{Headers+3,42} = 'True';
                     Data{Headers+4,42} = 'True';
                end
             end
         end
     end
     end
end

% Save the Data in a new worksheet
xlswrite(FileName, Data, SaveTo);
```

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APPENDIX C. Pavement Preservation Treatment Decision Trees

Bleeding

Any Severity Level

<u>Treatment Options</u>

Full Depth Patch – T

Cold Mill / Thin Overlay – E

Crack Seal / Fill – T

Fog Seal – M,Q

Slurry Seal – E

Mircrosurfacing – E

Thin Overlay – M,Q

Chip Seal – E

Surface Patch – M,Q

Sand Seal – E

OGFC – TM,Q

CI{R – E

HIPR – E

Partial Depth Patch - T

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Block Cracking

Low Severity – Cracks with a mean width ≤ 6 millimeters (mm); or sealed cracks with sealant material in good condition and with a width that cannot be determined.	Medium Severity – Cracks with a mean width > 6 mm and ≤ 19 mm; or any crack with a mean width ≤ 19 mm and adjacent low severity random cracking.	High Severity – Cracks with a mean width > 19 mm; or any crack with a mean width ≤ 19 mm and adjacent moderate to high severity random cracking.
Treatment Options	Treatment Options	Treatment Options
Full Depth Patch – T	Full Depth Patch – T	Full Depth Patch – E
Cold Mill / Thin Overlay – E	Cold Mill / Thin Overlay – E	Cold Mill / Thin Overlay – M
Crack Seal / Fill – E	Crack Seal / Fill – E	Crack Seal / Fill – T
Fog Seal – T	Fog Seal – T	Fog Seal – T
Slurry Seal – T	Slurry Seal – T	Slurry Seal – T
Mircrosurfacing – T	Mircrosurfacing – T	Mircrosurfacing – T
Thin Overlay – E	Thin Overlay – E	Thin Overlay – E
Chip Seal – E	Chip Seal – E	Chip Seal – E
Surface Patch – T	Surface Patch – T	Surface Patch – T
Sand Seal – E	Sand Seal – M	Sand Seal – T
OGFC – M,Q	OGFC – M,Q	OGFC – M,Q
CIPR – T	CIPR – T	CIPR – T
HIPR – T	HIPR – T	HIPR – E
Partial Depth Patch - T	Partial Depth Patch - T	Partial Depth Patch - E

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Fatigue Cracking

Low Severity – An area cracks with no or only a few connecting cracks.	Medium Severity – An area of interconnected cracks forming a complete pattern.	High Severity – An area of moderately or severely spalled interconnected cracks forming a complete pattern.
Treatment Options	Treatment Options	Treatment Options
Full Depth Patch -T	Full Depth Patch -E	Full Depth Patch -E
Cold Mill and Thin Overlay - T	Cold Mill and Thin Overlay -M	Cold Mill and Thin Overlay -M
Crack Seal /Fill -E	Crack Seal /Fill -M	Crack Seal / Fill – T
Fog Seal -E	Fog Seal – T	Fog Seal – T
Slurry Seal-E	Slurry Seal -M	Slurry Seal – T
Microsurfacing -E	Microsurfacing - M	Microsurfacing -M
Thin Overlay -E	Thin Overlay -E	Thin Overlay -M
Chip Seal -E	Chip Seal -E	Chip Seal – T
Surface Patch -E	Surface Patch -E	Surface Patch -E
Sand Seal – E	Sand Seal – M	Sand Seal – T
OGFC – M,Q	OGFC – M,Q	OGFC – T
CIPR -T	CIPR – T	CIPR -T
HIPR – T	HIPR – T	HIPR – T
Partial Patch - T	Partial Patch - E	Partial Patch - E

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Longitudinal Cracking

Low Severity – Crack with mean width ≤ 6mm or sealed w/ sealant material in good condition and width cannot be determined.	Medium Severity – Crack with mean width >6mm and ≤ 19mm or any crack with mean width ≤19mm and adjacent low severity random cracking.	High Severity – Crack with mean width > 19mm or any crack with mean width ≤19mm and adjacent moderate to high severity random cracking.
Treatment Options	Treatment Options	Treatment Options
Full Depth Patch – T	Full Depth Patch – T	Full Depth Patch – T
Cold Mill / Thin Overlay – M	Cold Mill and Thin Overlay -M	Cold Mill and Thin Overlay -M
Crack Seal /Fill -E	Crack Seal /Fill -E	Crack Seal / Fill – M
Fog Seal -M	Fog Seal - T	Fog Seal – T
Slurry Seal-E	Slurry Seal -M	Slurry Seal -M
Microsurfacing -E	Microsurfacing -M	Microsurfacing -M
Thin Overlay -E	Thin Overlay -E	Thin Overlay -E
Chip Seal -E	Chip Seal -E	Chip Seal – E
Surface Patch – T	Surface Patch - T	Surface Patch – T
Sand Seal – E	Sand Seal – M	Sand Seal -M
OGFC – M,Q	OGFC – T	OGFC – M,Q
CIPR – T	CIPR – T	CIPR – T
HIPR – T	HIPR – T	HIPR – E
Partial Depth Patch - T	Partial Depth Patch - T	Partial Depth Patch - T

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Reflective Cracking

Low Severity-
Unsealed crack with a mean width ≤ 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Treatment Options

- Full Depth Patch – T
- Cold Mill / Thin Overlay – M
- Crack Seal / Fill – E
- Fog Seal – M
- Slurry Seal – E
- Mircrosurfacing – E
- Thin Overlay – E
- Chip Seal – E
- Surface Patch – T
- Sand Seal – E
- OGFC – M,Q
- CIPR – T
- HIPR – T
- Partial Depth Patch - E

Medium Severity-
Crack with a mean width > 6 mm and ≤ 19 mm; or any crack with a mean width ≤ 19 mm and adjacent low severity random cracking

Treatment Options

- Full Depth Patch – T
- Cold Mill / Thin Overlay – M
- Crack Seal / Fill – E,M
- Fog Seal – T
- Slurry Seal – M
- Mircrosurfacing – M
- Thin Overlay – E
- Chip Seal – E
- Surface Patch – T
- Sand Seal – M
- OGFC – M,Q
- CIPR – T
- HIPR – T
- Partial Depth Patch - E

High Severity-
crack with a mean width > 19 mm; or any crack with a mean width ≤ 19 mm and adjacent moderate to high severity random cracking.

