A PERFORMANCE EVALUATION OF HOT MIX ASPHALT THIN LIFT TREATMENTS

by

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ABSTRACT

When applied at the right time, Hot Mix Asphalt (HMA) Thin Lift Treatments (TLTs) extend the life of flexible pavements. Correct application depends largely upon pavement condition and rate of deterioration. State Highway Agencies (SHAs) utilize an Open Grade Surface Course (OGSC), Dense Grade Asphalt (DGA), and Stone Matrix Asphalt (SMA) for TLTs. No criteria currently exist to select the best performing mix for factors such as traffic, climate, previous road conditions, and prior treatment methods. Additionally, TLT performance is largely dependent upon local climate conditions and individual state Pavement Management Systems (PMSs). Thus, performance evaluation needs to be done at the local level.

This study assessed the early performance of TLTs in Utah by measuring surface cracking within the first two years of service life. This study evaluated 14 TLTs, consisting of eight OGSC, four DGA, and two SMA mixes. Pavement Condition Indices (PCIs), deterioration rate, failure thresholds, and expected design lives identified five early failures. Four of five of these failures resulted from cold temperature thermal cracking. A comparison made from local TLTs to national TLTs, monitored through the Federal Highway Administration's (FHWA) Long Term Pavement Project, showed a much higher failure rate for the nationally treated roads of 87% to 36%. Cold-temperature related cracking was the predominant early distress type found, both locally and nationally.

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1 INTRODUCTION

The traveling public demands a smooth and safe riding experience. A functional road network promotes economic opportunity and improves quality of life. It is well known, however, that pavements deteriorate and are often in need of routine maintenance and repairs. To maintain quality road surfaces, each year, the Utah Department of Transportation (UDOT) spends over $20M in maintenance alone. A slight improvement in pavement performance can result in substantial savings for a state highway agency (SHA). A significant portion of this maintenance consists of surface treatments. UDOT applies surface treatments, also known as preservation treatments, as a preventative measure to retard structural deterioration and prolong the lifespan of an existing road.

The decision as to which maintenance treatment to apply is made by SHAs which utilize a system commonly known as a Pavement Management System (PMS). The ultimate goal of any PMS is to maximize pavement life while minimizing cost. To do this, pavement condition data are collected and processed through a PMS. Once the data are in the database, forecasting techniques are then used to estimate the remaining life of a pavement. Maintenance decisions are based on these forecasts. Figure 1 shows a pavement condition curve and three types of maintenance activities: routine, preservation, and rehabilitation (Galehouse et al. 2003). However, due to the nonlinear relation between pavement age, condition, and maintenance cost, it is not always clear as to which maintenance activity is the most cost effective. These maintenance activities provide different functions, increasing in cost as pavement condition deteriorates.

UDOT incorporates routine maintenance into the operational and maintenance cost of a pavement during its initial construction. It consists of actions such as pothole filling and crack sealing. These actions are necessary in order for a pavement to reach its design life. Preservation maintenance, performed on pavements in good to fair conditions, maintains or improves that pavement to a good or new condition and extends the lifespan of the pavement. For flexible pavements, this consists of a bituminous layer applied to the surface of the pavement to prevent water ingress and structural deterioration. Rehabilitation maintenance is used when a pavement condition deteriorates rapidly and is indicative of structural failure. Rehabilitation applies to the base layers of a pavement and may involve increasing pavement thickness to correct structural deficiencies.

The most cost-effective maintenance treatment type during a pavement's life at times is uncertain. Delaying maintenance for rehabilitation can increase cost by as much as seven times compared to preservation. Furthermore, applying preservation treatment too soon does not provide a benefit that is worth the cost of a preservation treatment (Morian et al. 1998). Additionally, electing for preservation when rehabilitation is needed will result in rapid deterioration and a "backlog of pavements in need of repair" (Baladi and Novak 1992). Therefore, it is important to understand, within the PMS, where the thresholds are so a pavement engineer may apply the most appropriate treatment at the right time.

Preservation treatments, when applied correctly, extend pavement life with minimal costs. Common preservation treatments for asphalt pavements include chip seals, slurry seals, and thin lift overlays or treatments. Thin lifts treatments (TLTs) are more robust than the other preservation treatments but they are more effective across a wider range of climate and distress conditions. However, they are also more expensive. TLTs are thicker than other surface treatments and thus require more material. TLTs are an important tool within the maintenance preservation toolbox. TLTs are hot mix asphalt (HMA) surface mixtures and are at most one and a half inches thick. They are comprised of either an Open Grade Surface Course (OGSC), Dense Grade Asphalt (DGA), or Stone Matrix Asphalt (SMA) mix. The decision as to which maintenance treatment to apply will depend upon many factors including: pavement age, traffic volume, climate, road thickness, construction quality, past maintenance, and budget (Al-Mansour et al. 1994).

