2018 Michigan Local Agency Pavement Treatment Life Study

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EXECUTIVE SUMMARY

The Michigan Transportation Asset Management Council (TAMC) tasked the Center for Technology & Training (CTT) to determine updated statewide extended service life averages for pavement repair treatments used by Michigan's local agencies. The CTT, on behalf of the TAMC, previously conducted this study in 2014 and issued the report *Local Agency Capital Preventative Maintenance Extended Treatment Life Study* (Colling, Kiefer, & Farey, 2014). The 2014 study relied on the Extended Service Life (ESL) Calculator in the Roadsoft program, which is available to all Michigan local agencies at no cost to them. The current study used an updated version of the ESL Calculator. Thirty-six Michigan local agencies volunteered their data to the CTT for analysis, and twenty-nine of those agencies had data that met the criteria set forth in this study. This qualifying data set contained 6,236 road segments and 1,709.774 miles (2,751.615 kilometers) of roadway.

Large enough sample sizes were present to make statewide conclusions on five pavement treatments: chip seal, chip seal plus fog, thin overlay, crush and shape, and thick overlay (see Table 1 below). Michigan local agencies obtain a three-year increase in ESL when applying a fog seal in conjunction with a chip seal. Also notable is the 0.3-year decrease in ESL when applying a chip seal treatment to a pavement that has previously received a chip seal treatment.

Table 1: Summary of Weighted Average ESLs for Five Treatment Types

Treatment	Weighted Avg ESL
Heavy CPM	
Chip seal	**4.1**
Chip seal plus fog seal	**7.1**
Thin overlay	**6.9**
Rehabilitation	
Crush and shape	**11.3**
Thick overlay	**9.1**

The project team attempted to further analyze the data set by legal system, National Function Class, number of lanes, and region of the state. However, breaking the data into smaller subdivisions offered less opportunity to make any significant determinations. The factors that impact the effectiveness of repair treatments are highly variable when comparing multiple projects in aggregate, and trying to determine why segments of the data differed from others is difficult with the variability in pavements and practice. The statewide average ESL gain provides the best guidance for ESL gain because it includes samples that span a number of variables (e.g., agency policies, soil type, annual snowfall, underlying pavement structure, materials used, and construction methods) that are beyond the control of this study. The large data set available for analysis in Michigan demonstrates that the many types of treatments used by Michigan local agencies provide significant increases in extended service life.

1 INTRODUCTION

This study focuses on determining the extended service life (ESL) that can be gained for asphalt pavements by selecting and applying various preventive maintenance and repair treatments from data provided by Michigan local agencies. The Michigan Transportation Asset Management Council (TAMC) commissioned this study to collect ESL data for their own use as well as to show local agencies that they also have the tools and data necessary to complete their own ESL analyses as part of their annual business processes. The Center for Technology & Training (CTT), on behalf of the TAMC, conducted a similar study in 2014; in their final report *Local Agency Capital Preventative Maintenance Extended Treatment Life Study*, the CTT was only able to make definitive conclusions on chip seal treatments due to the limited data set (Colling, Kiefer, & Farrey, 2014). TAMC suggested repeating this study in 2018 due to the expected larger data set.

Analysis of data for the 2018 study exclusively uses distresses found in asphalt pavement since asphalt is the primary pavement type owned by Michigan local agencies. The study determined that local agencies in Michigan are actively using many types of repair treatments to maintain their asphalt pavements. However, chip seals are still the most widely used preventive maintenance treatment.

Modeling the extended service life resulting from repair treatments can effectively illustrate the value gained by applying repair treatments (Colling, Kiefer, & Farrey; 2014). Figure 1 shows a pavement that has been maintained in fair condition for nearly 22 years with three successive chip seal applications.

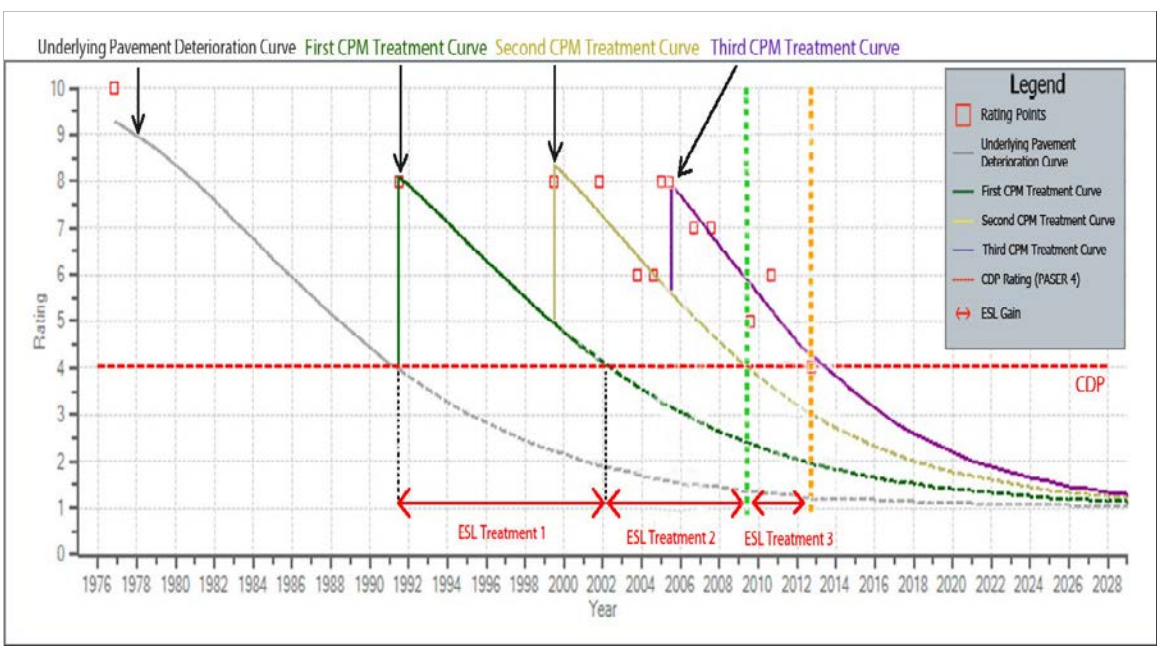

Figure 1: Example of multiple chip seal treatments. Note the diminishing ESL with successive treatment applications.

2 BACKGROUND

As a condition of Public Act 199 of 2007, Michigan road-owning agencies must collect road condition data annually on their Federal-aid-eligible road network. Additional condition data can also be collected on the non-Federal-aid-eligible portions of their road network at the discretion of the individual road-owning agency. Agencies rate road conditions using the Pavement Surface Evaluation and Rating (PASER) system, which is based on the severity, type, and extent of distresses present in the pavement. Since 2008, agencies have been collecting and submitting 100 percent of their Federal-aid-eligible road-network condition data on a two-year cycle with a minimum goal of 50-percent collection each year; between 2004 and 2007, agencies were collecting 100 percent of the network condition data each year. For the purpose of this study, agencies were not required to collect any data in addition to what was already collected for annual reporting.

Over 400 Michigan road-owning agencies currently use Roadsoft, a roadway asset management software program developed in the early 1990s at Michigan Technological University in cooperation with the Michigan Department of Transportation (MDOT) (see Roadsoft.org for more information). This software—made available to Michigan local agencies at no charge—provides tools for the data collection, storage, and analyses necessary to effectively apply asset management principles. The agencies that have been using Roadsoft typically store road condition and treatment data in Roadsoft that, in turn, could be used for ESL analyses.

In 2013, the TAMC funded the development of a Roadsoft tool—the Extended Service Life (ESL) Calculator—that enables local agencies to perform ESL analyses for their historical repair treatments. Roadsoft also has performance modeling functionality: it can generate a deterioration curve for the underlying pavement and for the same pavement subsequent to repair treatments (Figure 2). These modeling functions use a road segment's condition data (i.e., its PASER score) and treatment data (i.e., its maintenance history).

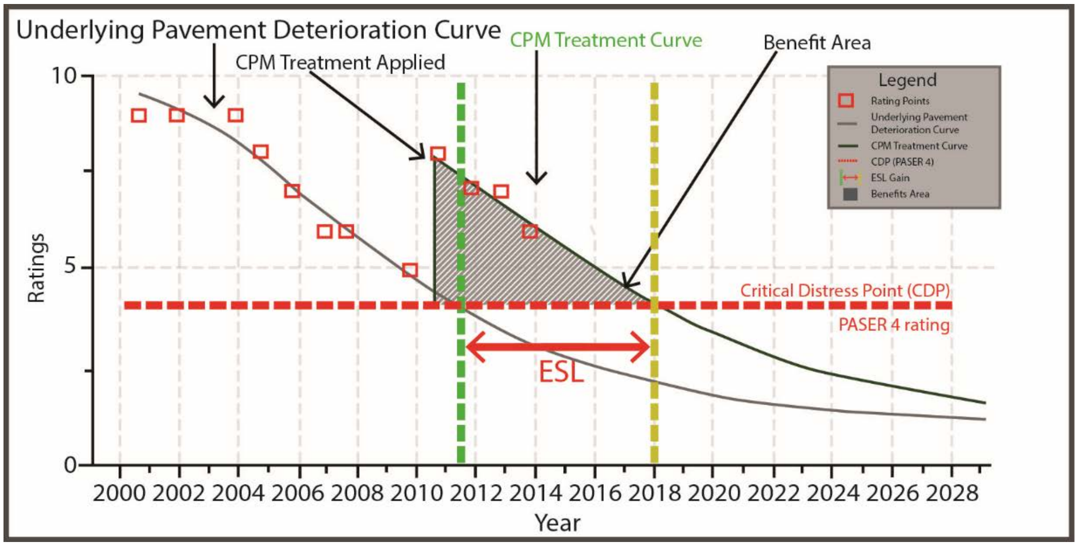

Figure 2: Example deterioration curve for the underlying pavement and subsequent repair treatment

2.1 Definition of Pavement Deterioration Technical Terms

The following terms refer to elements of the pavement deterioration curves [1]:

Underlying pavement deterioration curve: deterioration for the asphalt pavement prior to repair treatment

Repair treatment curve: deterioration for the asphalt pavement following the application of a repair treatment

Treatment applied: the time when the repair treatment was applied over the asphalt surface

Rating points: actual pavement condition ratings (using PASER) documented during TAMC data collection

Critical distress point (CDP): the PASER 4 line—when pavement deterioration changes from exhibiting age-related to structural distresses

ESL gain: the time in years gained by the application of a treatment

Benefits area: the area above the CDP that lies between the underlying pavement deterioration curve and the repair treatment curve.

2.2 Cost-effective Management of Assets

Asset management is the ongoing process of maintaining, upgrading, and operating physical assets in a cost-effective manner; it relies on continuous physical inventory and condition assessment.[2] Asset management principles give guidance for the cost-effective management of

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[1] For more information on the technical process that Roadsoft uses for pavement modeling, refer to Dong, McNinch, and Colling's "*Validation of the Use of PASER Condition Data and the Application of Growth Models for Predicting Local Agency Pavement Deterioration*" in Conference Proceedings Transportation Research Board, 8th National Conference on Asset Management, October 18, 2009.

[2] From Act 499, Public Acts of 2002, Michigan Department of Transportation. Available at: *www.mcgi.state.mi.us/mitrp/document.aspx?id=348*

pavements. In other words, the premise of asset management is to “keep good roads maintained in good condition.” The primary way of doing this is by applying relatively-low-cost repair treatments to extend pavement life, thereby delaying the need for costly rehabilitation and reconstruction.

Cost-effectiveness is a prime factor that road agencies use when selecting treatments because they generally need to maximize the use of limited agency funds. Determining the cost-effectiveness of repair treatments requires an agency to be cognizant of two factors: the treatment’s cost per-lane-mile and the amount of ESL that the treatment provides. Local agencies are usually very aware of the cost of repair treatments; however, the value of repair treatments in terms of ESL is seldom known beyond theoretical studies.

An accurate analysis of the ESL afforded by each repair treatment based on local data allows agencies to do two things: set a data-driven policy for applying specific treatments and provide a quantitative means for assessing the viability of treatment locations.

2.3 Asphalt Pavement Deterioration

Age-related distresses result from exposure to the environment over time. The primary environmental factors driving age-related distresses are water (which enters the pavement structure and weakens it), ultra-violet light, and atmosphere (which causes degradation of the asphalt binder and subsequent hardening). Asphalt binder is the “glue” that holds together the aggregates in an asphalt pavement. As the asphalt binder hardens, it becomes less flexible and is subject to cracking from tensile forces that develop during low-temperature events when the pavement contracts. Cracking allows the intrusion of water into the underlying pavement structural layers. Excess water makes the aggregate base and sub-base layers less rigid, which results in a larger magnitude displacement of the pavement layers at a given load. Distressed asphalt is then subject to increased vertical displacement of the pavement due to traffic loads, causing increased cracking and structural damage to the asphalt layer. Examples of age-related distresses include transverse cracking, longitudinal joint cracking, and block cracking (Figure 3). These cracks are “non-working” cracks: the pavement on each side has the ability to transfer load from one side of the crack to the other so the pavement on each side moves in unison as a load passes over.

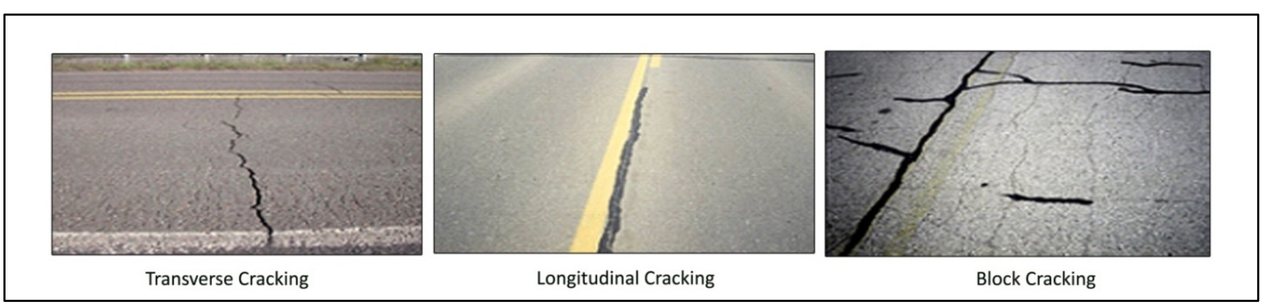

Figure 3: Age-related distresses

Structural distresses can occur at any time in the life of a pavement. These distresses typically result from traffic loading. Traffic loads in excess of the pavement's design load can speed the occurrence of structural distress. Examples of structural distresses include rutting, cracking in the wheel path, and alligator (fatigue) cracking (Figure 4). Structural-distress-related cracks are "working" cracks: the pavement on each side of a working crack moves independently as a load passes over. Capital preventive maintenance treatments are not structural in nature and, therefore, have a limited ability to span and maintain continuity across a working crack.

Figure 4: Structural distresses

2.4 Capital Preventive Maintenance

Capital preventive maintenance (CPM) treatments typically address age-related pavement distresses prior to the presence of structural distresses. These treatments retard or offset age-related distresses. The TAMC classifies CPM treatments as either light or heavy. Common light CPM treatments include crack seal and fog seal, whereas common heavy CPM treatments include chip seal, slurry seal, cape seal, microsurface, and thin asphalt overlays. Other more specialized or proprietary CPM treatments exist.

2.4.1 Crack Seal (Light)

Description: A crack seal is a localized treatment method for cracks less than 0.75 inches (1.91 centimeters) wide. It is a sealant that fills a crack, which has been cleaned of debris by using a saw or router to create a clean reservoir. Crack seal is effective for approximately two years and has a lower per lane mile cost, making it a cost-effective solution in terms of per-year cost of extending service life.

Purpose: Crack seal prevents water and/or incompressible material from entering the pavement structure. Intrusion of water and/or incompressible material can weaken a pavement's base and inhibit the pavement from expanding and contracting freely.[3] Traffic loads can cause more damage to these weakened pavements

2.4.2 Cape Seal (heavy)

Description: A cape seal is a chip seal followed by a microsurface cover.

[3] From *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

Purpose: Cape seal treatments maximize the positive aspects of both chip seal and microsurface treatments by applying them together. The microsurface provides a dimensionally-stable layer that bridges defects, such as minor rutting, and provides a smoother travelling surface.[4] The chip seal provides a flexible membrane that disperses stress from cracks or defects in the underlying pavement; this protects the microsurface from early reflective cracking and provides additional waterproofing in the event of a crack in the microsurface.

2.4.3 Chip Seal or Seal Coat (Heavy)

Description: A chip seal—also known as seal coat—is an emulsion bond coat followed by an aggregate cover. A double chip seal is two consecutive layers of chip seal (asphalt bond coat and aggregate cover). Chip seal cures using a thermal-break process, which takes two to eight hours depending on climate conditions. Rapid-setting asphalt emulsions are available and commonly used. Chip seal lasts approximately five years. In some applications, chip seal can be combined with fog seal (see Fog Seal, below).

Purpose: Chip seal treatment protects pavement from environmental deterioration. A chip seal creates a waterproof membrane that prevents hardening and/or oxidation of the pavement and prevents water intrusion into the pavement structure, thereby helping an asphalt pavement to retain its flexibility and resistance to cracking.[5] Chip seal can also provide low-severity crack sealing and restore surface friction.

2.4.4 FOG Seal (Light)

Description: Fog seal is a diluted asphalt emulsion without a cover aggregate. Fog seal is applied to a pavement using an asphalt distributor. Fog seal lasts approximately two years. While fog seal itself is considered a light CPM treatment, it can be combined with chip seal for a heavy CPM treatment. Many Michigan local agencies apply fog seal directly over new chip seal as a standard practice on heavily traveled roads since the fog seal treatment provides waterproofing for the chip seal's stone chips and guarantees sufficient asphalt cement to retain the stone chips.

Purpose: Fog seal treatment seals and enriches the asphalt pavement surface, seals minor cracks, prevents raveling, and provides shoulder delineation.[6] While fog seal has been used on both low- and high-volume roads to prevent raveling and create delineation between travel lanes and shoulders, its use on high-volume roads is restricted due its reduction of pavement friction.

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[4] From Central Federal Lands Highway website, http://www.cflhd.gov/programs/techDevelopment/pavement/context-roadway-surfacing/documents/context5-append-a1.pdf

[5] From: *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

[6] From *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

2.4.5 Microsurface (Heavy)

Description: Microsurface uses a modified liquid asphalt, small stones, water, and portland cement—much like slurry seal—that are cured in a chemically-controlled process. Consequently, it is sometimes incorrectly referred to as a polymer-modified slurry seal. Microsurface lasts approximately seven years.