Treatment Options

- Full Depth Patch – T
- Cold Mill / Thin Overlay – M
- Crack Seal / Fill – M
- Fog Seal – T
- Slurry Seal – T
- Mircrosurfacing – T
- Thin Overlay – M
- Chip Seal – T
- Surface Patch – T
- Sand Seal – T
- OGFC – M,Q
- CIPR – T
- HIPR – E
- Partial Depth Patch - E

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Transverse Cracking

Low Severity – Unsealed crack with mean width ≤ 6mm or sealed w/ sealant material in good condition and width cannot be determined.	Medium Severity – Crack with mean width >6mm and ≤ 19mm or any crack with mean width ≤19mm and adjacent low severity random cracking.	High Severity – Crack with mean width > 19mm or any crack with mean width ≤19mm and adjacent moderate to high severity random cracking.
<u>Treatment Options</u>	<u>Treatment Options</u>	<u>Treatment Options</u>
Full Depth Patch – T	Full Depth Patch – T	Full Depth Patch – T
Cold Mill / Thin Overlay – M	Cold Mill / Thin Overlay – M	Cold Mill / Thin Overlay – M
Crack Seal / Fill – E	Crack Seal / Fill – E	Crack Seal / Fill – M
Fog Seal – M	Fog Seal – T	Fog Seal – T
Slurry Seal – E	Slurry Seal – M	Slurry Seal – T
Mircrosurfacing – E	Mircrosurfacing – M	Mircrosurfacing – T
Thin Overlay – E	Thin Overlay – E	Thin Overlay – M
Chip Seal – E	Chip Seal – E	Chip Seal – T
Surface Patch – T	Surface Patch – T	Surface Patch – T
Sand Seal – E	Sand Seal – M	Sand Seal – T
OGFC – M,Q	OGFC – M,Q	OGFC – M,Q
CIPR – T	CIPR – T	CIPR – T
HIPR – T	HIPR – T	HIPR – E
Partial Depth Patch - T	Partial Depth Patch - T	Partial Depth Patch - T

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

Rutting

Low Severity- < ½”

Treatment Options

Full Depth Patch – E
Cold Mill / Thin Overlay – E
Crack Seal / Fill – E
Fog Seal – E
Slurry Seal – E
Mircrosurfacing – E
Thin Overlay – E
Chip Seal – E
Surface Patch – T
Sand Seal – E
OGFC – M,Q
CIPR – T
HIPR – T
Partial Depth Patch - E

Medium Severity- ½” - ¾”

Treatment Options

Full Depth Patch – E
Cold Mill / Thin Overlay – T
Crack Seal / Fill – M
Fog Seal – T
Slurry Seal – M
Mircrosurfacing – E
Thin Overlay – T
Chip Seal – M
Surface Patch – T
Sand Seal – M
OGFC – M,Q
CIPR – T
HIPR – E
Partial Depth Patch - E

High Severity- > ¾”

Treatment Options

Full Depth Patch – E
Cold Mill / Thin Overlay – T
Crack Seal / Fill – T
Fog Seal – T
Slurry Seal – T
Mircrosurfacing – M
Thin Overlay – T
Chip Seal – T
Surface Patch – T
Sand Seal – T
OGFC – T
CIPR – T
HIPR – E
Partial Depth Patch - E

Legend

E: Effective treatment
M: Marginally effective treatment
Q: Quality control and expertise recommended
T: Not an effective treatment

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APPENDIX D. Pavement Condition Evaluation and Treatment Selection Guidelines

Due to the large number of lane-miles in the SCDOT pavement network and limited equipment and resources, it is not feasible to perform condition evaluations on pavements in the Non-Federal Aid Secondary system more frequently than every 3-5 years. To track pavement deterioration with any level of confidence, this frequency of formal evaluation is not adequate. The guidelines included in this appendix were developed in an effort to enable pavement condition evaluation on pavement preservation candidate sections (or any section) at the local level.

Prior to conducting an evaluation, the evaluators should be trained and understand how to differentiate between different asphalt pavement distresses and severities as outlined in the *SCDOT Comprehensive Guide for Rating Routes with the Mobile Data Recorder* (see Appendix A). This information is also included in the *SCDOT Guidelines for Selecting Preventive Maintenance Treatments for Asphalt Pavements*. Once the evaluator is proficient in identifying different asphalt pavement distresses and severities and has completed the appropriate roadway safety training, they can be certified to conduct manual pavement evaluations in the field.