1.1 Problem Statement

Thin lift treatments (TLTs) are preservation treatments known to increase the lifetime of a pavement; however, the lifetime performance of TLTs is not well understood for various traffic and climate conditions amongst the different types. A previous study, part of the Long Term Pavement Project (Experiment SPS-3), looked only at the performance for one mixture type, Dense Graded Asphalt (DGA). Additionally, this study was on mixes designed with the Marshal Design method and not the current Superpave method. The Superpave Design Method takes into account traffic loading and climate conditions in the design and binder selection of a pavement, increasing pavement performance. Thus, studies looking at the performance of mixtures constructed with the Marshal Design do not reflect current performance standards. Quantifying the performance between the three different mixture types, DGA, OGSC, and SMA, with current design methods is needed to accurately determine design lives.

In order to gather such data, an evaluation method needs to be selected. Choosing this method requires a literature review and a data collection model to measure performance. Additionally, the literature review identified expected design lives and failures thresholds. This study is to pose as an example for further research studies to evaluate asphalt surface treatments, which will lead to selecting the most beneficial surface treatment for given conditions.

1.2 Objectives

The objectives of this study are to:

- *select a surface treatment performance assessment method to evaluate the surface condition which includes pretreatment condition and deterioration rate in order to evaluate the short-term performance of asphalt surface treatments;*
- *evaluate the performance of three types of TLTs: OGSC, HMA, and SMA; and*
- *identify early failures amongst these treatments types.*

1.3 Scope

Fourteen TLTs applied on state routes in UDOTS Region II area were evaluated. They were an Open Grade Surface Course (OGSC), Dense Graded Asphalt (DGA), and Stone Matrix Asphalt (SMA). Of the 14 TLTs evaluated, eight were OGSC, four DGA, and two SMA. Out of the 14, 12 were constructed in 2012 and the other two in 2013. They were evaluated two to three years after construction. Pre treatment condition was also evaluated. Although the sample population is limited, it provides a general idea on performance between the treatment types. Additionally, any poor performing treatments within this time are easily identifiable as early failures.

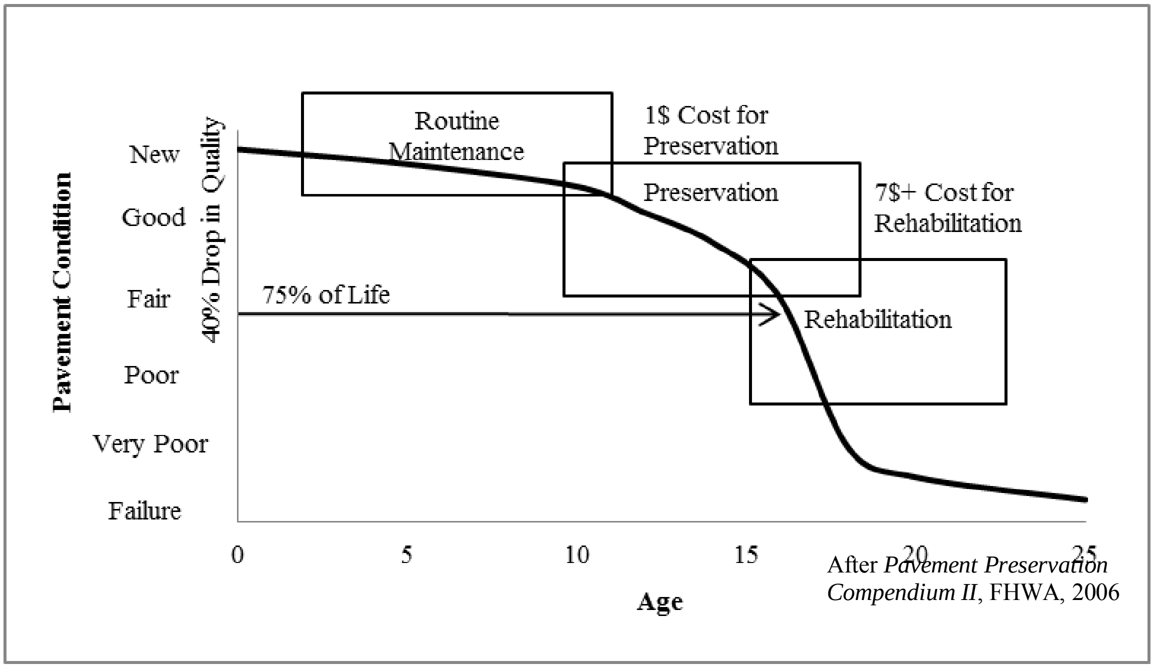

Figure 1. Pavement condition curve.