Purpose: Microsurface restores the transverse cross-section of a pavement profile.[7] It is used for rut filling, surfacing for roads with moderate- to heavy-volume traffic, increasing skid resistance, and reducing water intrusion into the pavement structure. Generally, microsurface is applied as a surfacing at less than 0.5 inches (1.27 centimeters), which adds no strength to the pavement structure but simply seals it from environmental deterioration agents.

2.4.6 Slurry Seal (Heavy)

Description: Slurry seal is a mixture of fine aggregate, asphalt emulsion, water, and mineral filler (often portland cement) that uses a thermal-break process for curing. Thermal-break curing requires heat from the sun and pavement, and can take two to eight hours depending on the heat and humidity. Slurry seal lasts approximately four years.

Purpose: Slurry seal treatment seals the asphalt surface, slows surface raveling, seals minor cracks, and improves surface friction. Slurry seal effectively remedies pavements prone to excessive oxidation and hardening of the existing surface. However, it is minimally effective if the underlying pavement contains extensive cracks.[8]

2.4.7 Thin Overlay (Heavy)

Description: Thin hot-mix-asphalt (HMA) overlays are blends of aggregate (different gradations possible) and asphalt cement often modified with polymer. Three gradation types of thin overlay are dense-graded, open-graded friction courses, and gap-graded. Typically, thin overlay range in thickness from 0.75 to 1.5 inches (1.91 to 3.81 centimeters).

Purpose: Thin overlays provide functional (non-structural) improvement as well as enhance smoothness, friction, and/or profile of asphalt pavements. However, they add little or no additional load-carrying capacity. Thin overlays are effective in all climatic conditions and on all types of roadways; they are particularly suitable for high-volume roads in urban areas where longer life and relatively low-noise surfaces are desired.[9]

2.5 Rehabilitation

Road requiring rehabilitation typically exhibit structural distresses like alligator cracking and rutting. Rutting is evidence of underlying structural failure and must be treated with a

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[7] From *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

[8] From *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

[9] From *Best Practices Handbook on Asphalt Pavement Maintenance,* Minnesota Technology Transfer Center/LTAP, 2000. Available at: http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf

rehabilitation option like crush and shape. In some cases, structural failure may call for reconstruction instead of rehabilitation.

2.5.1 Cold in-Place

Description: Cold in-place (CIP)—also known as CIP recycling—is a rehabilitation technique that requires pulverizing the existing asphalt, milling it, mixing it with new binder and materials, laying the new mixture as a base layer, and applying an overlay or surface treatment. It works well on moderate- to high-volume roadways. CIP maximizes use of existing materials and is a quick rehabilitation process.[10]

Purpose: CIP treats surface distresses that can reach up to 4 inches (10.2 centimeters) into the pavement structure.[11]

2.5.2 Crush and Shape

Description: Crush and shape is pulverization of a pavement and its base, followed by adding new gavel (optional), re-profiling the pavement, and placing a new wearing surface (such as an HMA overlay or chip seal). When crush and shape is used on urban roads, curb-and-gutter work is necessary. Crush and shape generally lasts 14 years.

Purpose: This treatment corrects severe structural distresses on rural roads. Additional gravel and an HMA overlay boost the pavement's structural capacity.

2.5.3 Hot in-place

Description: Hot in-place (HIP)—also known as HIP recycling—is a rehabilitation technique that incorporates surface recycling, remixing, and repaving. The existing asphalt is softened and then mixed with new asphalt; this softened and mixed asphalt is then laid over the remaining pavement structure and overlaid with HMA. HIP is a quick rehabilitation process but is sensitive to cooler temperatures and precipitation.[12]

Purpose: HIP treats distresses in a pavement's surface layer (typically those distresses in the top 2 inches, or 5.1 centimeters). It also corrects functional distresses like surface cracking, raveling, and friction loss.[13]

2.5.4 Hot-mix-asphalt Wedge

Description: Hot-mix-asphalt (HMA) wedge is a narrow 2- to 6-foot-wide (0.6- to 1.8-meter wide) wedge placed along the entire outside edge of a lane; the entire lane—including the section with the wedge—often receives an HMA or chip seal overlay to provide a new riding surface. This repair is often used as a stop-gap treatment in replace of a more expensive

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[10] From *Identifying Best Practices in Pavement Design, Materials, Construction, and Maintenance in Wet-Freeze Climates Similar to Michigan*, You, Z., Gilbertson, C., Van Dam, T., 2017: Michigan Department of Transportation.

[11] From *Identifying Best Practices in Pavement Design, Materials, Construction, and Maintenance in Wet-Freeze Climates Similar to Michigan*, You, Z., Gilbertson, C., Van Dam, T., 2017: Michigan Department of Transportation

[12] From *Identifying Best Practices in Pavement Design, Materials, Construction, and Maintenance in Wet-Freeze Climates Similar to Michigan*, You, Z., Gilbertson, C., Van Dam, T., 2017: Michigan Department of Transportation

[13] From *Identifying Best Practices in Pavement Design, Materials, Construction, and Maintenance in Wet-Freeze Climates Similar to Michigan*, You, Z., Gilbertson, C., Van Dam, T., 2017: Michigan Department of Transportation

repair that may not be fiscally possible. HMA wedge lasts approximately four years or longer for overlaid wedges.

Purpose: HMA wedge corrects edge damage. It adds strength to severely settled areas of the pavement.

2.5.5 Thick Overlay

Description: Thick overlay is a layer of new asphalt (liquid and stones) placed on an existing pavement. The overlay is over 1.5 inches (3.81 centimeters). Thick overlay lasts approximately five to ten years. It can be combined with mill treatment, which is the removal of the pavement surface via milling.

Purpose: This treatment creates a new wearing surface for traffic and seals the pavement from water, debris, and sunlight. Depending on the overlay thickness, this treatment can add significant structural strength. A mill and overlay removes severe damage, preventing reflected structural problems, and omits the need for curb-and-gutter work.

2.6 Reconstruction

Description: Pavement reconstruction involves complete removal of the old pavement and base followed by the construction of an entirely new road. Reconstruction lasts approximately 15 years. Comparatively, it is the most expensive treatment option and most disruptive to daily traffic. During its service life, a reconstructed pavement will likely require one or more CPM or rehabilitation treatments.

Purpose: Reconstruction is appropriate when more cost-effective treatment options have been exhausted or when a road requires significant changes to its geometry, base, or underlying utilities.

3 GOAL OF THIS STUDY

ESL can be gained by applying the appropriate repair treatment on a pavement deteriorating from distress. The goal of this study is to determine the average ESL gain broken down by the category of treatment for the various treatments used by Michigan local agencies from the data set provided. The data will also be analyzed for any other similarities that can be associated with variations in the data set.

4 METHODS

This study employed an updated version of the ESL Calculator to select candidate roadway segments and evaluate whether they met the study selection criteria; the study also relied on Roadsoft's performance modeling functionality, including the deterioration curves that it can generate (see Figure 1).

Measuring the ESL created by a given treatment can help determine the benefit of repair treatments. ESL is the additional time in years that the pavement is above the CDP—or the additional time in years before the pavement experiences structural distresses (PASER 4 or below)—due to the repair treatment (Figure 5). This method evaluates the additional time before a pavement needs expensive treatments like rehabilitation or reconstruction. The ESL benefit directly affects the cost of roadway maintenance since it creates a tangible extension in pavement life.

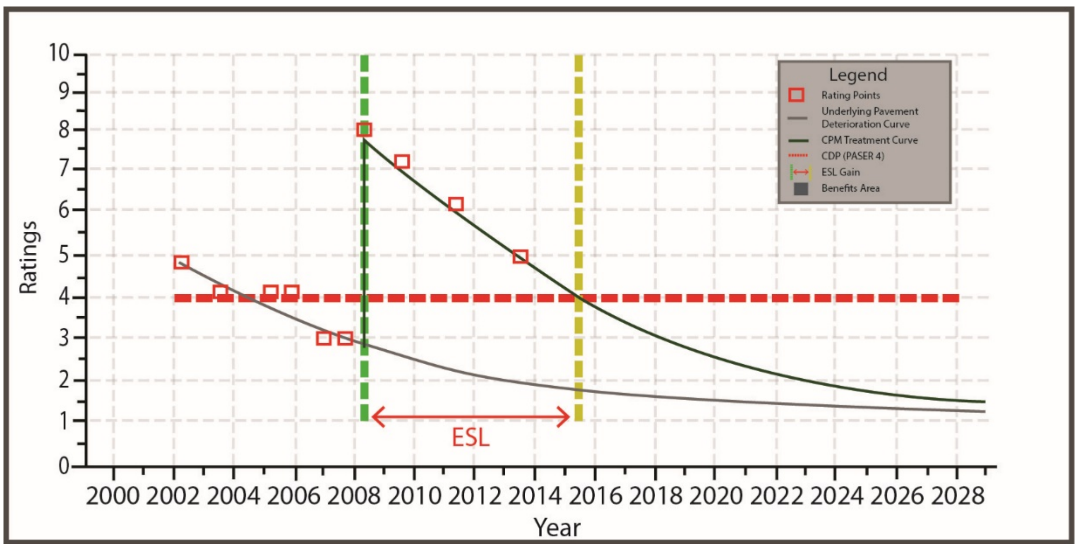

Figure 5: Example segment showing ESL with a positive improvement (gain) resulting from repair treatment and a decrease in pavement condition over time. In this instance, the underlying pavement deterioration curve crosses the CDP (PASER 4 line) prior to the pavement receiving a repair treatment.

4.1 Development of Data Set

The Center for Technology & Training (CTT) requested that Michigan local agencies submit their pavement condition and treatment data for this study. Because participation was voluntary, marketing was necessary to generate interest. Approximately 1,100 Michigan local agencies in the CTT database were contacted to request agency participation in the study. Advertisements for participation in the study were also circulated at conferences and training where local agency participation was expected.

The study did not require local agencies to perform excessive or in-depth data collection in order to illustrate how ESL analyses can be integrated into a local agency business process.

Local agencies only needed to provide basic data that they were already collecting as part of the annual TAMC collection effort. Local agencies exported data sets from Roadsoft—which most Michigan road-owning agencies already use to collect, analyze, and store their pavement management data—and sent them to the CTT via e-mail or FTP site uploads. Received data sets were verified for completeness, and catalogued by date and by submitting agency.

4.2 Selection Criteria of Qualifying Data for Analysis

Stringent criteria for selecting repair treatments minimizes modeling effects that would potentially bias results of this study. Restrictive selection criteria ensure that the study results are reliable and reflects the actual benefit provided by the repair treatment. Two sets of selection criteria were used to generate the final data set: road network selection criteria and repair treatment selection criteria.

Each agency's data set was evaluated in Roadsoft using the network builder and filter tools to isolate the portions of the road network meeting selection criteria. Road network selection criteria used in this study were as follows:

- Pavement segments must be asphalt designated with an asphalt standard surface sub-type or designated as a similarly-constructed asphalt pavement with a surface sub-type name defined by the local agency. Asphalt pavements comprise the majority of paved roadway miles owned by local agencies in Michigan. Since the expected life of an asphalt pavement without preventive maintenance treatments is approximately 15 years, asphalt segments in Michigan will fall into various PASER categories. Limiting asphalt pavements to standard surface sub-types provides uniformity in the construction of the asphalt pavement whereas other asphalt pavements may be built to varying standards that affect both their service life and extended service life consequent to repair treatments.
- Segments must be Federal-aid-eligible. Because the Federal-aid network is eligible for Federal funding, it likely receives the majority of repair treatment activity, thus providing the greatest number of candidate segments for the study.

Qualifying road segments were assessed for repair treatments meeting selection criteria. An updated version of Roadsoft's ESL Calculator was used to identify and evaluate repair treatments on the qualifying network that met repair treatment selection criteria. The updated ESL Calculator, which will be released to Roadsoft users in the near future, was used to produce modified ESL calculations to simplify data analysis for this study. The repair treatment selection criteria used in this study were as follows:

- The repair treatments must be the first treatment in its TAMC treatment classification system (i.e., light CPM, heavy CPM, rehabilitation, or reconstruction) applied over the original asphalt pavement or over a heavier or lighter treatment than the one being analyzed; treatments applied over similar treatment classes were separated into a data set that analyzed diminishing returns. When a treatment of the same classification is applied multiple times over a surface without increasing the pavement's structure with an HMA overlay (e.g., a chip seal applied over a chip seal), the subsequent treatment yields diminishing returns, or reduced effectiveness at extending the pavement's life or realizing ESL consequent to treatment.

- Qualifying road segments must have a minimum of three PASER scores prior to and three following the treatment of interest. This can reasonably define the underlying pavement deterioration curve (determined from three scores or more prior to treatment) as well as the repair treatment curve (determined from three scores or more following the treatment).
- The treatment could not be a crack seal or a crack fill. The PASER system is not sensitive enough to show rating changes due to applying a crack seal treatment, which makes measuring benefit of this short-life treatment difficult. Nonetheless, crack seal is low cost, and research suggests it provides an additional ESL of one to three years when applied correctly.
- The data must be from the year 2000 or subsequent years. Data collected prior to the year 2000 is less reliable due to differences in construction, specifications, and materials, as well as the limited availability of PASER training for Michigan local agencies.

4.3 Application of Pavement Modeling to Qualifying Data Set

Roadsoft's pavement modeling functionality generated a unique performance model for each road segment in the qualifying data set. The performance model—comprised of an underlying pavement deterioration curve and a repair treatment curve—for each segment depended upon the segment's PASER scores and maintenance history data. Each of the unique performance models were reviewed individually, by hand, in order to verify that the results were reasonable and that the models fit the data well.

The ESL for each road segment was calculated as the time in years between curve and/or treatment application intersects with the CDP (PASER 4 line). In many cases, road segments received repair treatments prior to the pavement reaching its CDP (PASER 4 line); in these instances, the ESL was calculated as the time between the underlying pavement deterioration curve's theoretical intersection with the CDP and the repair deterioration curve's intersection with the CDP (see Figure 2). In cases where the pavement reached its CDP before receiving a repair treatment, the ESL was the time between the application of the repair treatment and the repair treatment curve's intersection with the CDP (Figure 5).

When there was an actual PASER 4 score following the repair treatment rather than just the modeled intersection, that rating point was considered as the end point for ESL measurement regardless of where the repair treatment curve intersected the CDP (Figure 6). This was an additional conservative measure to eliminate modeling effects.

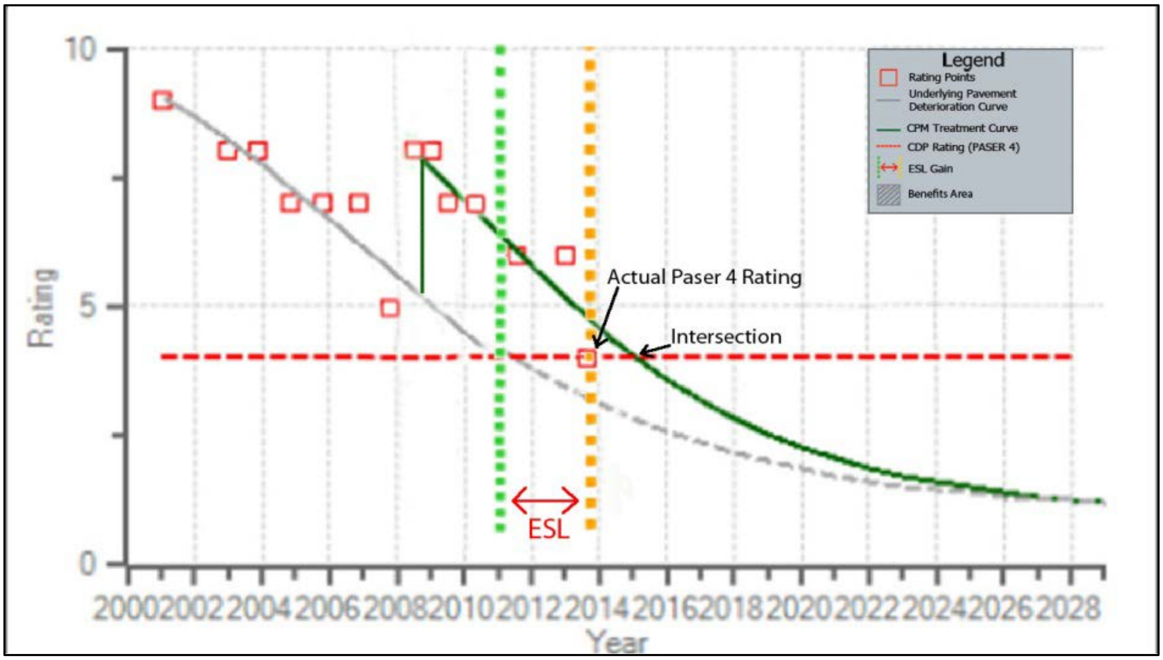

Figure 6: PASER 4 following repair treatment

Some repair treatment curves produced a negative ESL on paper when the curves intersected the CDP prior to the underlying pavement deterioration curve's intersection. It is assumed that a repair treatment will not negatively affect the life of the pavement but, in certain cases, may not provide an extended service life. Therefore, these performance models were classified as having an ESL equal to zero.

In some cases, the performance data indicated an ESL in excess of 15 years for heavy CPM treatments and 20 years for rehabilitation treatments. These ESLs are unexpected and outside the normal range of ESL for these treatment types. ESL was limited to a maximum of 15 years for heavy CPM treatments and a maximum of 20 years for rehabilitation treatments as a conservative measure to inhibit a few data points from skewing the entire data set (refer to the Discussion Topics section of this report for an explanation of limiting ESL for high performing segments and the sensitivity analysis of this decision).

Data was analyzed for each qualifying treatment category by agency, and then at a statewide level. ESL was assigned to each treated road segment meeting the selection criteria; these individual segment ESLs combined to create a weighted average using the length in miles of each segment as the weighting factor, which accounts for variation in segment lengths. Weighted average ESL was calculated for each treatment and each agency as well as an overall weighted average ESL for the state by treatment type. This data set was further segments by legal system classification (e.g., county primary, city major), National Functional Classification

(NFC), number of lanes, and by region in order to identify any common trends. The Cochran Formula was used to estimate sample sizes necessary to produce ESL results with a margin of error of 15% based on an estimate of the parent population. Required sample sizes ranged from 35 miles for relatively rare treatments like cape seal which have a small population size, to 43 miles for common treatments like chip seal that have a very large population size. The use of miles of treatment as a sample size estimator was considered to be conservative, since there are likely several separate observations per mile which tend to lower the required sample size.