Manual pavement evaluations can be conducted following the procedures outlined in this appendix that have been adapted from the Asphalt PASER Manual developed by the Wisconsin Transportation Information Center (Walker et al., 2002). The images on the following pages are screenshots from an interactive pavement evaluation recording tool to support pavement preservation at the county level. This is a simplified evaluation protocol intended to be used for all pavement preservation candidates annually to track pavement condition and rate of deterioration. The Pavement Section Rating (PSR) is conducted on a 10-point scale with a rating of 1 indicating a pavement section that has failed to a rating of 10 indicating a new or rehabilitated section. For each rating, there are up to 6 potential qualifying factors/characteristics of the pavement condition that can be selected to provide further information on distress types found on the segment. The rating and supplemental factor contributions are to be recorded for each evaluation segment of 0.5 to 1-mile.

Pavement Evaluation Tool for Pavement Preservation Candidates

The following is a proposed framework for a local level pavement evaluation method to be used by SCDOT personnel at the county level to assess the condition of pavement sections deemed to be pavement preservation candidates based on PQI (i.e., PQI ≥ 3.0). This is a visual evaluation methodology based on the Asphalt PASER Manual developed by the Wisconsin Transportation Information Center (Walker et al., 2002).

This evaluation considers four main categories of asphalt pavement distress that can occur as the result of environmental factors, traffic loading, or a combination of the two. These four categories include:

Surface Defects (raveling, flushing, and polishing)

Surface Deformation (rutting or distortion)

Cracking (transverse, longitudinal, slippage, block, fatigue, reflection)

Patches and Potholes

It is recommended that preservation candidates be evaluated on an annual basis following this protocol. Doing so will enable SCDOT personnel to track the deterioration of these pavement sections locally when resources may not be available to perform more sophisticated evaluations to determine PQI. Understanding the condition deterioration will enable decision makers to prioritize sections for preservation each year to maximize the overall effectiveness of the pavement preservation program and available funding.

Notes to the user:

- It is recommended that pavement sections be 0.5 to 1.0 miles in length.
- The objective is to assign the condition that represents the majority of pavement section. Isolated areas of concern should not influence the rating of the section as whole.
- Take note of isolated areas of concern, so these areas can be monitored and/or appropriately repaired.
- It is important to be consistent with pavement evaluations. Consistency in evaluation will enable meaningful comparisons between sections and from year to year.

NEXT

Screen 1. Introduction screen with instructions and notes for the user.

Pavement Section Information

County:

Section ID:

Route Type:

Route Number:

Number of Lanes:

Direction:

Starting Point:

Ending Point:

Section Length:

AADT:

Evaluator Information

First Name:

Last Name:

Date:

NEXT

Screen 2. User inputs section information and evaluator information.

Pavement Section Rating

Check the box that best describes the condition of the pavement section being evaluated.

☐	**10** Excellent	▪ New construction. ▪ No visible distress.
☐	**9** Excellent	▪ Recent overlay. ▪ No visible distress.
☐	**8** Very Good	▪ No longitudinal cracks except reflection of paving joints. ▪ Occasional transverse cracks, widely spaced (40' or greater). ▪ All cracks sealed or tight (less than 1/4" width).
☐	**7** Good	▪ Very slight or no raveling, surface shows some traffic wear. ▪ Longitudinal cracks (open 1⁄4") due to reflection or paving joints. ▪ Transverse cracks (open 1⁄4") spaced 10' or more apart, little or slight crack raveling. ▪ No patching or very few patches in excellent condition.
☐	**6** Good	▪ Slight raveling (loss of fines) and traffic wear. ▪ Longitudinal cracks (open 1⁄4"– 1⁄2"), some spaced less than 10'. ▪ First sign of block cracking. ▪ Sight to moderate flushing or polishing. ▪ Occasional patching in good condition.
☐	**5** Fair	▪ Moderate to severe raveling (loss of fine and coarse aggregate). ▪ Longitudinal and transverse cracks (open 1⁄ 2") show first signs of slight raveling and secondary cracks. ▪ First signs of longitudinal cracks near pavement edge. ▪ Block cracking up to 50% of surface. ▪ Extensive to severe flushing or polishing. ▪ Some patching or edge wedging in good condition.
☐	**4** Fair	▪ Severe surface raveling. ▪ Multiple longitudinal and transverse cracking with slight raveling. ▪ Longitudinal cracking in wheel path. ▪ Block cracking (over 50% of surface). ▪ Patching in fair condition. ▪ Slight rutting or distortions (1⁄2" deep or less).
☐	**3** Poor	▪ Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion ▪ Severe block cracking. ▪ Some alligator cracking (less than 25% of surface). ▪ Patches in fair to poor condition. ▪ Moderate rutting or distortion (1" or 2" deep). ▪ Occasional potholes.
☐	**2** Very Poor	▪ Fatigue cracking (over 25% of surface). ▪ Severe distortions (over 2" deep) ▪ Extensive patching in poor condition. ▪ Potholes.
☐	**1** Failed	▪ Severe distress with extensive loss of surface integrity.

NEXT

Screen 3. User selects appropriate surface condition rating for the pavement section.

Surface Rating | **9 & 10** Excellent

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

New construction

Recent overlay in a rural area

Recent overlay in an urban area

NEXT

Screen 4a. Sample photos of pavements having a surface condition rating of 9 or 10. Visible to the user if a rating of 9 or 10 is selected from Screen 3.