2 LITERATURE REVIEW

2.1 Data Collection

Pavement condition surveys provide necessary data for pavement performance and analysis. Data are used to forecast pavement performance, anticipate maintenance needs, establish maintenance priorities, and allocate funding. Pavement condition data come from two main types of collection methods: manual and automatic (Timm and McQueen 2004).

A human walking along a paved section visualizing, identifying, and assessing pavement distresses is manual data collection. This is known as a pavement survey. Alternatively, a vehicle mounted with imaging software driving down the road is automatic data collection. The technology on these vehicles includes global positioning systems (GPS), sensory lasers to measure transverse and longitudinal profiles, and high resolution cameras. Data are captured with the vehicle moving at or near traffic speed (McGhee 2004). Manual data were measured and assessed onsite. A human who reviews footage or a software program assesses automatic data.

Pavement performance measurement originated from the AASHO road tests in the early 1960s. The first metric was the Present Serviceability Rating (PSR). The PSR uses a panel of judges to rate their ride on a pavement between a score of 0-5. This rating score was subjective and costly. This subjective scoring of pavement condition through the PSR was replaced by the Pavement Serviceability Index (PSI), which uses numerical values based on observed and measurable distresses. The PSI equation for flexible pavements is

(Carey Jr and Irick 1960)

$$PSI = 5.03 - 1.91\log(1 + SV) - 1.398RD^2 - 0.01\sqrt{C + P} \qquad \text{Eq (1)}$$

where, SV is the mean of the slope variance in the two wheel paths, C and P are measures of cracking and patching in ft^2 per 1000 ft^2 of pavement, and RD is the average rut depth (in.).

Modern pavement condition data mostly consist of the International Roughness Index (IRI), rutting, faulting, and surface distresses. Surface distresses include cracking, patching, bleeding, and raveling. Automatic or manual data collection records the extent and severity of surface distresses to quantify pavement condition. An initial pavement condition score is reduced by deduct values. Deduct values are assigned to distresses based on extent, severity, and type. Using a Pavement Condition Index (PCIs), as developed by the U.S. Army Corps of Engineers, a pavement's initial score of 100 represents a pavement in perfect condition. PCIs may measure distress of certain types or combined to represent an overall pavement condition, an example includes climate and loading related distresses. PCIs are then used with forecasting techniques which incorporate the rate of deterioration to predict pavement performance and plan maintenance activities (Shahin and Kohn 1981).

2.2 Data Forecasting

Prediction models use PCIs, deterioration rate, and a predetermined threshold to estimate remaining service life. This study considered two prediction models, the "Shahin" and the "Baladi" methods. Both of these methods use a PCI as developed by the U.S. Army Core of Engineers. The Shahin method groups distress data through deduct values into one combined PCI (Shahin 2005). The deduct values are based on a database from 18 civilian agencies and two military installations. Baladi, on the other hand, separates distress data according to type and assigns PCIs to represent these distresses: for example, rut index, roughness index, and a surface distress index. The Baladi method allows a state highway agency (SHA) to determine deduct values based on their individualized Pavement Management Strategies (PMS) and experience (Baladi and Novak 1992). The separation of PCIs to represent different distress types provides insight into failure mechanisms. This study used the Baladi method to predict pavement performance as is utilized by UDOT.

Pavement performance is dependent upon many factors and affects the reliability of forecasting techniques. Variables that affect pavement performance can be separated into four main categories: loading, environmental, construction, and materials. Loading variables include wheel loading, load distribution, loading area, number of wheels and axles, and speed. Environmental factors affecting performance include temperature, moisture, and seasonal freeze thaw patterns. Construction factors include layer thickness and variability, level of compaction, and residual compaction stresses. Variance in materials affects performance through binder selection, aggregate source, and binder/aggregate adhesion affinity (Lytton et al. 1993). Furthermore, accurate pavement forecasting is dependent upon pavement condition score variability, data collection frequency, pavement age, and the forecasting method (Haider et al. 2010).