5 RESULTS

Thirty-six agencies submitted data for consideration of use in this study. The analyzed data included 51,645 road segments, which consisted of 10,578.360 road miles (17,024.220 kilometers)—or 12% of Michigan's paved Federal-aid network)—that met the following criteria in Roadsoft:

- Act 51 equals true
- Sub Base equals Asphalt Standard (one agency used Asphalt)

Of the originally submitted data pool, 29 agencies' data met the selection criteria defined in the Methods section of this report. The application of the selection criteria resulted in 6,236 road segments—or 1,709.774 miles (2,751.615 kilometers) of road data—that had qualifying repair treatments. The seven agencies whose data did not meet selection criteria comprised a significant amount of data. Reasons for excluding their data included segment data pertained to pavements constructed and treated prior to 2000 (see maximum age selection criterion in the Methods section) and segment data pertained to pavements with successive repair treatments of the same TAMC classification (see discussion about diminishing returns in the Methods section).

The 29-agency data pool produced 14 discrete treatments that met the selection criteria for analysis. Table 2 summarizes these treatments. Six of the 14 treatments— cape seal, chip seal, chip seal plus fog, thin overlay, crush and shape, and thick overlay—has significantly large enough sample sizes to produce a sound statewide average ESL.

Only two agencies, in close proximity to each other, used cape seal; so this data is representative of local or regional level rather than at a state level. A larger number (10-25) of agencies used the other five treatments and covered a more diverse portion of the qualifying road network statewide, so these data are representative at a statewide level.

Table 2: Summary of Extended Service Life by Treatment Type

Treatment	Agencies	Segment Count	Total Miles	Weighted Avg ESL
Heavy CPM				
Cape seal	2	**260**	**35.042**	6.0
Chip seal	**21**	**2372**	**784.858**	**4.1**
Chip seal plus fog seal	**10**	**514**	**195.890**	**7.1**
Microsurface	3	129	26.679	2.3
Slurry seal	1	20	1.999	3.7
Thin overlay	**20**	**666**	**161.899**	**6.9**
Rehabilitation				
Cold-in-place (CIP) plus overlay	1	7	2.092	6.1
Crush and Shape	**10**	**453**	**142.537**	**11.3**
Hot-in-place (HIP)	1	12	1.349	11.1
HIP plus overlay	2	15	2.095	7.3
HMA wedge plus chip seal	1	13	5.060	4.6
HMA wedge plus overlay	4	58	25.003	5.7
Thick overlay	**25**	**1584**	**301.760**	**9.1**
Reconstruction				
Reconstruction	6	133	23.511	9.9
Total	**29**	**6236**	**1709.774**	

5.1 Cape Seal

Cape seal treatments meeting the selection criteria totaled 35.042 miles (56.394 kilometers) (Figure 7). Cape seal is a relatively new treatment in Michigan, and records from the TAMC Investment Reporting Tool (IRT) indicate that only 46 miles of this treatment were applied in 2017 on local agency owned roads. In the data set two agencies indicated use of cape seal; their total segment count was 260. The weighted average ESL for this regional data set was 6.0 years. It is interesting to note that only 0.58 miles (0.93 kilometers) of cape seal resulted in a zero ESL improvement. This may be due to the limited amount of agencies in the data set, or to the increased care these agencies use in selecting locations for cape seals.

Figure 7 shows a fairly-uniform bell-curve shaped distribution with the most frequently observe cohort of seven years of ESL. This is indicative of a normally distributed data set. The box plot of this data is depicted in Figure 8 which illustrates the distribution of data points. The non-weighted average is represented as a blue line and the median is represented as a black line in Figure 8 The left side of Figure 8's black skeletal box plot represents the first quartile, the center is the median, and the right side is the third quartile. Black tick marks represent the minimum and maximum on the left and right side, respectively. The black dashed-line area illustrates the 95% confidence interval containing the median; the blue dashed-line area is the 95% confidence interval containing the unweighted average. The blue dashed-line area centers over the unweighted average. Since these data points are not weighted by miles, the box plot and mean plot will show a skew due to segment length.

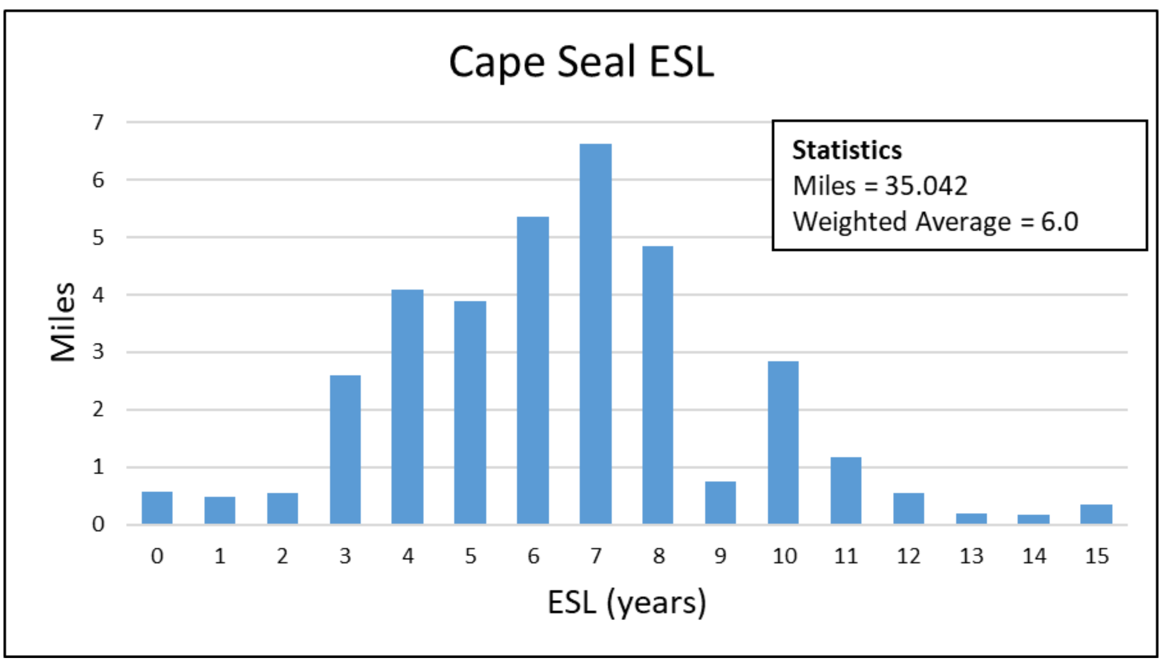

Figure 7: Cape seal qualifying miles distribution by ESL

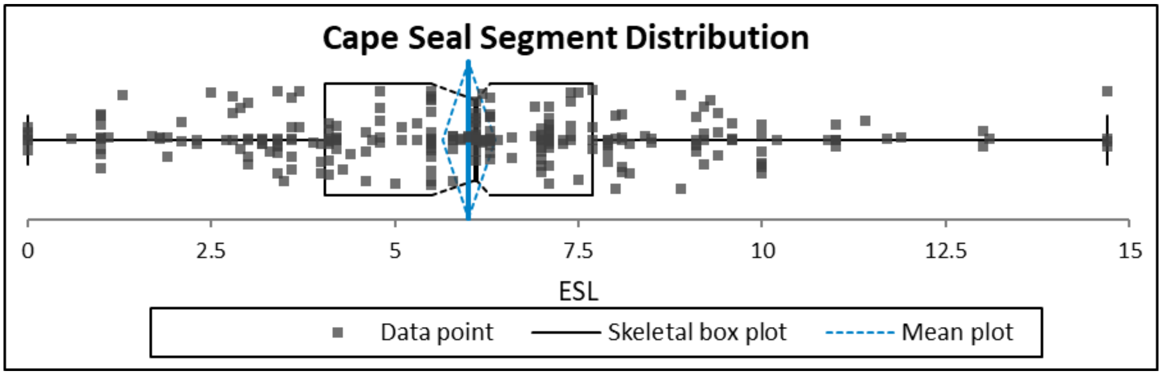

Figure 8: Cape seal non-weighted average ESL segment distribution

5.2 Chip Seal

Chip seal was the most prevalent repair treatment in the data set. Chip seal prevalence is likely due to chip seals' long-time use in the United States and, thus, the good understanding that agencies have of chip seal treatment as well as the ability local agencies have to apply it with minimal equipment, work forces, and cost. Treatments such as slurry seal, microsurface, and cape seal are newer and offer attractive aesthetic properties but cost considerably more, and most studies have shown that they have similar performance lives to chip seal.

As Table 2 indicates, chip seals meeting the selection criteria totaled 784.858 miles (1,263.107 kilometers). Twenty-one agencies indicated use of chip seal; their total segment count was 2,372. A fairly-uniform trend in a histogram plot of increasing ESL values indicates that ESL gains of over 9 years are uncommon and ESL gains between 0 and 7 years are frequent (Figure 9). This data set did have 114.59 miles (184.415 kilometers) with an ESL gain of zero, which is depicted as 364 segments in Figure 10. The weighted average ESL for the data set was 4.1 years and is the same weighted average that was found in the 2014 ESL study (Colling, Keifer, & Farrey; 2014) using different data sets and different local agencies. This weighted average accounts for instances where no ESL was gained by the treatment.

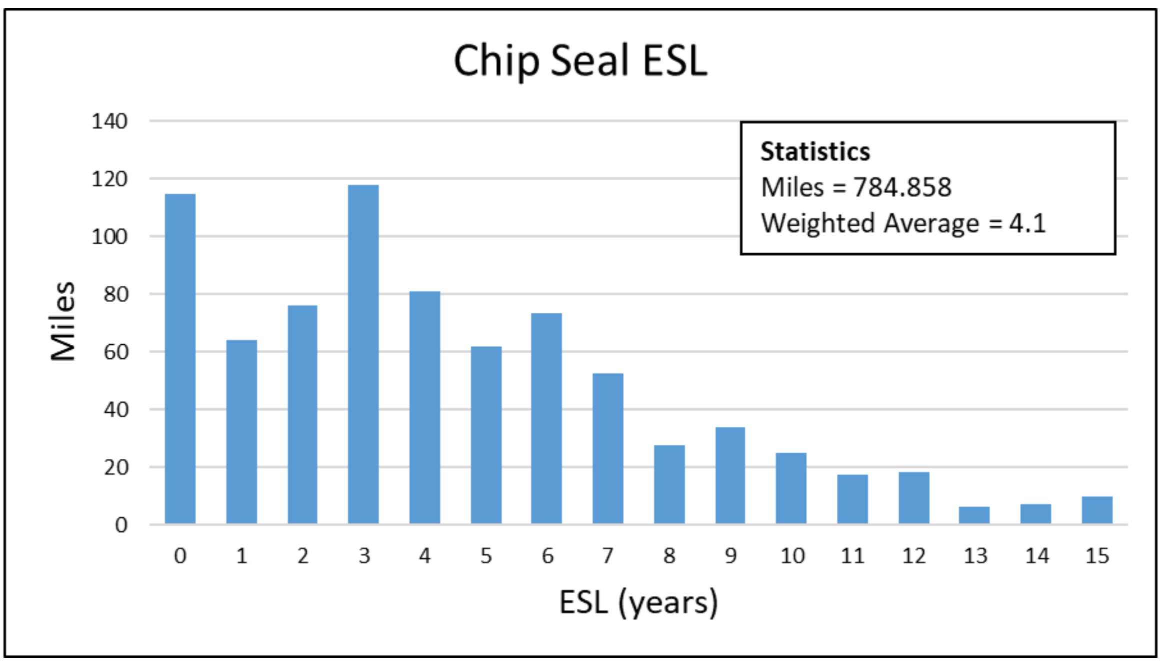

Figure 9: Chip seal qualifying miles distribution by ESL

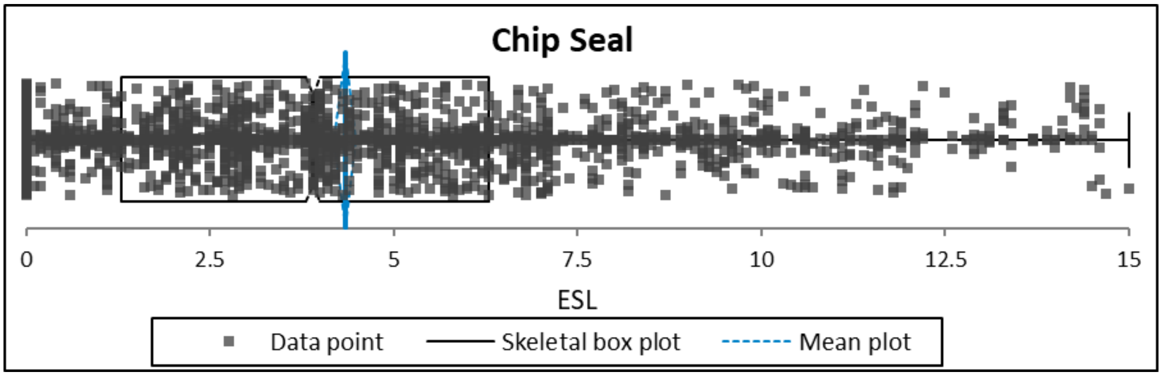

Figure 10: Chip seal non-weighted average ESL segment distribution

5.3 Chip Seal *Plus* Fog Seal

This combination treatment was specifically identified in the data set and analyzed separately. Chip seal plus fog seal treatments that met the selection criteria totaled 195.890 miles (315.254 kilometers) (Figure 11). Ten agencies included this treatment as a distinct data set; with a total segment count of 514. Figure 11 shows a total of 44.769 miles (72.049 kilometers)of chip seal plus fog seal that have over 10 years of ESL, which is 22.8% of this data set. Another interesting find is that there is only 0.222 miles (0.357 kilometers) with zero ESL gain, which is significantly lower than standard chip seals. The weighted average ESL for the data set was 7.1 years. Of the six significant treatments, chip seal plus fog seal had the most change in ESL after adjusting for skew due to segment size; this can be shown when comparing the weight average of 7.1 years to the non-weighted average of 6.4 years. Figure 12 shows the non-weighted data points for chip seal plus fog seal treatment.

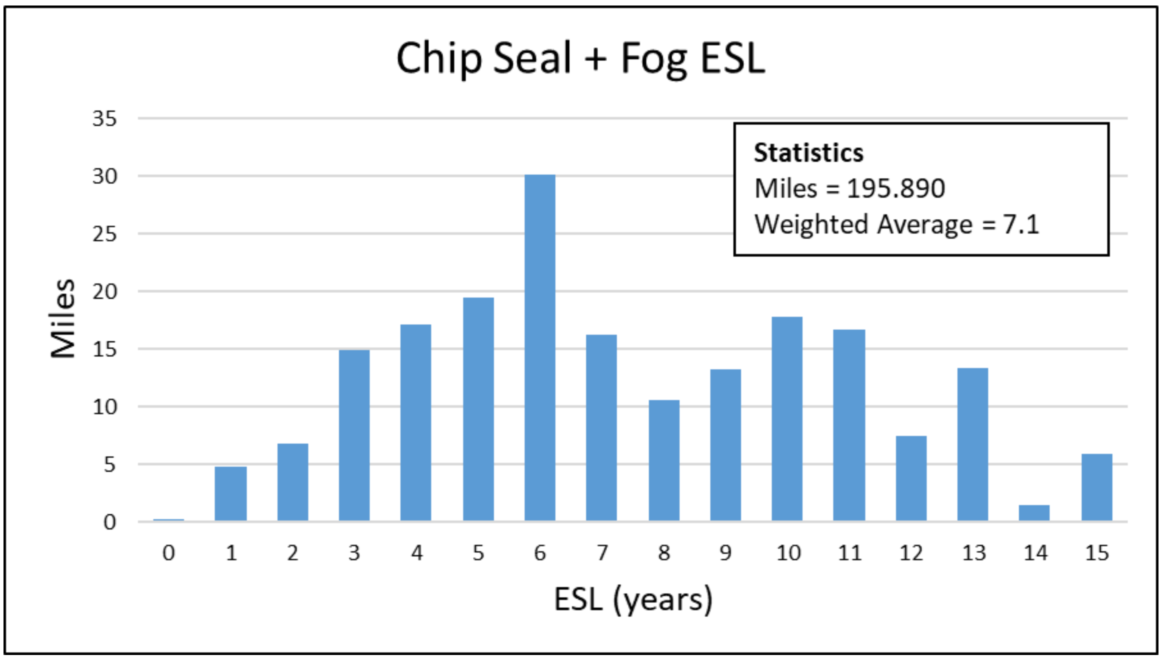

Figure 11: Chip seal plus fog seal qualifying miles distribution by ESL

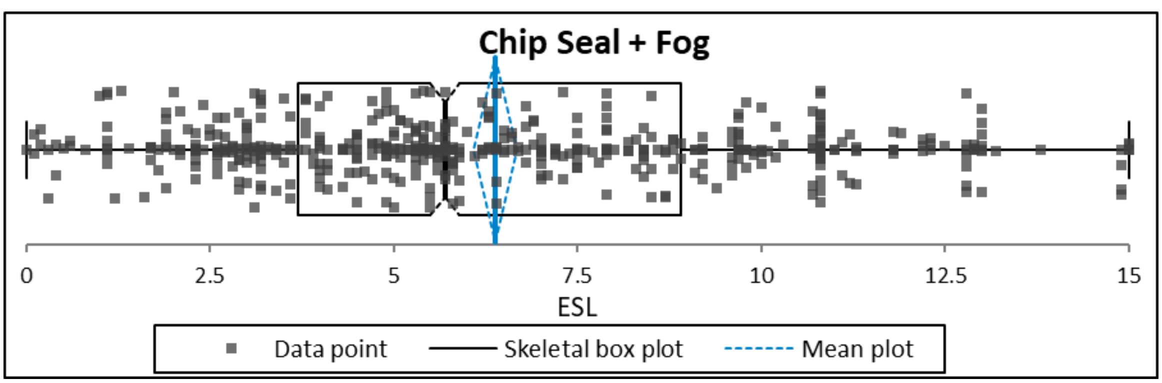

Figure 12: Chip seal plus fog seal non-weighted average ESL segment distribution

An interesting finding was the increased ESL for placing a fog seal on top of a chip seal. Twenty-one agencies used chip seal alone and had a weighted average ESL of 4.1 years. Ten agencies used chip seal plus fog seal and had a weighted average ESL of 7.1 years; nine of these agencies used both chip seal and chip seal plus fog seal. The nine agencies were analyzed separately to minimize uncontrollable factors influencing treatment life (Figure 13 and Table 3). Applying the Student's *t*-test analysis to the central tendency of the two treatments—chip seal and chip seal plus fog seal—used by these nine agencies revealed that their average ESL gains are statistically significant. This means that there are differences in the central tendency (average ESL) for both of these treatments that is not a result of the variability of the data. The non-weighted average ESL gain for chip seal plus fog seal was 1.7 while the weighted average ESL gain was 2.9 years.