Surface Rating | **8** Very Good

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Recent chip seal

Recent slurry seal

New cold mix surface

Widely spaced, sealed cracks

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ No longitudinal cracks except reflection of paving joints.
- ☐ Occasional transverse cracks, widely spaced (40' or greater).
- ☐ All cracks sealed or tight (less than 1/4" width).

NEXT

Screen 4b. Sample photos of pavements having a surface condition rating of 8 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 8 is selected from Screen 3.

Surface Rating | **7** Good

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Tight and sealed transverse and longitudinal cracks.

Tight and sealed transverse and longitudinal cracks.

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ Very slight or no raveling, surface shows some traffic wear.
- ☐ Longitudinal cracks (open 1⁄4") due to reflection or paving joints.
- ☐ Transverse cracks (open 1⁄4") spaced 10' or more apart, little or slight crack raveling.
- ☐ No patching or very few patches in excellent condition.

NEXT

Screen 4c. Sample photos of pavements having a surface condition rating of 7 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 7 is selected from Screen 3.

Surface Rating | **6** Good

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Slight raveling with tight cracks less than 10' apart

Large blocks and early signs of raveling

Moderate flushing

Transverse cracking less than 10' apart (well-sealed).

Check the box or boxes that best describe the visible distresses on this pavement section.

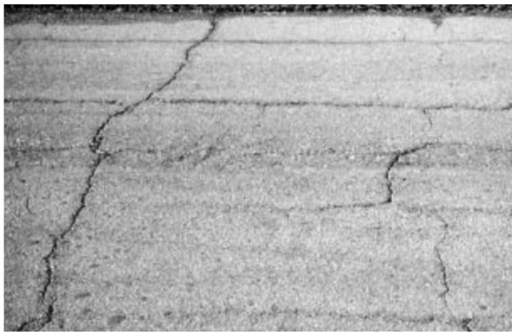
- ☐ Slight raveling (loss of fines) and traffic wear.
- ☐ Longitudinal cracks (open 1⁄4"–1⁄2"), some spaced less than 10'.
- ☐ First sign of block cracking.
- ☐ Slight to moderate flushing or polishing.
- ☐ Occasional patching in good condition.

NEXT

Screen 4d. Sample photos of pavements having a surface condition rating of 6 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 6 is selected from Screen 3.

Surface Rating | **5** Fair

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).



Block cracking with open cracks

Moderate to severe raveling in wheel paths

Severe flushing

Wedges and extensive patches,
but in good condition

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ Moderate to severe raveling (loss of fine and coarse aggregate).
- ☐ Longitudinal and transverse cracks (open ½") show signs of slight raveling and secondary cracks.
- ☐ First signs of longitudinal cracks near pavement edge.
- ☐ Block cracking up to 50% of surface.
- ☐ Extensive to severe flushing or polishing.
- ☐ Some patching or edge wedging in good condition.

NEXT

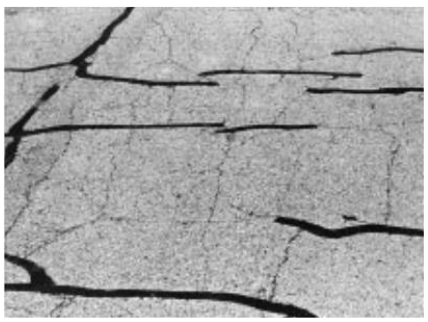
Screen 4e. Sample photos of pavements having a surface condition rating of 5 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 5 is selected from Screen 3.

Surface Rating | **4** Fair

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Load related longitudinal cracking and slight rutting in wheel path

Slight rutting with a patch in good condition



Extensive block cracking (tight and sound)

Severe raveling
(extreme loss of aggregate)

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ Severe surface raveling.
- ☐ Multiple longitudinal and transverse cracking with slight raveling.
- ☐ Longitudinal cracking in wheel path.
- ☐ Block cracking (over 50% of surface).
- ☐ Patching in fair condition.
- ☐ Slight rutting or distortions (1⁄2" deep or less).

NEXT

Screen 4f. Sample photos of pavements having a surface condition rating of 4 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 4 is selected from Screen 3.

Surface Rating

3
Poor

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Many wide and raveled cracks

Fatigue cracking; edge in need of repair; poor drainage

Open and raveled block cracks

2” rutting

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion.
- ☐ Severe block cracking.
- ☐ Some alligator cracking (less than 25% of surface).
- ☐ Patches in fair to poor condition.
- ☐ Moderate rutting or distortion (1” or 2” deep).
- ☐ Occasional potholes.

NEXT

Screen 4g. Sample photos of pavements having a surface condition rating of 3 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 3 is selected from Screen 3.

Surface Rating | **2** Very Poor

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Extensive fatigue cracking

Patches in poor condition and wheel-path rutting

Severe rutting

Check the box or boxes that best describe the visible distresses on this pavement section.

- ☐ Fatigue cracking (over 25% of surface).
- ☐ Severe distortions (over 2” deep).
- ☐ Extensive patching in poor condition.
- ☐ Potholes.

NEXT

Screen 4h. Sample photos of pavements having a surface condition rating of 2 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 2 is selected from Screen 3.

Surface Rating | **1** Failed

Below are some example photos that depict a pavement with this surface rating (Walker et al., 2002).