Through the Baladi method, SHAs measure pavement performance by selecting threshold values or Maximum Allowable Extents (MAEs) for distress types. MAEs vary per distress type. Deduct values are subtracted from a PCI. Within UDOT's PMS, a PCI of 100 represents a pavement in perfect condition and PCI value of 50 represents a pavement considered unacceptable or failed.

Distress extents at or exceeding the MAE represent a pavement in an unacceptable or failure condition. Thus, deduct values for distresses measured at the MAE must result in a PCI score of 50. For instance, the MAE for low severity longitudinal non wheel path (L-LNWP) cracking is 100%. Meaning that for a 500 feet section, 100% extent would be a L-LNWP crack 500 feet in length. The deduct value would then be 0.5 (L-LNWP) resulting in a PCI score of 50. Similarly, for medium severity longitudinal wheel path (M-LNWP) cracking, the MAE is 75% and the deduct value would be 50*M-LNWP/75. For high severity longitudinal non wheel path (H-LNWP) cracking, the MAE is 50% and the deduct value is 50*H-LNWP/50. Deduct values for distress types and severities are cumulative. Thus, a PCI may score well below the acceptable threshold value of 50 for a severely distressed pavement. The deduct value for longitudinal non wheel path (LNWP) cracking alone is (UDOT 2009A)

$$Deduct\ Value\ (LNWP) = 100 - \left(HLNWP + \frac{2}{3} * MLNWP + \frac{1}{2} LLNWP\right) \text{........Eq (2)}$$

Distress data and MAEs for a 528 feet long sample section are shown in Table 1. The MAEs are determined from threshold percentages of the surveyed area. Deduct values for bleeding and raveling are not shown. UDOT incorporates these distresses into a roughness index as measured by the International Roughness Index (IRI) for which data were not available in this study. Potholes are not assigned a deduct value as UDOT's PMS strategy is to fix these when they occur (UDOT 2009B).

2.2.1 Wheel Path (WP) Cracking

WP cracking is also known as alligator cracking or fatigue cracking. Threshold values consider a sample area of one and a half feet wide area in both wheel paths in a 528 feet long sample section for a total of 1,584 square feet per sample section. The MAEs for low, medium, and high severity respectively are 40%, 20%, and 10% of the total area. Low severity WP cracks are longitudinal cracks in the wheel path with few secondary cracks. Medium severity has interconnected cracks resembling the alligator cracking. High severity is interconnected cracks with moderate to high severity spalling between them. WP cracking is primarily considered load related (Miller and Bellinger 2014; UDOT 2009A).

2.2.2 Transverse Cracking

Transverse cracks are cracks whose predominate length is perpendicular to the longitudinal direction of the pavement. Transverse cracks are counted to determining deduct values. MAE (100%) for low severity cracking is one for every 10 feet or 53 cracks for a 528 feet section. Medium severity and high severity are 75% and 50% of the surveyed section, respectively. Low severity cracks are cracks less than a quarter of an inch thick, medium are between one quarter and three quarters of an inch, and high are greater than three quarters of an inch thick. Transverse cracks primary formation mechanism is climate, specifically low temperatures (Miller and Bellinger 2014; UDOT 2009A).

2.2.3 Longitudinal Cracking

Longitudinal cracks are cracks that run parallel to the direction of the pavement. Longitudinal non wheel path (LNWP) cracks mostly occur on joints and are considered environment-related distresses. The linear lengths of LNWP cracks are measured to determine extent. Maximum extent for LNWP cracks is 100% of the length of the sample unit. Medium and high severity MAEs are 75% and 50%. Longitudinal wheelpath (LWP) cracks are counted as low severity WP cracks. Severity levels are determined by the same width as are transverse cracks and block cracks (Miller and Bellinger 2014; UDOT 2009A).

2.2.4 Block Cracking

Block cracking divides the pavement into small rectangular pieces up to a 10 feet by 10 feet area. The longitudinal length of the section is recorded with maximum extent being 100% of the entire sample unit. Medium and high severity levels are 75% and 50%. Severity levels are the same as they are for transverse and longitudinal cracks (Miller and Bellinger 2014; UDOT 2009A).

2.2.5 Bleeding

Segregated binder on the pavement surface is bleeding. It may be a result of excessive binder in the mix or segregation during construction. Some bleeding is expected and normal with surface layer thin lifts. It is noticeable through dark discolorations on the mat. Low severity bleeding shows obvious discoloration on the mat. In medium severity bleeding, excess or accumulated binder on the surface is noticeable. High severity bleeding is a shiny surface with tire marks indicative of binder transfer to vehicle tires (Miller and Bellinger 2014; UDOT 2009A).