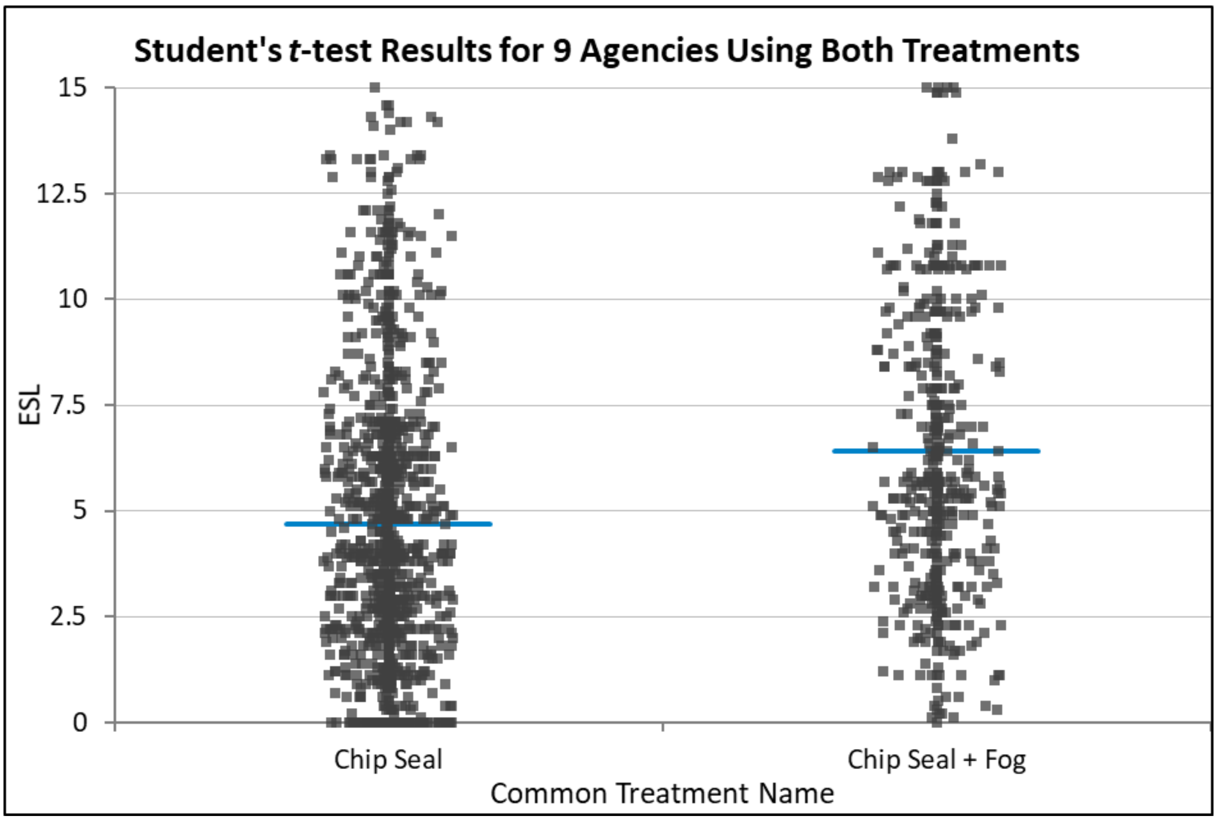

Figure 13: Chip seal vs. chip seal plus fog seal non-weighted average ESL segment distribution

Table 3: Nine Agencies that use Both Chip Seal and Chip Seal Plus Fog Seal

ESL by Common Treatment Name	n	Mean (not weighted)	Mean SE	SD
Chip seal	1265	4.68	0.091	3.24
Chip seal plus fog seal	509	6.40	0.151	3.41
Mean difference	1.72			
SE	0.173			
Student's *t* test				
Hypothesized difference	0		DF	1772[1]
t statistic	9.95		*p*-value	<0.0001

[1] Reject the null hypothesis in favor of the alternative hypothesis at the 10% significance level.

5.4 Microsurface

Microsurface treatment meeting the selection criteria totaled 26.679 miles (42.936 kilometers) (Figure 14). Three agencies indicated use of microsurface; their total segment count was 129. The weighted average ESL for the limited data set was 2.3 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive. Figure 15 shows the non-weighted average ESL median as 2.4 years and the mean as 2.9 years. The 2014 ESL study calculated a weighted average ESL of 5.4 years from a 7.9-mile (12.7-kilometer) data set (Colling, Kiefer, & Farrey; 2014). Whereas the 2014 study analyzed only one agency, this study analyzed three agencies' microsurface treatment segments. Both studies did not contain large enough sample sizes for microsurfacing to draw conclusions about the effectiveness of this treatment.

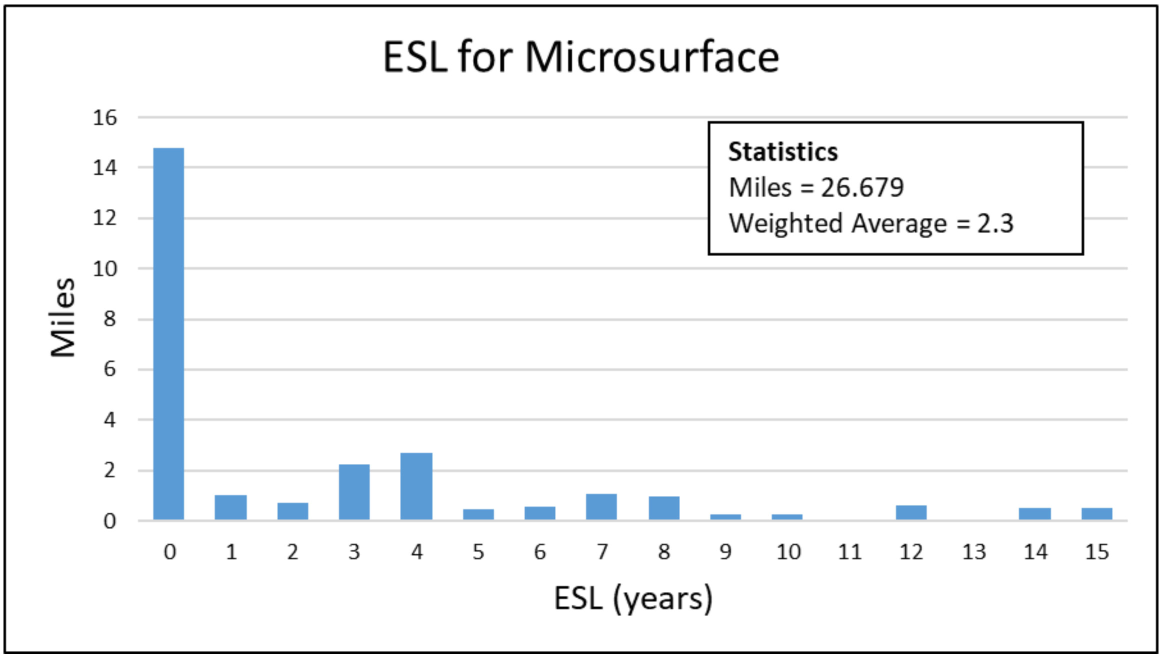

Figure 14: Microsurface qualifying miles distribution by ESL

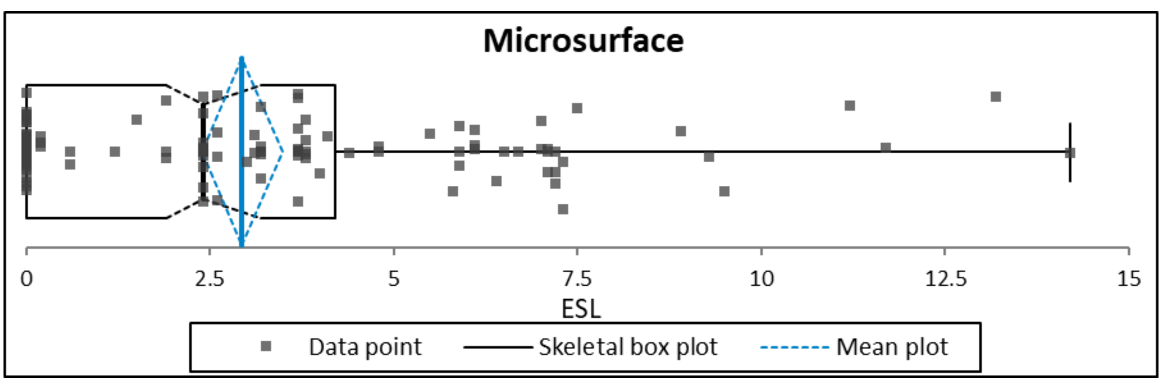

Figure 15: Microsurface non-weighted average ESL segment distribution

5.5 Slurry Seal

Slurry seal treatments meeting the selection criteria totaled 1.999 miles (3.217 kilometers) (Figure 16). One agency indicated use of slurry seal; their total segment count was 20. The weighted average ESL for the limited data set was 3.7 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 17).

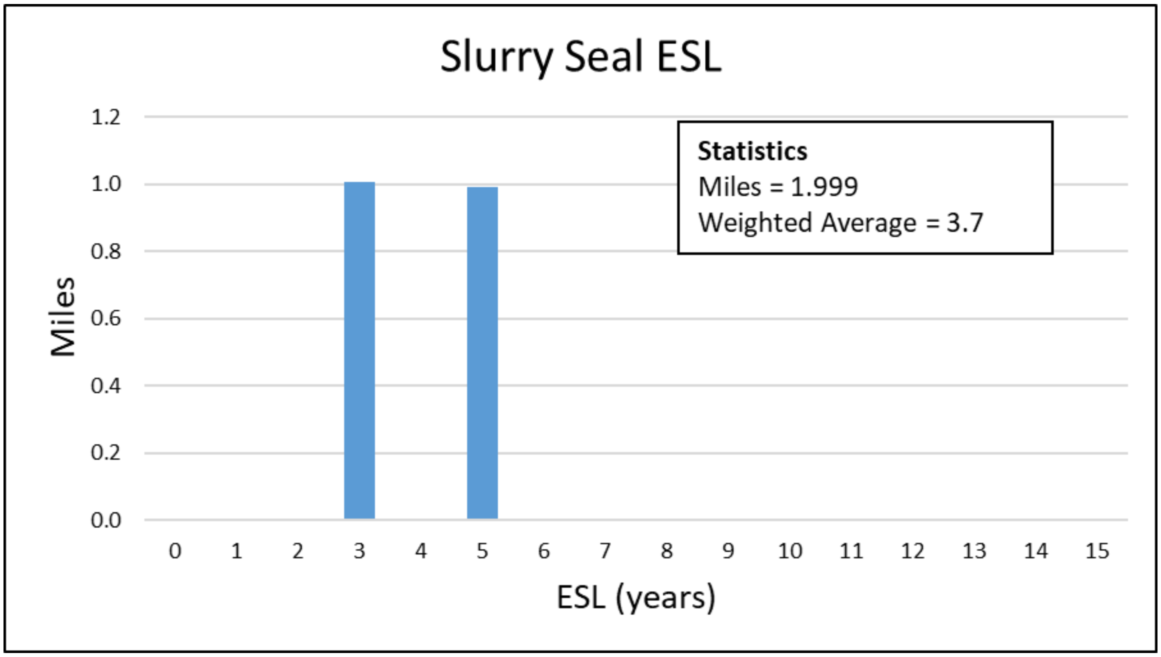

Figure 16: Slurry seal qualifying miles distribution by ESL

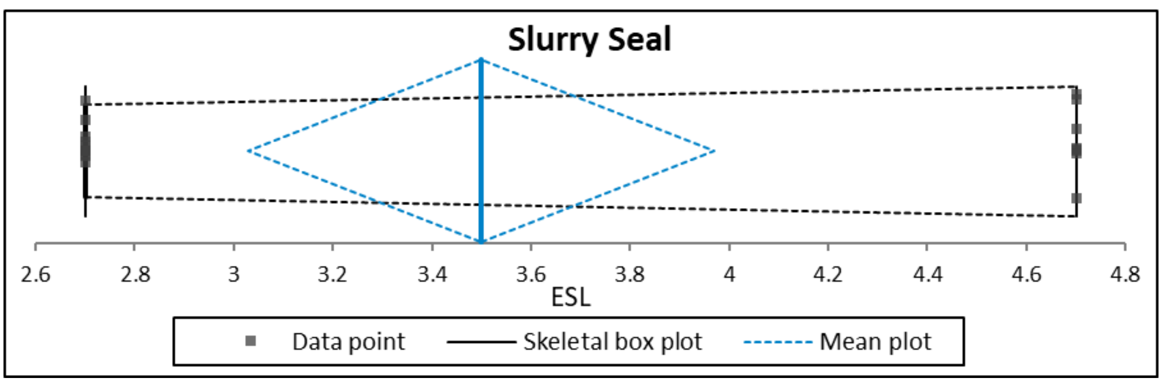

Figure 17: Slurry seal non-weighted average ESL segment distribution

5.6 Thin Overlay

Thin overlay treatments meeting the selection criteria totaled 161.899 miles (260.551 kilometers) (Figure 18). Twenty agencies indicated use of thin overlay; their total segment count was 666. The weighted average ESL for the data set was 6.9 years. There were 8.071 miles (12.989 kilometers)—or 21 segments—having more than 15 years of ESL (ESL ranging from 16 to 36 years) and a weighted average ESL of 18.7 years; these segments were excluded from Figure 19. There could be many reasons (e.g. agency policy, traffic volumes, and, underlying distresses, more careful selection criteria) why the chip seal plus fog achieved a higher ESL weighted average as compared to thin overlay treatments, which could only be identified with a more intensive study.

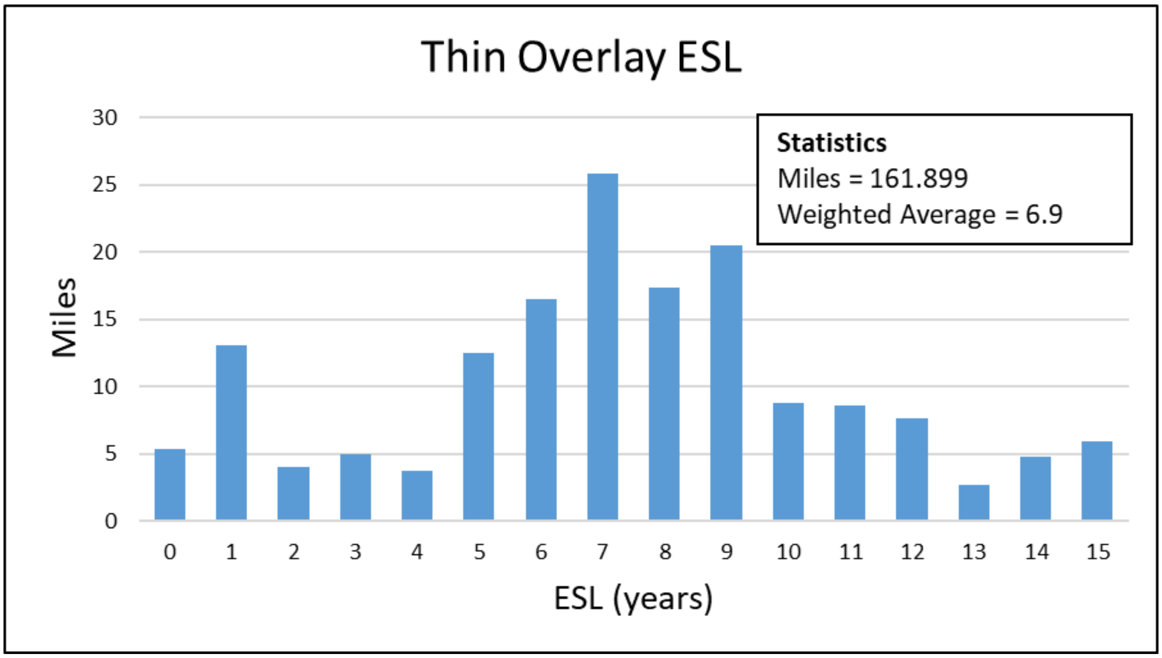

Figure 18: Thin overlay qualifying miles distribution by ESL

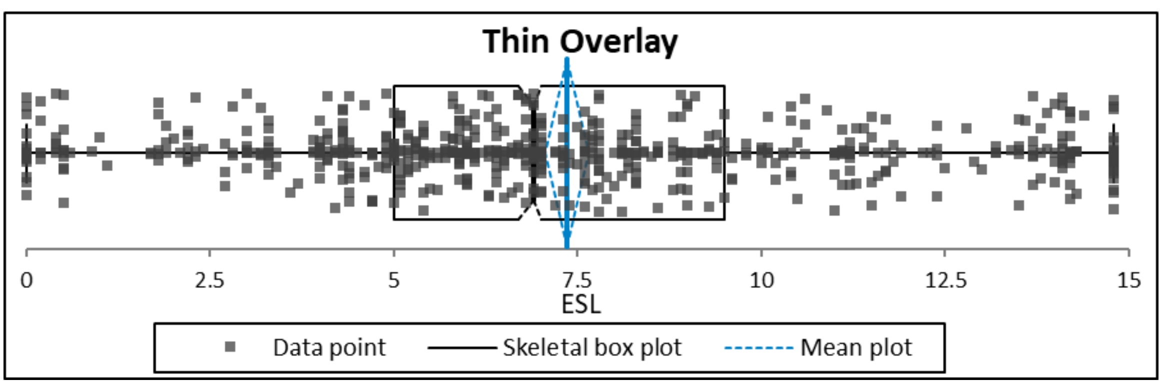

Figure 19: Thin overlay non-weighted average ESL segment distribution

5.7 Cold-in-Place *Plus* Overlay

Cold-in-place (CIP) plus overlay treatments meeting the selection criteria totaled 2.092 miles (3.367 kilometers) (Figure 20). One agency indicated use of CIP plus overlay; their total segment count was 7. The weighted average ESL for the limited data set was 6.1 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 21).