Potholes and severe fatigue cracking

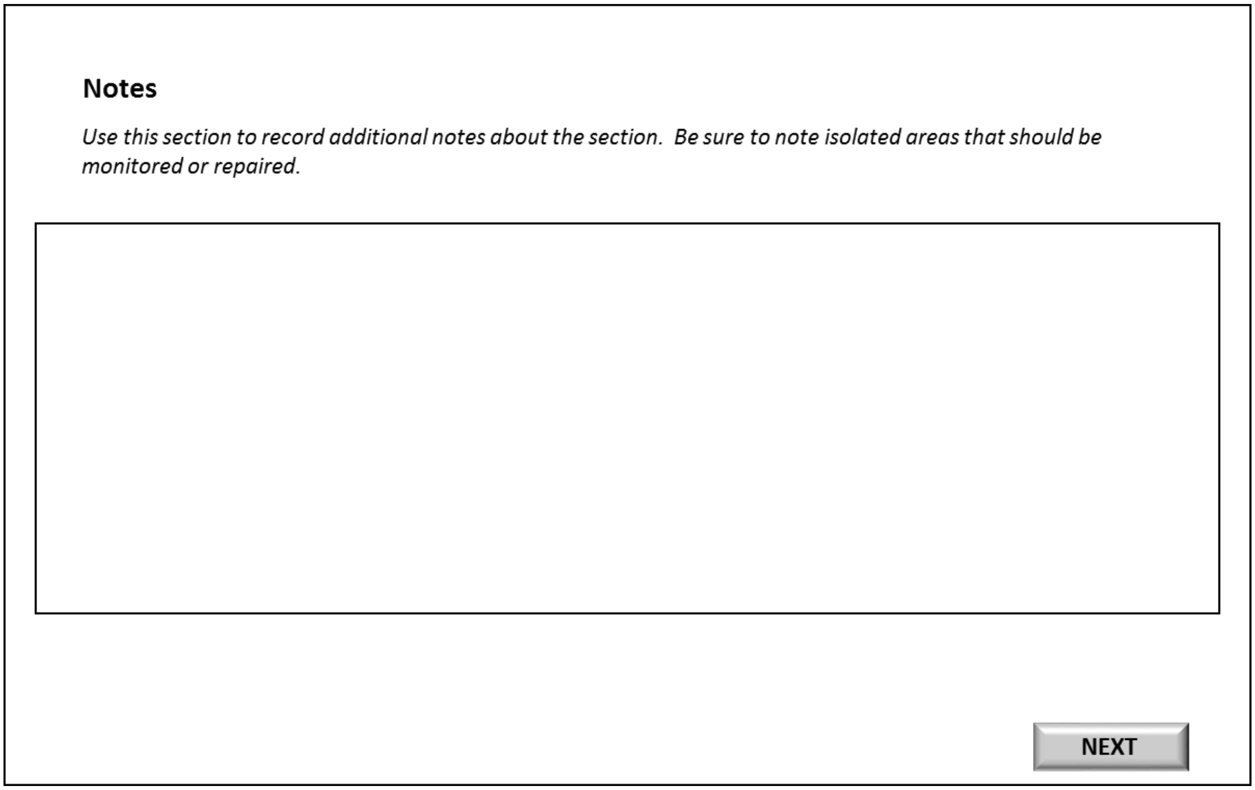
Extensive loss of surface

Check the box or boxes that best describe the visible distresses on this pavement section.

☐ Severe distress with extensive loss of surface integrity.

NEXT

Screen 4i. Sample photos of pavements having a surface condition rating of 1 and condition observation checklist for the user to select distress conditions present on the pavement. Visible to the user if a rating of 1 is selected from Screen 3.



Screen 5. User inputs additional notes of interest about the pavement section.

Summary

Section ID: XYZ123
Route: S-1344-NS
Length: 1.0 miles
No. of Lanes: 2
AADT: 450
Date: 08-15-2016
Evaluator: John Doe

Surface Rating: 7
Distress Summary:
- Very slight or no raveling, surface shows some traffic wear.
- Transverse cracks (open 1⁄4”) spaced 10’ or more apart, little or slight crack raveling.
- No patching or very few patches in excellent condition.

Notes: There is a little ponding near the edge in a couple of locations.

Recommendations

Based on the information collected from this pavement evaluation, the following courses of action are recommended to be considered for this pavement section:

- Fog seal
- Crack filling
- Crack filling as needed

FINISH

Screen 6. Summary of the pavement section details and pavement preservation recommendations based on the evaluation results.

Table D-1. Rules for treatment recommendation based on evaluation (not visible to the user).

Rating	**Visible Distress** *(to be checked on appropriate screen [screen 4-12])*	**Action Based on Visible Distress**
10	▪ No visible distress.	→ Not needed
9	▪ No visible distress.	→ Not needed
8	▪ No longitudinal cracks except reflection of paving joints. ▪ Occasional transverse cracks, widely spaced (40' or greater). ▪ All cracks sealed or tight (less than 1/4" width).	→ Consider crack sealing, but may not be necessary → Consider crack sealing, but may not be necessary → Consider crack sealing, but may not be necessary
7	▪ Very slight or no raveling, surface shows some traffic wear. ▪ Longitudinal cracks (open 1⁄4") due to reflection or paving joints. ▪ Transverse cracks (open 1⁄4") spaced 10' or more apart, little or slight crack raveling. ▪ No patching or very few patches in excellent condition.	→ Fog seal → Crack filling → Crack filling → Crack filling as needed
6	▪ Slight raveling (loss of fines) and traffic wear. ▪ Longitudinal cracks (open 1⁄4"– 1⁄2"), some spaced less than 10'. ▪ First sign of block cracking. ▪ Sight to moderate flushing or polishing. ▪ Occasional patching in good condition.	→ Fog seal, chip seal, microsurfacing, or thinlay → Crack filling → Crack filling → Chip seal, microsurfacing, or thinlay → Crack filling as needed
5	▪ Moderate to severe raveling (loss of fine and coarse aggregate). ▪ Longitudinal and transverse cracks (open 1⁄ 2") show first signs of slight raveling and secondary cracks. ▪ First signs of longitudinal cracks near pavement edge. ▪ Block cracking up to 50% of surface. ▪ Extensive to severe flushing or polishing. ▪ Some patching or edge wedging in good condition.	→ Chip seal, microsurfacing, or thinlay → Crack filling + chip seal, microsurfacing, or thinlay → Crack filling + chip seal, microsurfacing, or thinlay → Crack filling + chip seal, microsurfacing, or thinlay → Chip seal, microsurfacing, or thinlay → Crack filling as needed
4		→ Preventive maintenance is not recommended, structural improvement is recommended.
3		
2		→ Preventive maintenance is not recommended, reconstruction is recommended.
1		

Because the ratings are somewhat subjective, the research team recommends training and assessment of inter-rater reliability to ensure that pavement evaluations conducted across a district or across the state are consistent. Inconsistent ratings will lead to increased error in determination of treatment effectiveness, as well as determination of site priority and selection of treatment type. A description of the Inter-Rater Reliability Test is provided in the following sections.

The Inter-Rater Reliability test is helpful in assessing the level of agreement (alternatively termed consistency or repeatability) among evaluators who participate in rating pavement sections and estimating quality values of common distresses such as surface defects (raveling, flushing, and polishing), surface deformation (rutting or distortion), cracking (transverse, longitudinal, slippage, fatigue, and reflection), and patches or potholes. Inconsistency in estimation and measurement is a significant issue when a human coder is used, especially if the data being coded is in any way subjective. These problems are intensified when more than one evaluator is involved. If certain estimations require evaluators to determine into which category, among a continuous array of possibilities, the observation best fits then there can be disagreement between evaluators. Evaluators who disagree on rating a single pavement section (Figure D-1) will introduce error into the pavement management decision process; thus, by assessing the percent agreement between the raters can improve the overall reliability of the system. Additional information can be found on the Research Methods Knowledge Base wet site (http://www.socialresearchmethods.net/kb/reltypes.php).

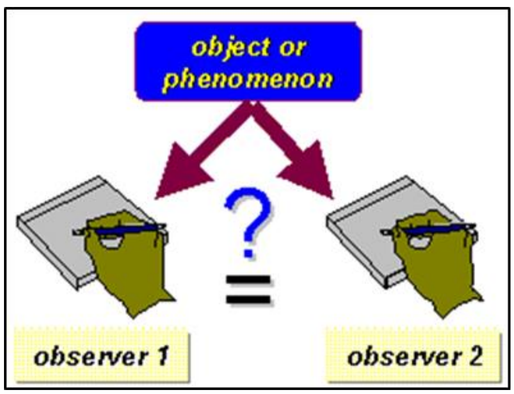


Figure D-1. Inter-Rater test illustration (Source: http://www.socialresearchmethods.net/kb/reltypes.php)

Numerous research and performance measurement strategies use the inter-rater reliability (IRR) assessment to check and illustrate agreement and consistency between ratings and values provided by multiple evaluators/coders (Hallgren, 2012). By utilizing IRR, it is possible to determine if additional training is needed to improve the level of agreement on ratings, and further to determine if changes in processes or instructions are needed to achieve better accuracy with the desired results. The inter-rater assessment enables researchers to quantify: 1) the level of agreement among 2 or more coders involved in making independent ratings of pavement condition and distresses, and 2) the level of accuracy with a test set of data with known values derived from expert opinion (Hallgren 2012).

While it is unlikely that evaluators will ever reach 100% agreement on a continuous rating scale, significant agreement and accuracy can be achieved, and an acceptable threshold is usually set at approximately 80-85% agreement/accuracy. The first step to achieve inter-rater reliability is to develop a training program. The first round should include multiple expert evaluators, who will independently rate a significant sample of sections based on guidance material provided previously in this appendix. The sample should have an array of conditions and multiple samples for each condition – these should be taken from the photo log or other source that will be ultimately used to conduct evaluations. Once the initial evaluations are received, an assessment of agreement will be conducted. If 100 samples are provided and all evaluators had the same rating on 60, the reliability estimate would be 60%. This IRR would indicate issues in agreement between the raters and should be followed by a discussion of differences in ratings and development of additional guidance material based on group consensus. At this point, a second sample would be chosen and the process repeated. If on the second rating, an agreement level of 82% is achieved, the process would be deemed successful. Additional iterations could be used to obtain even better agreement within the expert pool and further refine the training.

This first set of data becomes the 'truth' from which individual raters can be trained. After reviewing the evaluation process documents and ratings guide, the evaluator would rate one set of the samples of data. For each site in which the rater did not agree with the 'truth', feedback would be provided to help calibrate the evaluator to the desired input. Following feedback, the evaluator will attempt the second set of sample data until the threshold level of accuracy is achieved. All evaluators should be required to meet a certain threshold level of accuracy to be certified to evaluate pavement sections. Further, the IRR process should be repeated to ensure that consistency is achieved over time. IRR can also be used to test for agreement on samples of real sections across the state for continual process improvement.