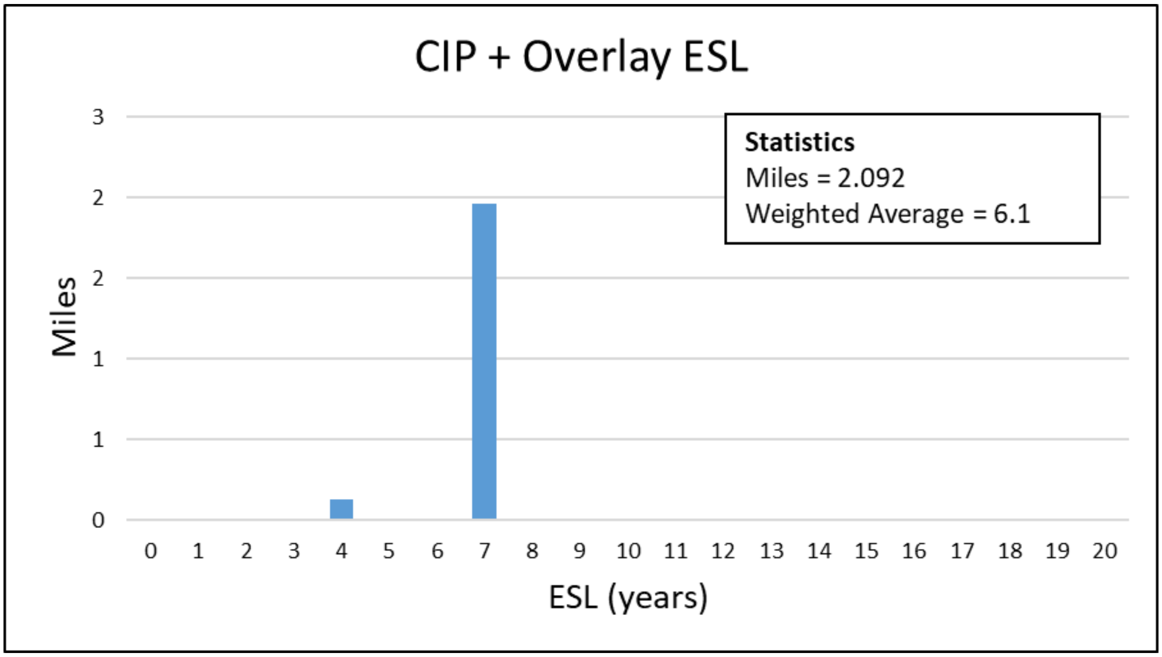

Figure 20: CIP plus overlay qualifying miles distribution by ESL

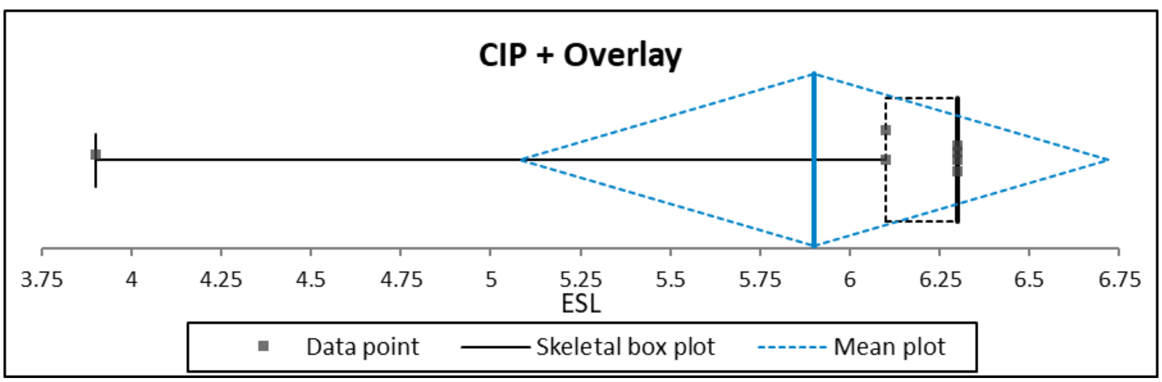

Figure 21: CIP plus overlay non-weighted average ESL segment distribution

5.8 Crush and Shape

Crush-and-shape treatments meeting the selection criteria totaled 142.537 miles (229.391 kilometers) (Figure 22). Ten agencies indicated use of crush and shape; their total segment count was 453. The weighted average ESL for the data set was 11.3 years (Figure 23).

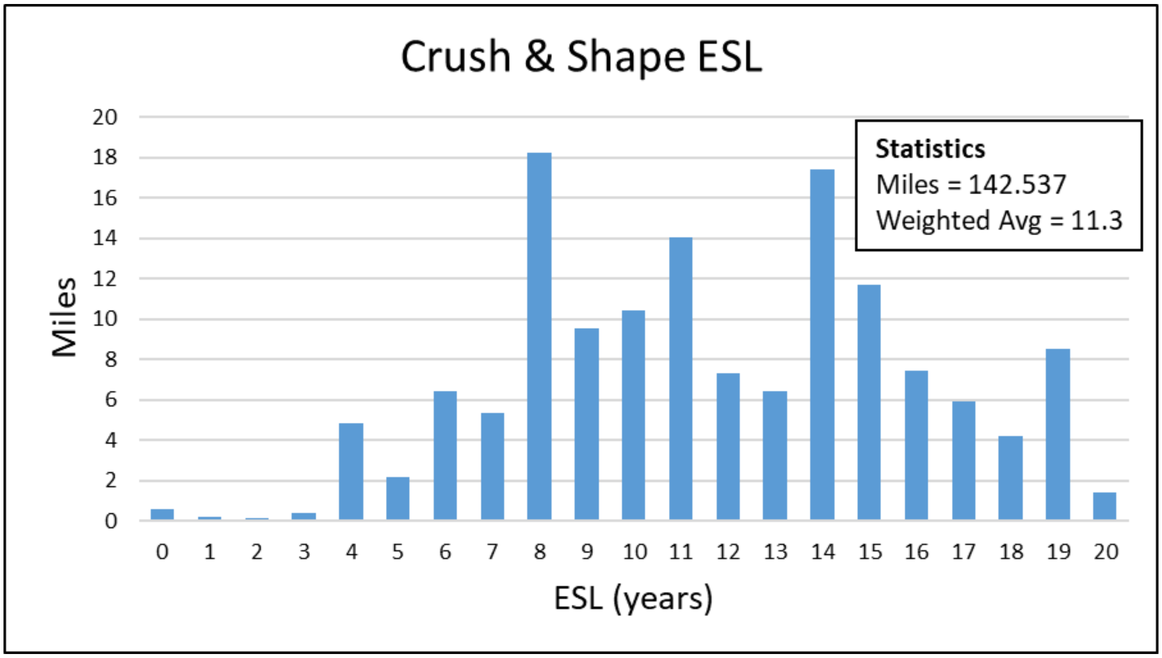

Figure 22: Crush and shape qualifying miles distribution by ESL

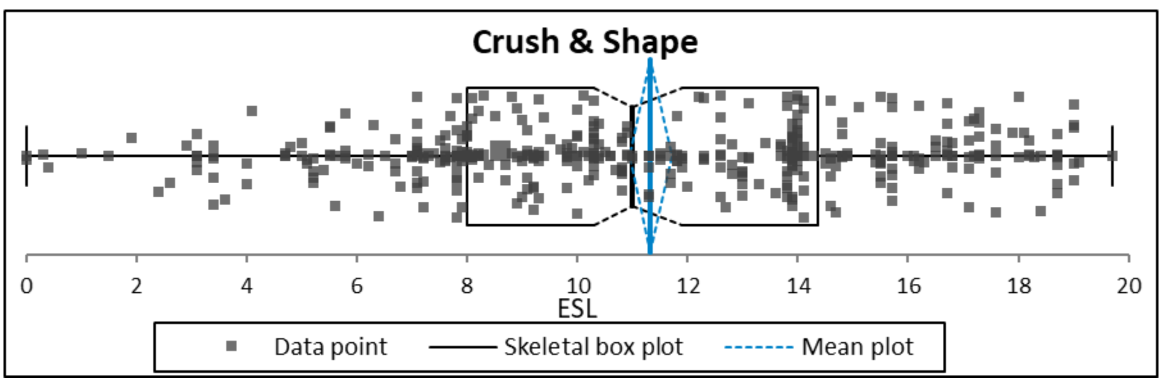

Figure 23: Crush and shape non-weighted average ESL segment distribution

5.9 Hot-in-Place

Hot-in-place (HIP) treatments meeting the selection criteria totaled 1.349 miles (2.171 kilometers) (Figure 24). One agency indicated use of HIP; their total segment count was 12. The weighted average ESL for the limited data set was 11.1 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 25).

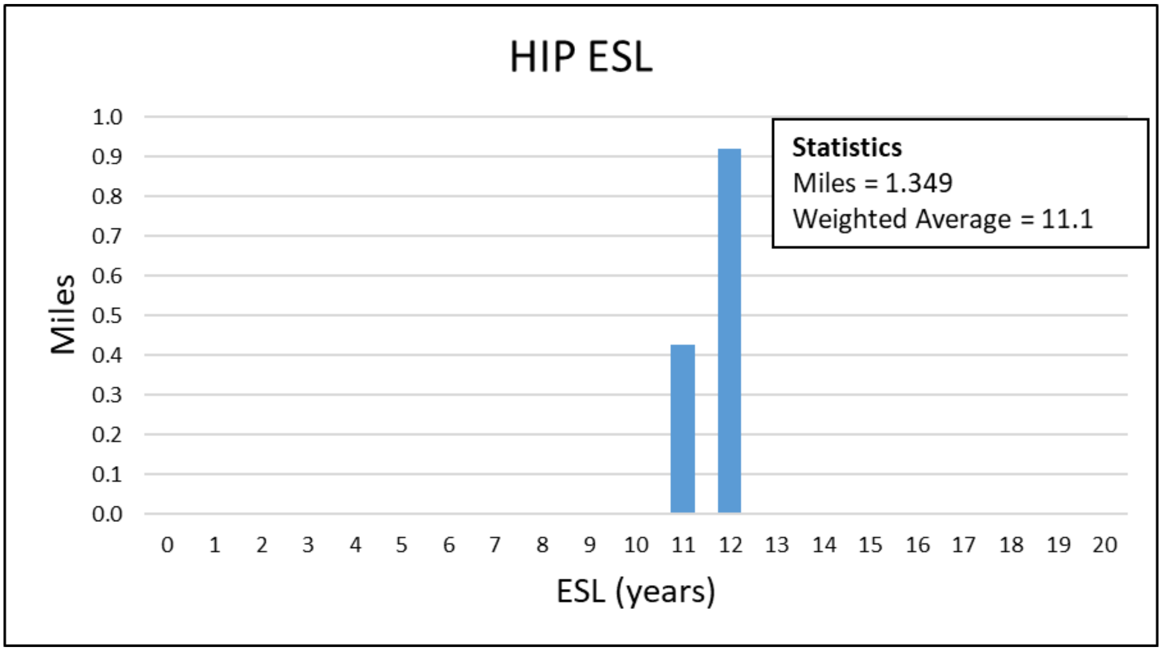

Figure 24: HIP qualifying miles distribution by ESL

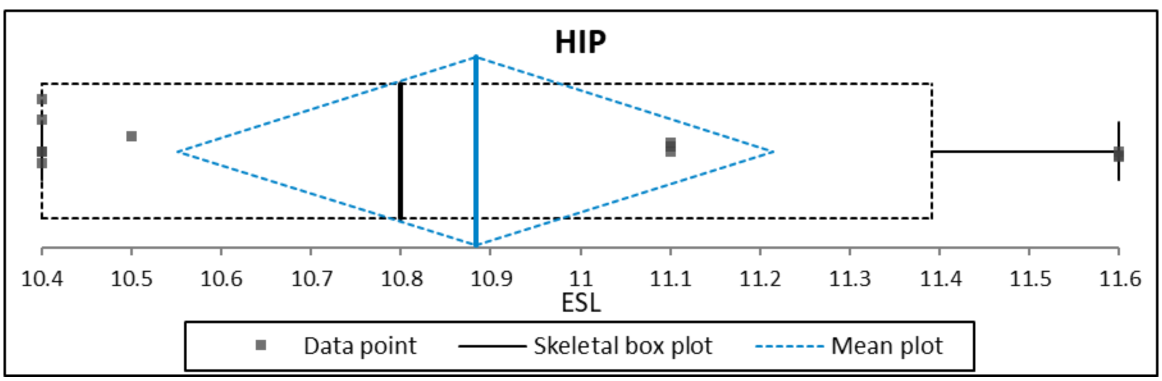

Figure 25: HIP non-weighted average ESL segment distribution

5.10 Hot-in-Place *Plus* Overlay

Hot-in-place (HIP) plus overlay treatments meeting the selection criteria totaled 2.095 miles (3.372 kilometers) (Figure 26). Two agencies indicated use of HIP plus overlay; their total segment count was 15. The weighted average ESL for the limited data set was 7.3 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 27).

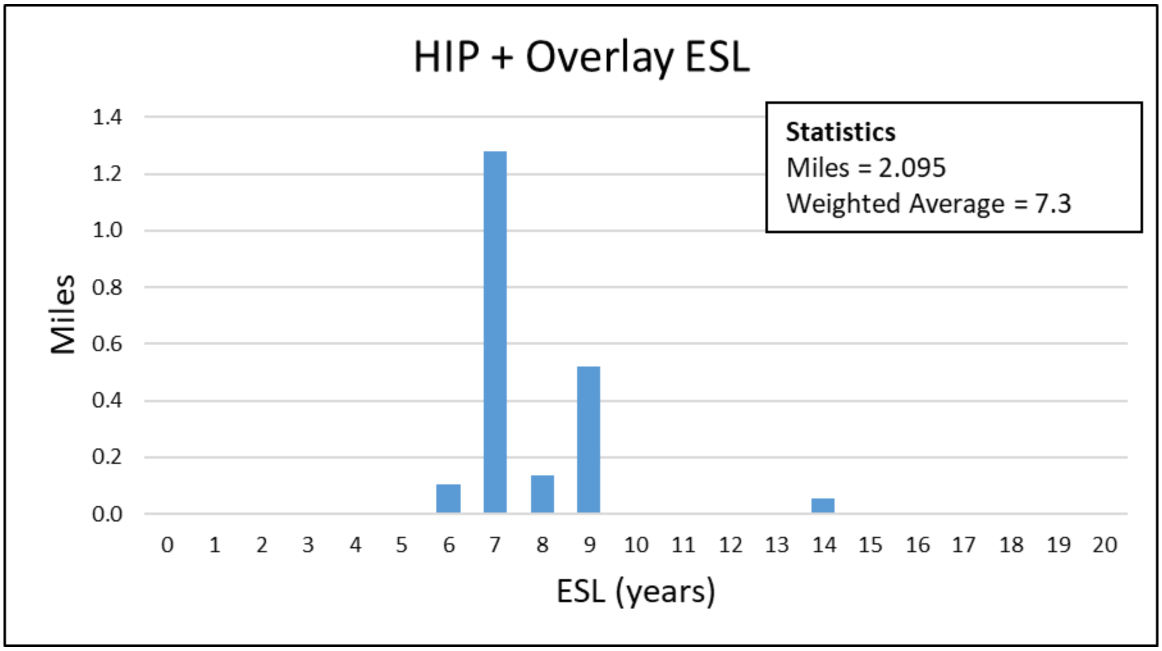

Figure 26: HIP plus overlay qualifying miles distribution by ESL

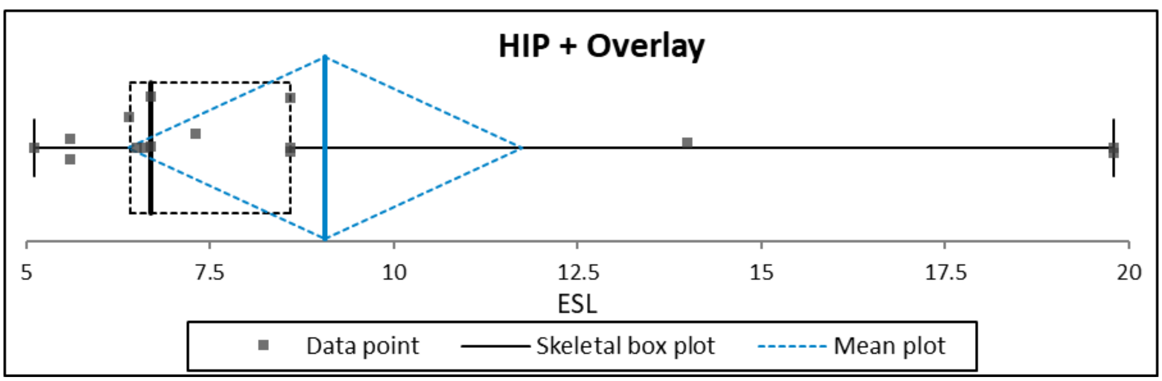

Figure 27: HIP plus overlay non-weighted average ESL segment distribution

5.11 Hot-mix-asphalt Wedge *Plus* Chip Seal

Hot-mix-asphalt (HMA) wedge plus chip seal treatments meeting the data selection criteria totaled 5.060 miles (8.143 kilometers) (Figure 28). One agency indicated use of HMA wedge plus chip seal; their total segment count was 13. The weighted average ESL for the limited data set was 4.6 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 29).