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APPENDIX E. Treatment Strategy Decision Support

A primary function of a pavement management system is to support decisions related to pavement maintenance, rehabilitation, and construction activities. This appendix outlines a procedure for decision makers to use to develop strategies for pavement preservation programming. This decision support is based on the concept of Remaining Service Life discussed in Chapter 2 where the goal is for the treatment strategy to add more lane-mile-years than total preservation candidate lane-miles in a given year while keeping the total cost within the budget constraints. The recommended procedure outlined in the following steps is intended for use at the county level.

1. **Identify Preservation Candidate Pavement Sections**. Use the procedure outlined in Chapter 4 and Appendix B to determine the number lane-miles that are candidates for pavement preservation (i.e., PQI ≥ 3.0) in the county. The number of candidates should change each year, so it is important to use the current information.
2. **Conduct Surface Condition Evaluation of Candidate Sections**. Use the procedure outlined in Appendix D to determine the surface condition rating of each candidate pavement section.
3. **Determine Appropriate Treatment(s) for Candidate Sections**. After completing the evaluation using the procedure outlined in Appendix D, the tool will provide the user with recommended treatments based on the evaluation.
4. **Estimate Cost and Life Extension**. If the unit cost and life extension of the treatment is known, the user should input the values in the spreadsheet. If these values are not known, the spreadsheet contains default values currently used by the SCDOT (Table F-1). With enough performance data, the actual costs and life extension (i.e., Benefit) can be determined using the tracking method outlined in Appendix F.
5. **Develop Preservation Strategy**. Use the “Treatment Selection” spreadsheet (Figure F-1) to assign treatment actions to each candidate section evaluated in Step 2. The goal is to maximize the total number of Treated Lane-Mile-Years while remaining within the budget constraints. If the total number of Treated Lane-Mile-Years is greater than the total Preservation Candidate Lane-Miles determined in Step 1, the overall health of the network will improve (i.e., the number of pavement sections in good condition will grow). The user must consider the following:
   - This process will require a certain degree of engineering judgement.
   - It is advisable to group preservation projects by geographical area to increase efficiency and potentially minimize costs.
   - Pay attention to pavement sections that are rapidly deteriorating and/or those sections that are in danger of falling off the preservation candidate list (i.e., PQI < 3.0 or Surface Condition Rating < 5). In some cases, these sections may be better suited for rehabilitation instead of preservation.
6. **Track Pavement Preservation Data**. To improve the reliability of treatment costs and performance, it is important to track the project specific information outlined in Chapter 7 and Appendix F.

Table E-1. Pavement preservation treatment cost and life extension estimates reported by the SCDOT.

Treatment	**Average Unit Cost** *(per lane-mile)*	**Estimated Life Extension** *(years)*	**Equivalent Uniform Annual Cost*** *(per lane-mile)*
Crack Seal	$1,587	3	$550
Full Depth Patching	$25,985	5	$5,513
Chip Seal	$9,786	6	$1,747
Microsurfacing	$19,008	7	$4,188
Thinlay	$27,104	7	$5,244

** EUAC calculated using an interest rate of 2%*

Pavement Preservation Treatment Selection

Preservation Candidate Lane Miles:	150	**Preservation Budget:**	$650,000
Treated Lane-Mile-Years:	217	**Total Strategy Cost:**	$645,782

Section ID	Lane Miles	Rating	Surface Treatment	Crack Sealing	Life Extension	Surface Treatment Unit Cost	Crack Sealing Unit Cost	LMY	Total Cost
1	4.16	9	Do Nothing	No	0	$0	$0	0	$0
2	4	6	Chip Seal	No	6	$9,786	$0	24	$39,144
3	13.94	7	Do Nothing	Yes	3	$0	$1,587	42	$22,123
4	6.12	8	Do Nothing	No	0	$0	$0	0	$0
5	1	5	Thinlay	Yes	7	$27,104	$1,587	7	$28,691
6	10.8	6	Thinlay	Yes	7	$27,104	$1,587	76	$309,863
7	1.96	7	Chip Seal	No	6	$9,786	$0	12	$19,181
8	0.58	7	Microsurfacing	No	7	$19,008	$0	4	$11,025
9	1.98	8	Do Nothing	No	0	$0	$0	0	$0
10	2.46	9	Do Nothing	No	0	$0	$0	0	$0
11	7.52	5	Thinlay	Yes	7	$27,104	$1,587	53	$215,756
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
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	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0
	0	0			0	$0	$0	0	$0

Figure E-1. Screenshot of the Pavement Preservation Treatment Selection spreadsheet.

APPENDIX F. Treatment Tracking for Benefit-Cost Ratio Analysis

Chapter 7 outlines a procedure to quantify the benefit-cost ratio of pavement preservation treatments. Such an analysis can only be completed if the following information is collected for specific projects:

- Pavement condition prior to treatment (PQI_{pre})
- Total unit cost of treatment ($/lane-mile)
- Pavement condition after treatment and each year thereafter (PQI_{post})

With this information, the Pavement Preservation Treatment Benefit-Cost Analysis Worksheet (Figures G-1 and G-2) can be used to determine the benefit-cost ratio for individual projects after enough data has been collected. The instructions for using this worksheet include:

1. Input the required information in the shaded areas in the “Section Information” box.
2. Input the required information in the shaded areas in the “Treatment Information” box.
3. Input the PQI data for each year in the shaded areas. The user must input the year of the first PQI data point in the shaded area.

After several years of data collection, a database can be created to keep track of the performance of pavement preservation treatments as they are applied to a variety of pavement sections across the state. This will provide the SCDOT with a more accurate data set from which a statistical analysis can be conducted.

Pavement Preservation Treatment Benefit-Cost Analysis Worksheet

Section Information	
ID:	XYZ123
Route:	S-1344-NS
BMP:	1
EMP:	2.5

Treatment Information		
Type:	Chip Seal	
Year:	2016	
Total Cost:	10000	$/lane-mile
PQI_{pre}:	3.1	

Treatment Performance		
T_{pre}:	4.5	years
$T_{3.0}$:	7.5	years
Benefit:	1.25	PQI·years
B/C:	12.5	

User shall input the information in the shaded cells

Year	PQI
2014	3.4
2015	3.2
2016	3.1
2017	3.4
2018	3.35
2019	3.3
2020	3.15
2021	3.05
2022	3
2023	3
2024	2.85
2025	2.7
2026	2.5
2027	0
2028	0
2029	0
2030	0
2031	0
2032	0
2033	0
2034	0
2035	0
2036	0
2037	0
2038	0
2039	0
2040	0
2041	0
2042	0
2043	0
2044	0

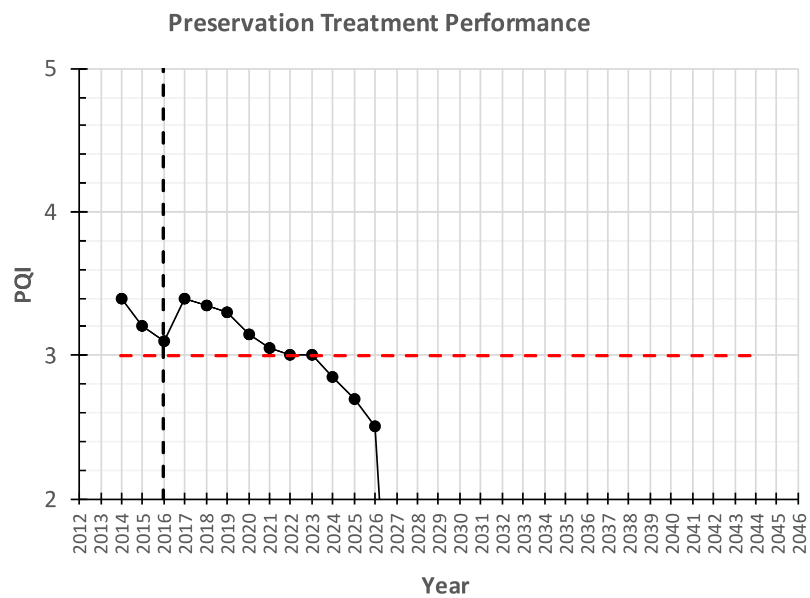

Figure F-1. Sample of the Pavement Preservation Treatment Benefit-Cost Analysis Worksheet.

Pavement Preservation Treatment Benefit-Cost Analysis Worksheet

Section Information	
ID:	ABC789
Route:	S-423-EW
BMP:	4.5
EMP:	5.2

Treatment Information		
Type:	Microsurfacing	
Year:	2016	
Total Cost:	19800	$/lane-mile
PQI_{pre}:	3.5	

Treatment Performance		
T_{pre}:	4.5	years
$T_{3.0}$:	9.5	years
Benefit:	4.325	PQI·years
B/C:	21.84343	

User shall input the information in the shaded cells

Year	PQI
2014	3.9
2015	3.7
2016	3.5
2017	4
2018	3.85
2019	3.75
2020	3.6
2021	3.4
2022	3.3
2023	3.25
2024	3.15
2025	3.05
2026	2.9
2027	0
2028	0
2029	0
2030	0
2031	0
2032	0
2033	0
2034	0
2035	0
2036	0
2037	0
2038	0
2039	0
2040	0
2041	0
2042	0
2043	0
2044	0

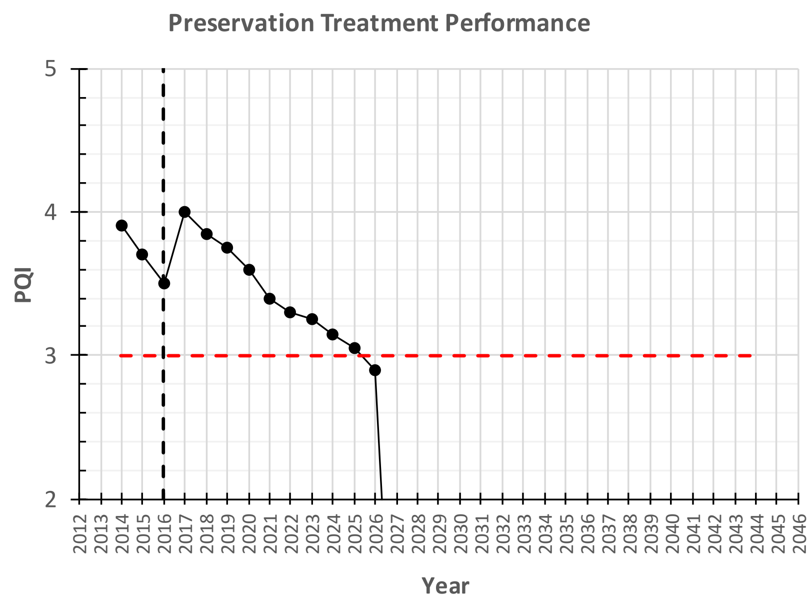

Figure F-2. Sample of the Pavement Preservation Treatment Benefit-Cost Analysis Worksheet.