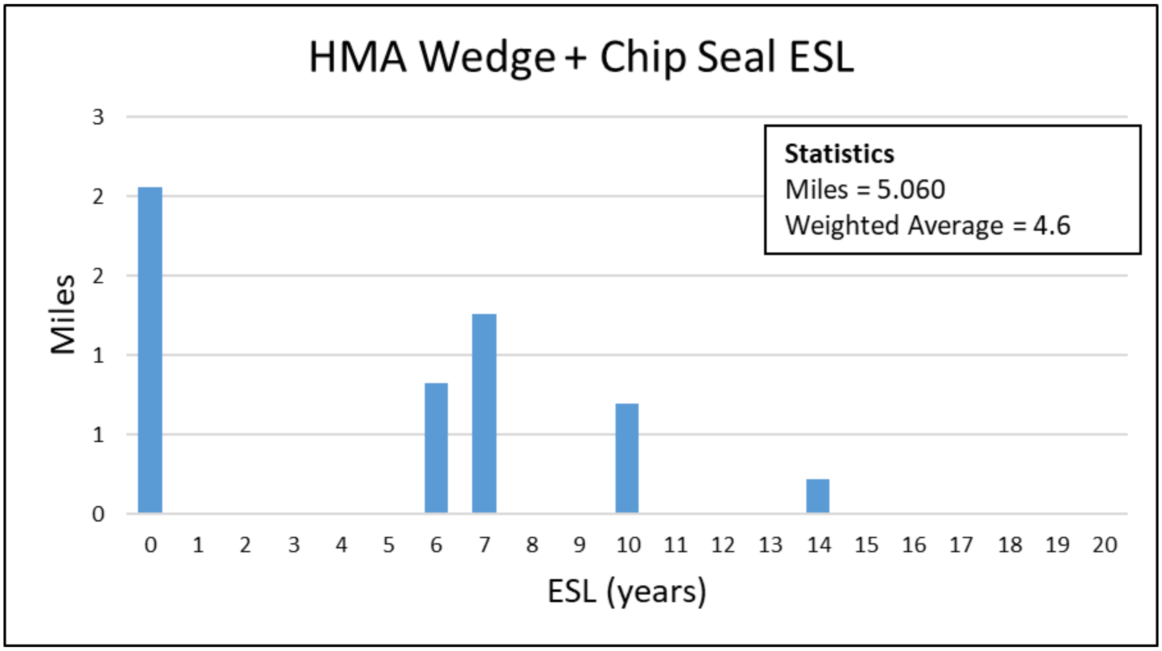

Figure 28: HMA wedge plus chip seal qualifying miles distribution by ESL

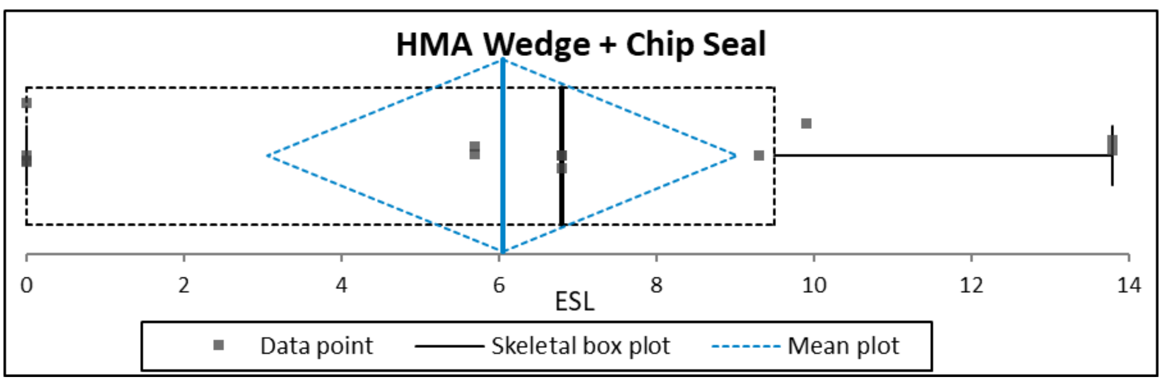

Figure 29: HMA wedge plus chip seal non-weighted average ESL segment distribution

5.12 Hot-mix-asphalt Wedge *Plus* Overlay

Hot-mix-asphalt (HMA) wedge plus overlay treatments meeting the data selection criteria totaled 25.003 miles (40.238 kilometers) (Figure 30). One agency indicated use of HMA wedge plus overlay; their total segment count was 58. The weighted average ESL for the limited data set was 5.7 years, however, this average ESL has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive. (Figure 31).

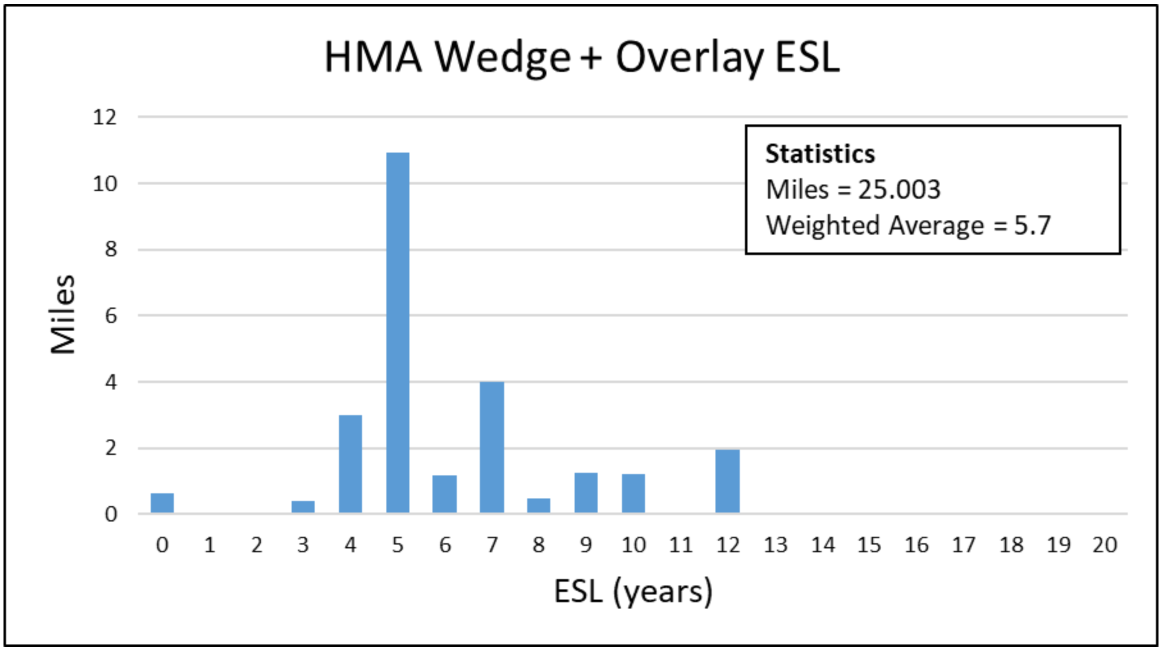

Figure 30: HMA wedge plus overlay qualifying miles distribution by ESL

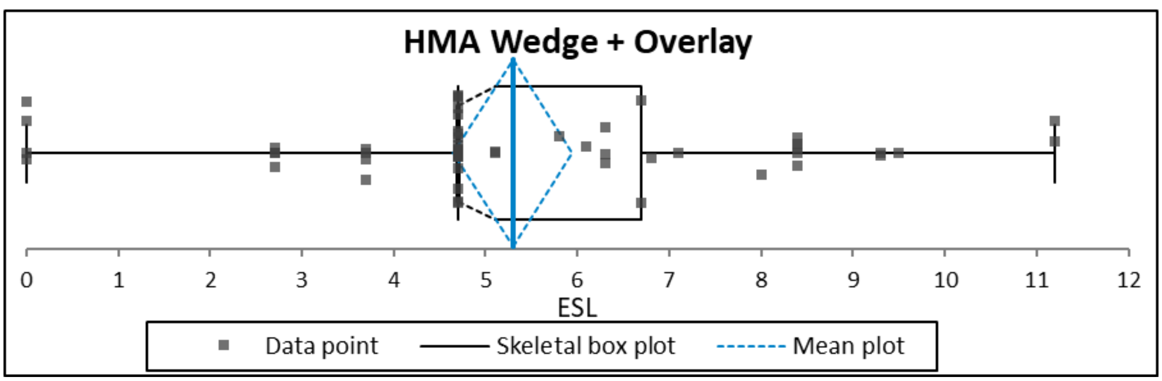

Figure 31: HMA wedge plus overlay non-weighted segment distribution

5.13 Thick Overlay

Thick overlay treatments meeting the data selection criteria totaled 301.760 miles (485.636 kilometers) (Figure 32). Twenty-five agencies indicated use of thick overlay; their total segment count was 1,584 (Figure 33). The weighted average ESL for the data set was 9.1 years. The thicknesses of the reported thick overlay treatments ranged from 1.75 to 5 inches (4.4 to 12.7 centimeters); a general trend showed an ESL gain as the thickness increased, which is what would be expected.

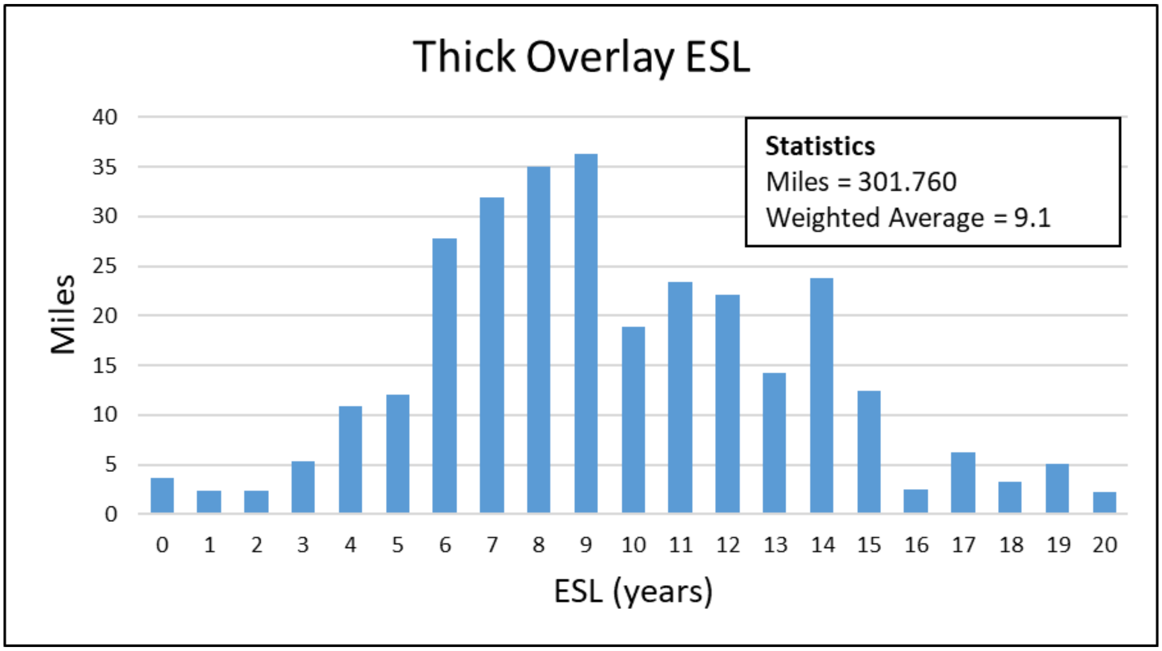

Figure 32: Thick overlay qualifying miles distribution by ESL

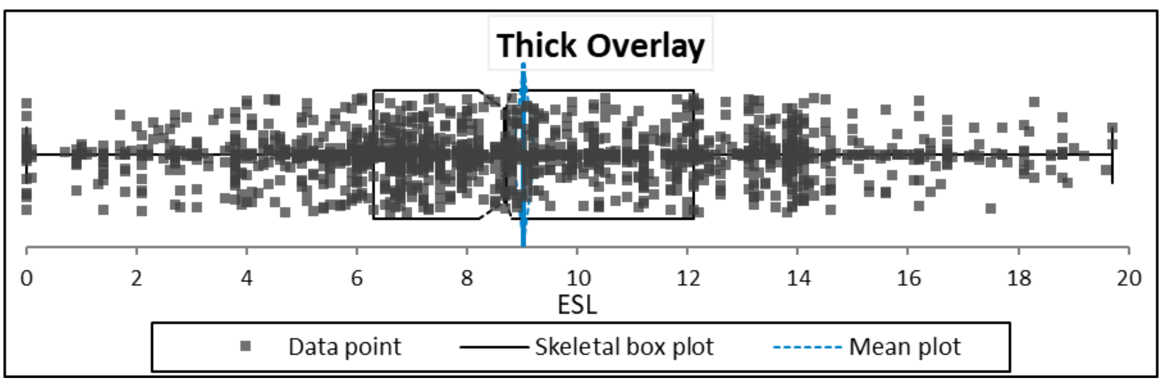

Figure 33: Thick overlay non-weighted average ESL segment distribution

5.14 Reconstruction

Reconstruction meeting the data selection criteria totaled 23.511 miles (37.837 kilometers) (Figure 34). Six agencies indicated use of reconstruction; their total segment count was 133. The HMA thickness layer of these reconstruction projects ranged from 1.5 to 3 inches (3.8 to 7.6 centimeters). This may help explain why the thicker HMA layers used in thick overlay treatments obtained a higher ESL value than the estimated service life of reconstruction. The estimated service life was used instead of extended service life because a reconstruction project creates a brand new pavement structure. The weighted average estimated service life for the limited data set was 9.9 years, however, this average has an unacceptable margin of error due to the small number of segments available for analysis making the results inconclusive (Figure 35). This data set included a large number of segments that were recently constructed, which limited the number of late age data points in this data group. As a result, the estimated service life calculated from this data is inconclusive.

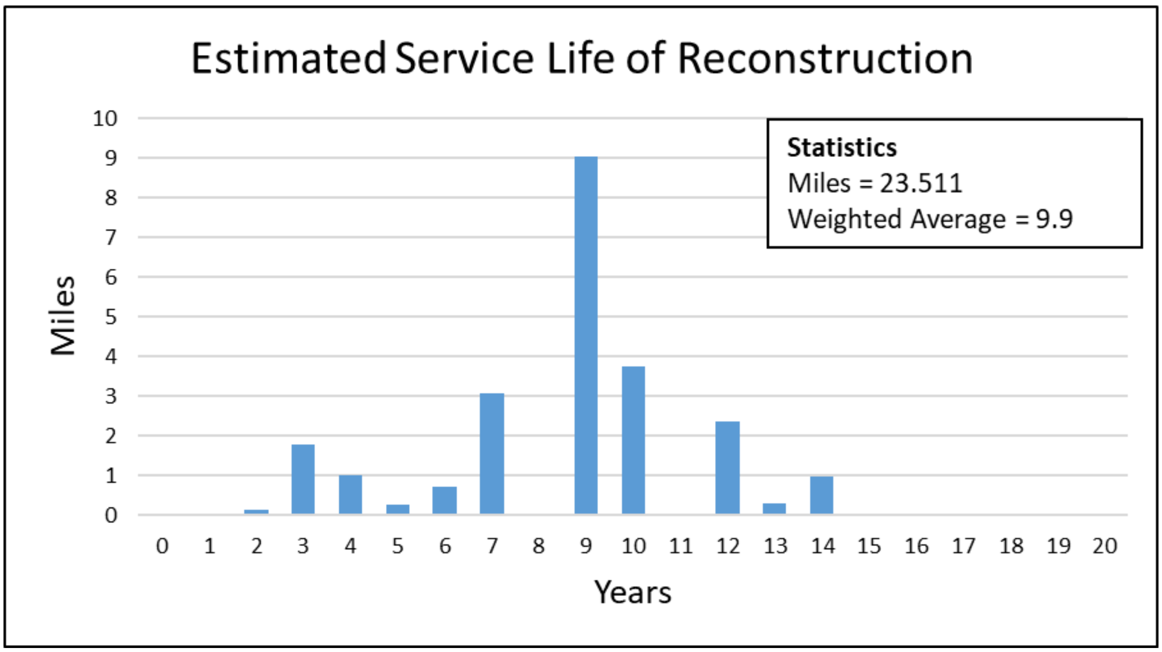

Figure 34: Reconstruction qualifying miles by estimated service life distribution

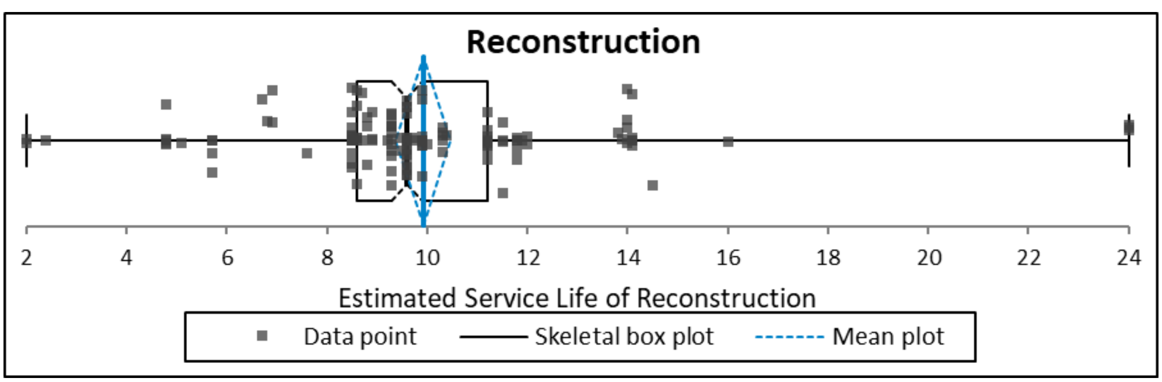

Figure 35: Reconstruction non-weighted average estimated service life segment distribution

5.15 Data Set Breakdowns for Analyses

Data sets were subdivided by different classification systems in order to analyze trends, identify and eliminate sampling biases, and compare and contrast the findings. Data sets were divided as follows:

5.15.1 By Legal System Classification

Examining the data based on the legal system classification aimed to facilitate analysis and to identify and eliminate sampling bias for differences in agencies' road classifications, which are maintained through agency-specific policies. The legal system classification breaks down the data set road miles (and segments) into county local, county primary, city major, city minor, and state trunkline. Federal-aid routes were isolated as a unique data set. In the Federal-aid-route dataset, (94.96%) were county primary. Table 4 summarizes mileage breakdown by legal classification and treatment class. There were too few miles (and segments) classified in the non-'county primary' categories to make determinations on differences for most of the treatment classes. The 1.444 miles (2.323 kilometers) marked as "State Trunkline" or "N/A" appeared to be mislabeled route(s).

Table 4: Mileage Breakdown by Legal Classification System and Treatment Class

Treatment Class	County Local	County Primary	City Major	City Minor	State Trunkline	N/A
Heavy CPM	4.824	1157.198	43.9	0.445	-	-
Rehabilitation	6.134	438.764	33.319	0.235	1.054	0.39
Reconstruction	-	15.241	8.27	-	-	-
Total	**10.958**	**1611.203**	**85.489**	**0.68**	**1.054**	**0.39**

5.15.2 By National Function Class

Examining the data based on national function class (NFC) aims to identify and eliminate sampling bias for differences in agencies' road classifications, which are maintained through agency-specific policies. The NFC breaks down the data set road miles (and segments) into major collector, minor arterial, minor collector, and principal arterial. Table 5 summarizes the mileage breakdown by NFC and treatment class. The 0.39 miles (0.628 kilometers) marked as "N/A" appeared to be mislabeled route(s).

Table 5: Mileage Breakdown by National Function Class and Treatment Class

Treatment Classification	Major Collector	Minor Arterial	Minor Collector	Principal Arterial	N/A
Heavy CPM	984.405	207.322	3.404	11.236	-
Rehabilitation	323.225	132.518	0.091	23.672	0.39
Reconstruction	11.732	10.709	-	1.07	-
Total	**1319.362**	**350.549**	**3.495**	**35.978**	**0.39**

When broken down by NFC, all of the treatment classes either showed no difference in ESL or had too few miles (and segments) to make determinations on differences for treatments with the exception of thick overlay treatment. For thick overlay treatment distributed by NFC, the classifications of major collector, minor arterial, and principal arterial had enough miles (and segments) to be considered statistically significant (Figure 36). The weighted average ESLs are 9.4 years for major collectors, 8.4 years for minor arterials, and 10.2 years for principal arterial. The principle arterial median data has a higher variability (Figure 36); therefore, this data set should be considered less reliable than major collector and minor arterial.

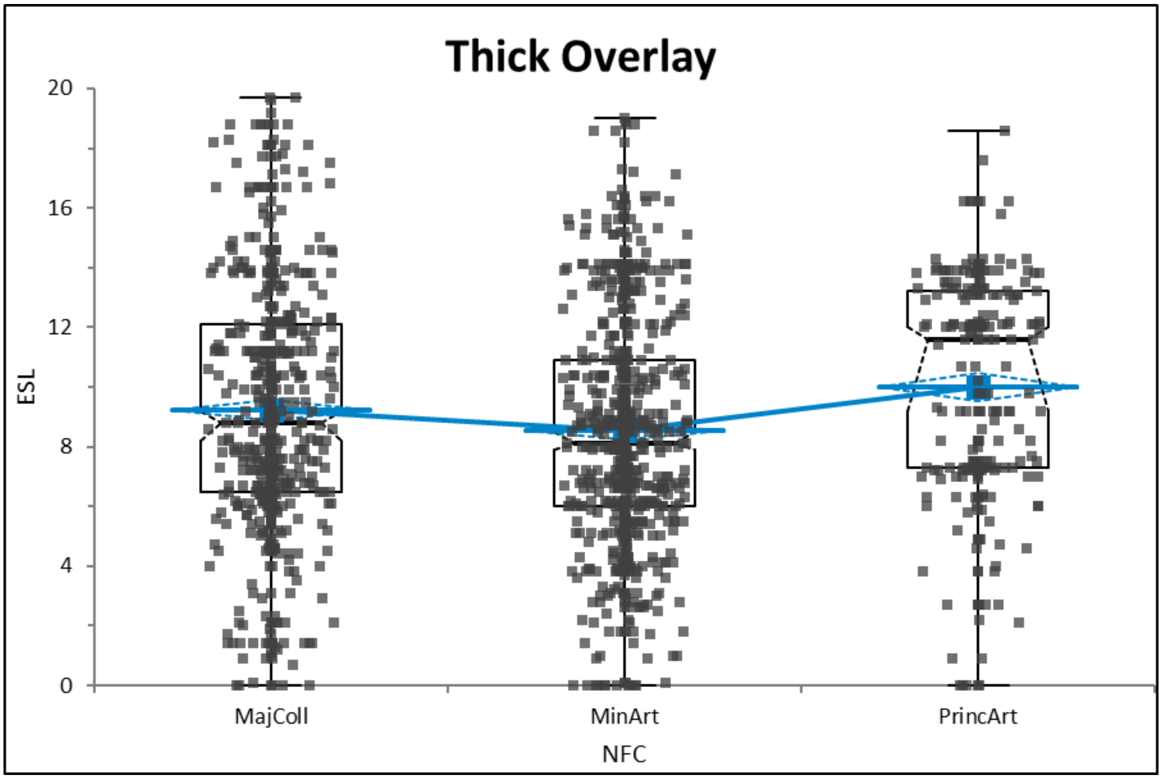

Figure 36: Thick overlay segment distribution by National Function Class

5.15.3 By Number of Lanes

Examining the data based on the segment's number of lanes enables analysis of how the ESL differs when lanes differ. Most of the road miles classified as two-lane; too few road miles classified in the other number-of-lane categories to compare treatments by number of lanes. Table 6 summarizes the mileage breakdown by number of lanes and treatment class. The 0.39 miles (0.628 kilometers) marked "N/A" appeared to be mislabeled route(s).

Table 6: Mileage Breakdown by Number of Lanes and Treatment Class

Treatment Classification	1	2	3	4	5	6	N/A
Heavy CPM	0.2	1143.059	25.013	19.139	18.956		
Rehabilitation	0.041	440.465	16.71	9.419	12.301	0.57	0.39
Reconstruction		19.54	2.249	0.363	1.359		
Total	**0.241**	**1603.064**	**43.972**	**28.921**	**32.616**	**0.57**	**0.39**

5.15.4 By Region

Examining the data based on regions aims to allow for analysis by similar traffic patterns, population density, and material and construction costs. The *2009 TAMC Local Agency Assessment of Average Cost Report* grouped areas of Michigan by region: northern region, southern region, population belt, and cities (their own separate region) (Figure 37).[14] Table 7 shows the mileage breakdown by treatment classification.

[14] From *Estimated Typical Costs for Reconstruction, Rehabilitation and Maintenance Treatments on Local Federal Aid Pavements in Michigan*, Colling, de Melo e Silva and McNinch, 2009.

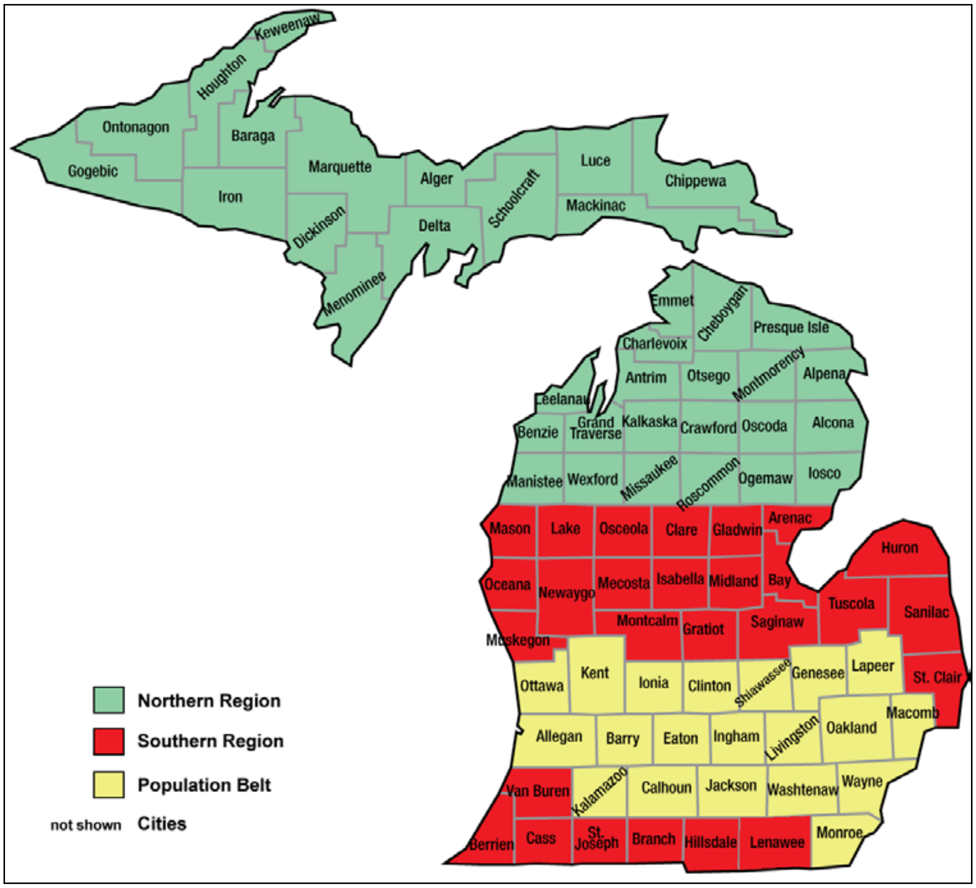

Figure 37: Region Breakdown Map

Table 7: Mileage Breakdown by Region and Treatment Class

Treatment Classification	City	Population Belt	Northern	Southern
Heavy CPM	41.942	133.192	451.857	579.376
Rehabilitation	37.961	66.453	186.573	188.909
Reconstruction	7.748	5.838	9.925	0.000
Total	**87.651**	**205.483**	**648.355**	**768.285**

When broken down by region, chip seal and thick overlay had enough data to show regional differences (Table 8 and Table 9); other repair treatments had too few miles (and segments) to make determinations about regional differences. The population belt and southern regions had enough chip seal and thick overlay miles (and segments) to identify significance (Figure 38 and Figure 39). Both regions' medians show a slight skew compared to the mean for both treatments.

The project team used student *t*-tests to determine whether the ESL results from each of these treatments are statistically discrete from each other. A finding of statistical significance means the variance in the data is minimal enough to detect the differences in central tendency between groups. These data sets exhibit statistical significance from each other; however, because other variables that influence the ESL (e.g., policies, soil type, annual snowfall) are not controlled by this study, the causality of this statistically significant difference cannot be determined. One variable—thickness of the HMA overlay for the thick overlay treatment—could be controlled; however, there were not enough segments to determine how thickness affects ESL although the general trend was that more ESL was obtained with thicker overlays.

Table 8: Mileage Breakdown of Chip Seal Treatment by Region

Agency Region	Agencies Using	Segment Count	Total Miles	Weighted Avg ESL
City	2	21	2.439	2.7
Northern	4	**173**	**78.687**	**5.3**
Population Belt	**7**	**989**	**290.923**	**4.5**
Southern	**8**	**1189**	**412.809**	**3.7**
Total	**21**	**2372**	**784.858**	

Table 9: Mileage Breakdown of Thick Overlay by Region

Agency Region	Agencies Using	Segment Count	Total Miles	Weighted Avg ESL
City	7	458	37.113	9.6
Northern	3	**148**	**56.403**	**10.3**
Population Belt	**6**	**568**	**99.133**	**9.2**
Southern	**9**	**410**	**109.111**	**8.2**
Total	**25**	**1584**	**301.760**	

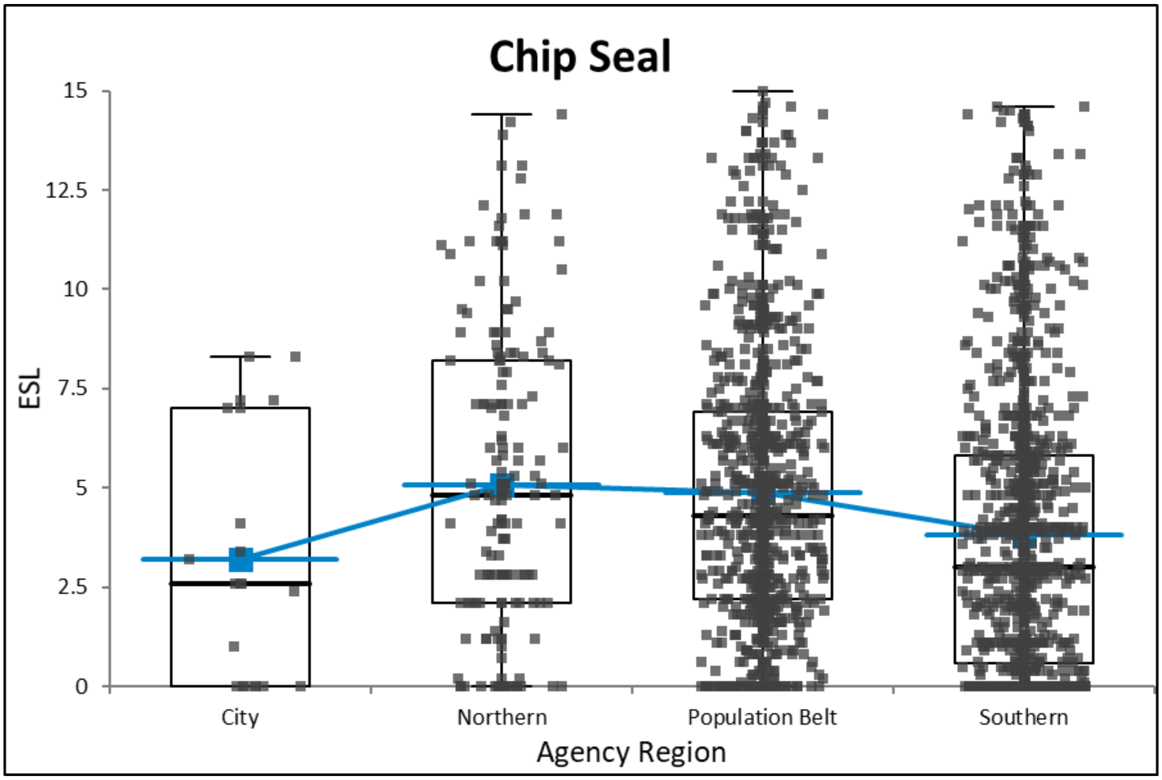

Figure 38: Chip seal non-weighted average ESL segment distribution by region

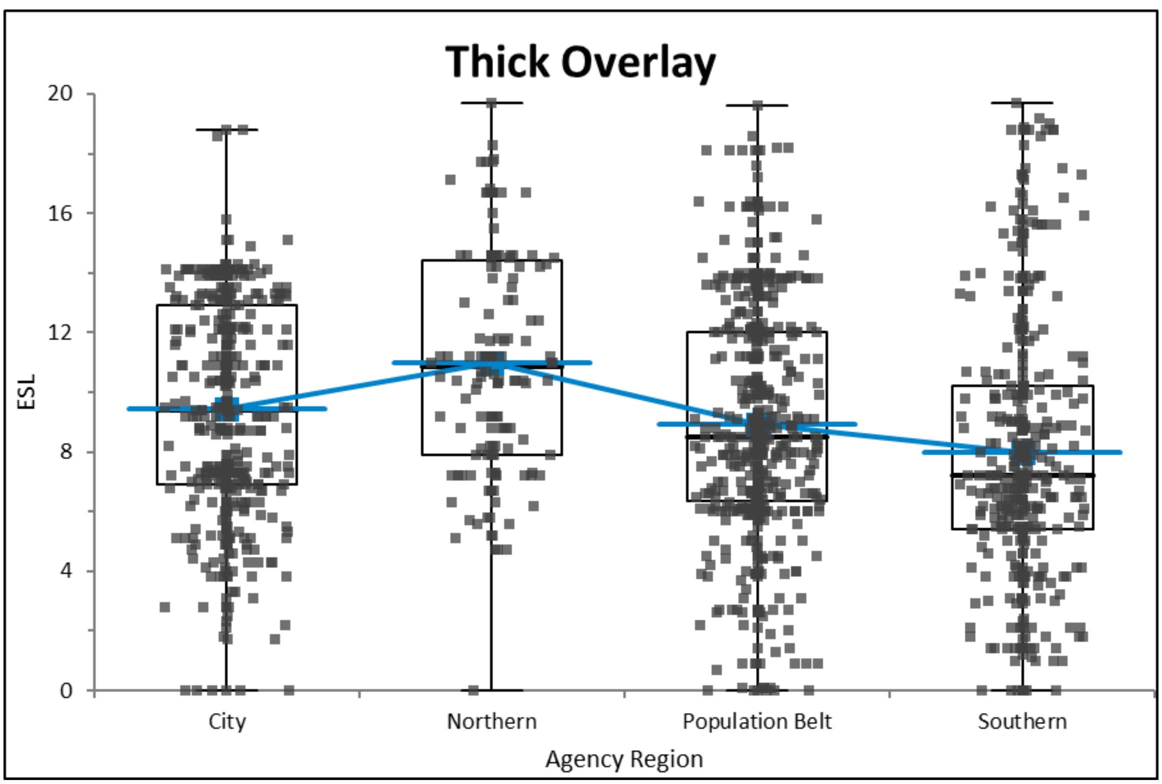

Figure 39: Thick overlay non-weighted average ESL segment distribution by region

5.16 Later-Life Chip Seal Treatments

Local agencies have long used chip seal treatments, which have a shorter service life than other common treatments (such as HMA overlays). This combination of widespread use and a short service life allows for analysis of successively-applied chip seal treatments.

The majority of this analysis looked at segments with no prior treatments. Table 10 shows a breakdown of a unique data set by zero to six prior chip seal treatments. The zero, one, and two prior chip seal treatments categories also had enough miles (and segments) to assess the statistical significance of their central tendency. Eight agencies had segments in each of these three categories (0, 1 and 2 prior treatment). The project team ran the student's *t*-test on these eight agencies' segment distribution; they determined that the central tendency of the data sets are statistically different from each other. The weighted average ESL for segments with one prior treatment decreased to 3.8 years from 4.1 years for segments with no prior treatments. A histogram distribution for segments with zero or one prior chip seal treatment shows a fairly-uniform decrease in frequency of segments achieving longer ESLs (Figure 40 and Figure 41). In contrast, the histogram distribution for segments with two prior chip seal treatments shows a less-uniform decrease in frequency of segments achieving longer ESLs, especially between eight and twelve years of ESL (Figure 42). The weighted average ESL for one prior chip seal treatment (3.8 years) was less than two prior chip seal treatments (4.5 years). This difference is mostly due to the fact that latter has fewer segments that generate low ESLs.

An increase in ESL with successive applications of treatment is unexpected if all things were equal for these two groups, however, it is likely that other factors are present such as more carefully selecting treatment locations.

Table 10: Treatment Breakdown of Prior Chip Seal Treatment(s) by Segment, Miles, and Weighted Average ESL

Prior Chip Seal Treatments	Number of Agencies	Segment Count	Total Miles	Weighted Avg ESL
0	**21**	**2372**	**784.858**	**4.1**
1	**15**	**1045**	**399.986**	**3.8**
2	**9**	**303**	**103.686**	**4.5**
3	5	59	20.599	5.3
4	2	5	2.433	4.9
6	1	1	0.509	3.8
Total	**21**	**3785**	**1312.071**	

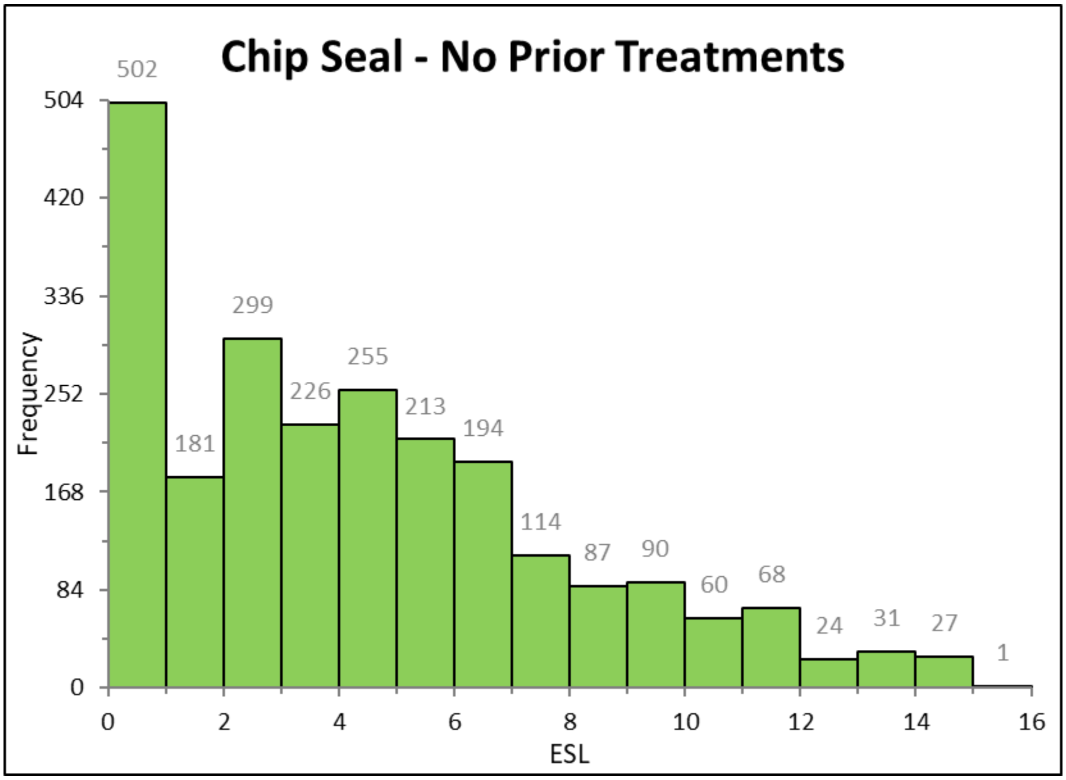

Figure 40: No prior chip seal treatment ESL segment count

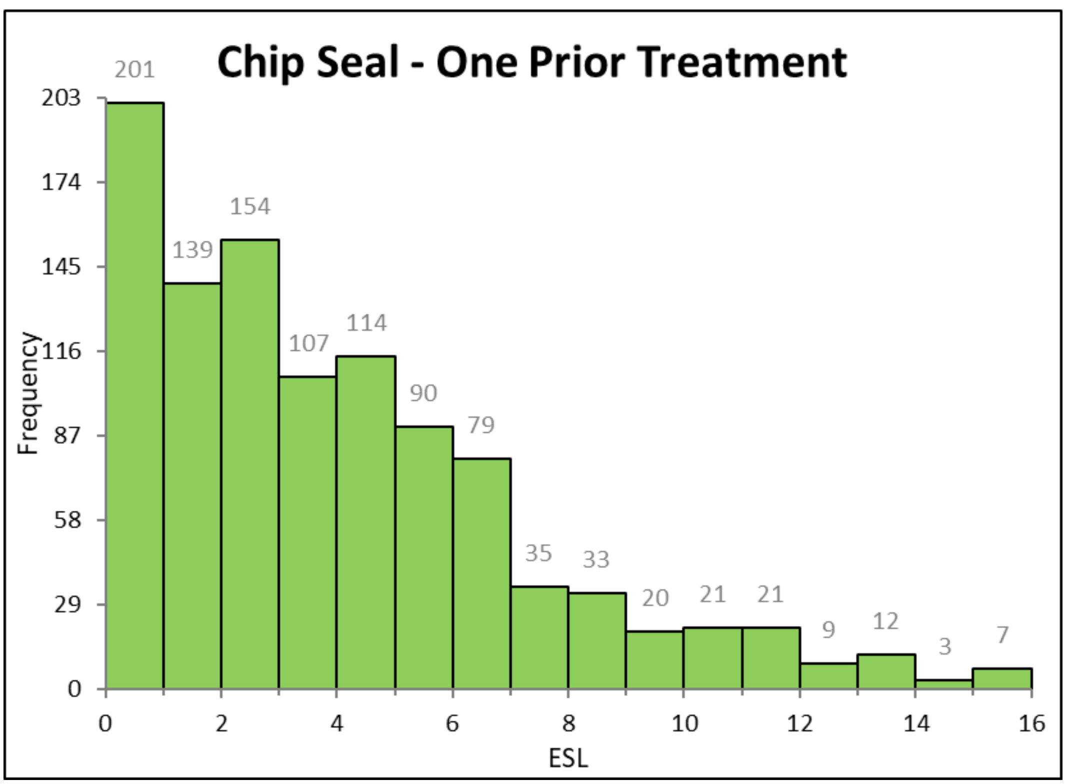

Figure 41: One prior chip seal treatment ESL segment count

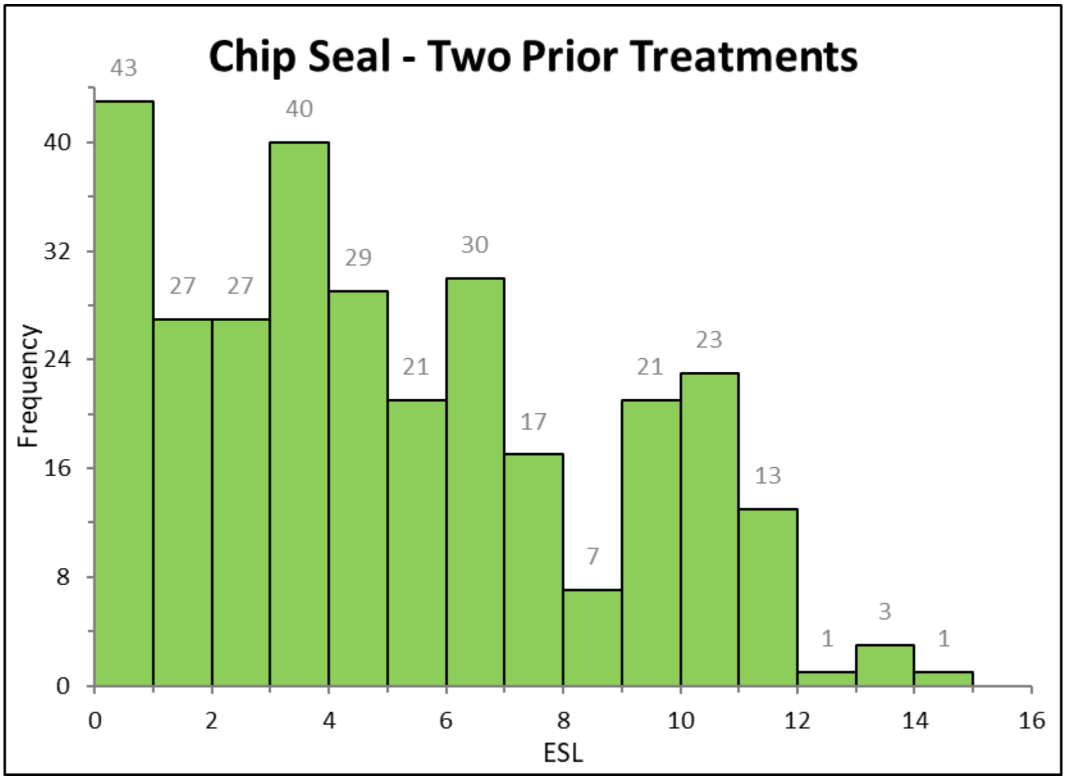

Figure 42: Two prior chip seal treatments ESL segment count

6 DISCUSSION TOPICS

6.1 Conservative Nature of the Study Results

The results from this study should be considered the minimum years of ESL gained by the analyzed treatment. The CTT made every reasonable effort to be conservative in the selection of roadway segments for analysis by using very stringent criteria. Decisions made during the study minimized software-related modeling effects unlike many contemporary studies that rely heavily on modeling repair treatments by aggregate data sets. Individual evaluation of pavement performance models further allowed for an assessment of the reasons for each segment's data fit, which is not possible in aggregate data modeling.

In many instances, the underlying pavement deterioration curves were well-defined by three rating points prior to and three rating points following the CDP (PASER 4 line). This eliminates the effect of modeling on the underlying pavement deterioration curves because the results rely on actual rather that hypothetical data. Similarly, the same practice applied to repair treatment curves, which relied on the presence of a PASER 4 or below score following treatment. The decision to use actual PASER 4—when available—as the ESL measure point also eliminated modeling bias.

Limiting segments with unusually high ESL to a maximum of 15 years ESL for heavy CPM and 20 years ESL for rehabilitation affected 162 heavy CPM segments and 180 rehabilitation segments. The weighted average ESL of these long-life treatments was 26.0 years for heavy CPM and 28.0 years for rehabilitation. Many of these cases were similar to the case shown in Figure 43 where the underlying pavement deterioration curve fit the data well and the repair treatment was clearly performing well according to performance data, however it had a large span of years between the last rating point and the CDP. In this case, it is clear that the repair treatment provided a benefit although the project team believes that additional data points in future years may drastically change the anticipated CDP projection of the model. Limiting the 162 heavy CPM segments to 15 years ESL and the 180 rehabilitation segments to 20 years ESL reduced the statewide weighted average by 0.89 and 1.31 years, respectively. A Minnesota study suggest that 12 or 15 years of ESL is possible for chip seals on properly selected projects, which was the basis for selecting 15 years as the maximum ESL[15]. Rehabilitated pavements would not be expected to last longer than 20 years for a statewide observation.

[15] From: *Rebirth of Chip Sealing in Minnesota*, Wood, Thomas J., Olson, Roger C., 1989: Transportation Research Board.

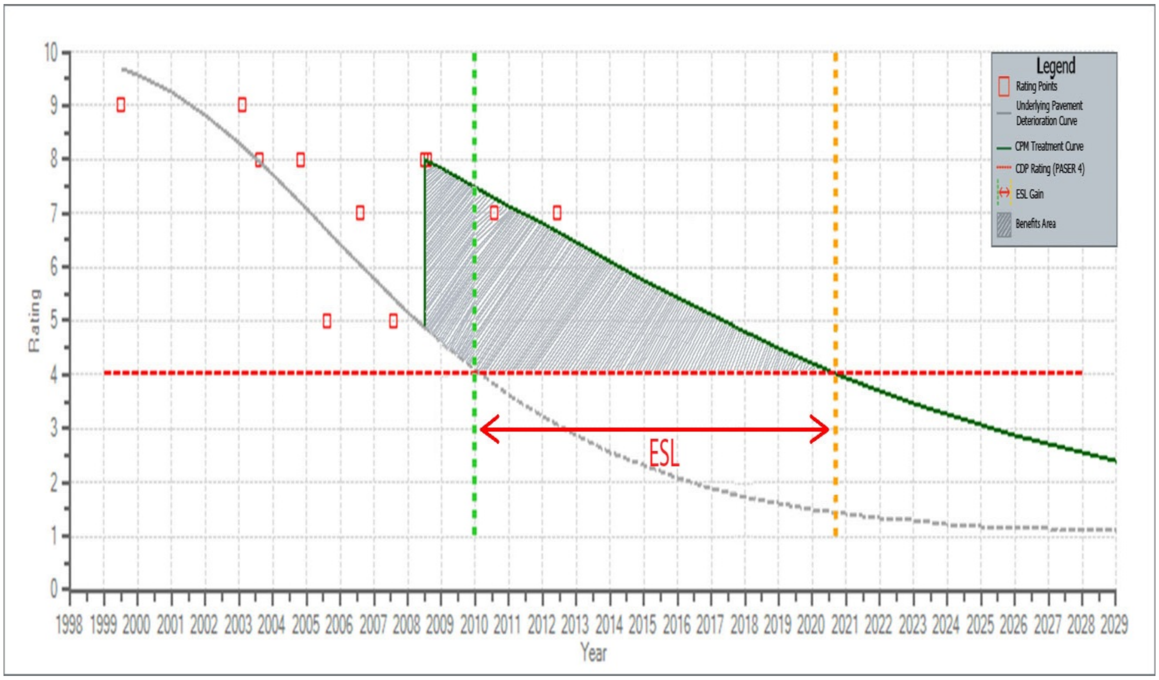

Figure 43: Example of High ESL

6.1.1 Factors Impacting the Effectiveness of Repair Treatments

The effectiveness of any repair treatment depends upon many factors, most of which are difficult to isolate and are highly variable when comparing multiple projects. In general, however, these factors include materials, construction methods, time of application, environmental conditions, and traffic volume. Each of these factors has many sub-variables. For example, the life of a chip seal can be impacted by construction-related variables, such as[16]:

- Cleanliness of the underlying pavement
- Sweeping and removal of excess stone cover chips
- Number of roller passes used before emulsion breaks
- Temperature of the pavement when the chip seal is applied
- Volume of excess chips placed; excessive aggregate or float
- Weather conditions, moisture, high humidity, temperature
- Proximity of asphalt distributor, chip spreader, and roller
- Equipment calibration.

Construction of the underlying asphalt pavement structure can differ greatly from agency to agency and even between segments of roads within an agency. Repair treatments rely on the underlying pavement structure as some treatments, such as CPM treatments, themselves provide little or no structural benefit. If pavement deterioration is driven by structural distresses, then CPM repair treatments will likely provide little or no ESL although other

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[16] From *Minnesota Seat Coat Handbook,* Minnesota Department of Transportation, 2006. Available at: http://www.lrrb.org/media/reports/200634.pdf

benefits may result. Pavements that have sufficient structure but are deteriorating due to age-related distresses provide the best base for realizing ESL gains when using CPM treatments. All of these variables result in large variances in ESL gain from project to project.

6.1.2 Low to Zero ESL Gain

The study identified approximately 142 miles (229 kilometers) of treated segments that did not produce a benefit in terms of ESL gain. After application of treatments, condition ratings initially jumped but quickly returned to the underlying pavement's deterioration pattern, thus producing no change in the pavement's predicted intersection with the CDP. Figure 44 illustrates an example of this type of behavior. Repair treatments and even structural improvements that provide no ESL have been observed by many other researchers. Weh-Hou Kuo outlined this behavior for structural overlays in Pavement Performance Models for Pavement Management Systems (MDOT unpublished report, 1995). Low-life extensions after a repair treatment can result from several factors related to either the underlying pavement or the treatment itself.

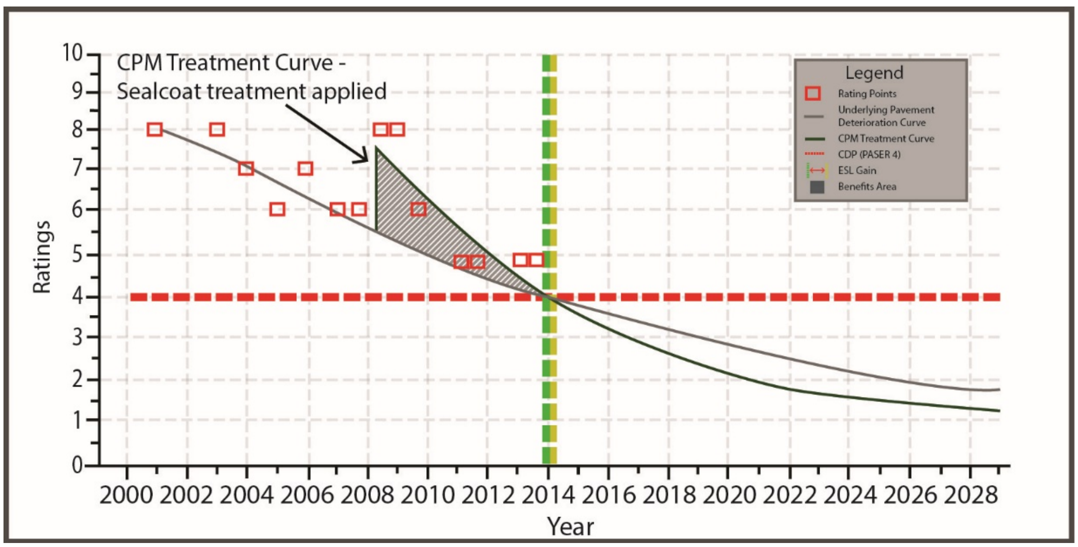

Figure 44: Example of Zero ESL Gain

Repair treatments that are poorly placed with low-quality materials may fail early and constitute a portion of these low or zero ESL cases. Pavements that are deteriorating because of load-related distresses likely comprise a number of these zero ESL cases since repair treatments cannot fix or slow down structural distresses. It is beyond the scope of this study to identify the causes of low or zero ESL cases.

7 CONCLUSIONS AND RECOMMENDATIONS

Data from this study indicated that local agencies were receiving an additional 3 years of ESL by applying fog seal in combination with a chip seal. Chip seal, chip seal plus fog seal, thin overlay, crush and shape, and thick overlay had enough data to deem the ESL findings as significant (Table 11). Also, an ESL decrease of 0.3 years occurs when a chip seal treatment is applied to a pavement with one existing chip seal treatment.

Table 11: Significant ESL Findings

Treatment	Weighted Avg ESL
Heavy CPM	
Chip seal	**4.1**
Chip seal plus fog seal	**7.1**
Thin overlay	**6.9**
Rehabilitation	
Crush and shape	**11.3**
Thick overlay	**9.1**

This study determined that Michigan local agencies are using a wide number of preventive maintenance treatments, and are obtaining ESL gain similar to that of other states.

The seven agencies whose data was not used for this study had submitted a significant amount of data and, after review, it was obvious that they were using asset management principles in their repair treatments. However, these agencies did not have road segments meeting this particular study's rigorous selection criteria.

7.1 Recommendations for Further Research

This study showed that high-quality ESL analyses are possible with the data collected by local agencies on a routine basis. This study also suggests that local agencies have the tools necessary to complete these analyses. The project team therefore recommends the following:

1. The TAMC should consider repeating this study in four to six years when more high-quality data will be available; this will yield a larger data set to analyze.
2. Future research should build upon these findings in order to determine why low or zero ESL gains exist.
3. The TAMC should continue to support and encourage local agencies to collect and evaluate data using pavement management systems, such as Roadsoft, in order to make high-quality ESL analyses easily accomplishable.
4. The TAMC should support agencies in their routine assessment of ESL treatments that they use.