2.2.6 Raveling

Raveling results from weathering causing wearing and disintegration of the pavement surface. Low severity is a noticeable loss of binder or aggregate. Medium severity includes a rough or depressed surface. High severity is when the loss of binder and/or aggregate is obvious and accompanied with a rough surface texture. Raveling is considered climate related (Miller and Bellinger 2014; UDOT 2009A).

2.2.7 Potholes

Potholes are measurements and reported by their diameter. No severity level is recorded. UDOT's policy with potholes is to treat them as they are found. Thus, their severity level affecting road condition is not accounted for as treatment will occur as soon as they are discovered (Miller and Bellinger 2014; UDOT 2009A).

2.2.8 Environmental (ENV) Index

The ENV index measures transverse, block, and longitudinal non wheel path (LNWP) cracking. Transverse and block cracking are considering climate related while LNWP is considered construction. Climate-induced distresses result from the time temperature-dependent behavior properties of asphalt. At lower temperatures, the ability for asphalt to dissipate stresses lessens. The material hardens and becomes susceptible to cracking. Cold temperature performance is accounted for in the Superpave performance grade (PG) specifications. AASHTO standard M320, *Performance Graded Asphalt Binder*, gives criteria in selecting binders with appropriate PGs for regional temperatures. However, it does not consider mixture properties and the inclusion of Recycled Asphalt Product (RAP) (Ho and Romero 2012).

Construction-related distresses are seen in LNWP cracks on asphalt pavement joints. They are a result of low compaction during construction. Additional environment-related distresses include raveling. Raveling is the weathering of asphalt concrete that results in a loss of bond strength and separation between the asphalt and the aggregate. While raveling was recorded, it was not considered in scoring the climate condition index. The calculation for the Environmental Index is as follows (UDOT 2009A):

$ENV = 100 - ((50/52.8) * Low\ Trans + (50/39.6) * Med\ Trans + (50/26.4) * High\ Trans + 50(528) * Low\ Long + (50/396) * Med\ Long + (50/264) * High\ Long + (50/528) * Low\ Block + (50/396) * Med\ Block + (50/264) * High\ Block)$ ....Eq (3)

2.2.9 Wheel Path (WP) Index

The WP index is a measurement of fatigue- and load-related distresses. It relates to the structural condition of the road. WP cracking is primarily caused by fatigue loading exceeding the flexural tensile strains limit of the bottom layer of the asphalt. The crack will then propagate to the surface. A pavement with a low WP index, or a recently treated pavement with a rapidly decreasing index, is indicative of a pavement in need of structural evaluation and rehabilitation. Poor drainage conditions may also cause a rapidly decreasing WP index (El-Korchi 2013).

Longitudinal wheel path (LWP) cracks were also counted as WP cracks and deduced from the WP index. LWP cracks are caused by the contact pressure from tire loading. This type of cracking is known as top down. This is opposed to the traditionally modeled fatigue cracking already mentioned. LWP cracks result from either high tensile or shear stresses (Myers et al. 1998; Su et al. 2008). The WP index calculation is given as (UDOT 2009A)

$WP = 100 - ((50/633.6) * Low\ WP + (50/316.8) * Med\ WP + (50/158.4) * High\ WP$ ....Eq (4)

2.3 Thin Lift Overlays

Thin lift overlays are hot mix asphalt (HMA) products that are typically one inch thick. Thin lift overlays, or thin lift treatments (TLTs), are a preservation maintenance measure that is well accepted by the pavement community to increase the lifespan of pavements (Morian et al. 1998). UDOT utilizes three mix designs in their TLTs: Open Grade Surface Course (OGSC), Dense Grade Asphalt (DGA), and Stone Matrix Asphalt (SMA).

2.3.1 OGSC

OGSC mixes differ from densely graded mixtures by decreasing the number of fines (passing No. 4 sieve) and increasing the course aggregate. The porous structure resulting from the course aggregate reduces water spray, decreases hydroplaning, reduces noise pollution, and improves wet surface friction. Richer binder quantity provides increased surface reflection, promoting safer nighttime travel and increased longevity. OGSC treatments are more expensive than DGA due to a higher binder content but cost less than SMA treatments due to less binder content and increased aggregate requirements. Performance issues include bleeding, raveling, and stripping in underlying asphalt layers. The porous structure may also become clogged by deicing salts and dust. The life expectancy of an OGSC pavement is between 8 and 12 years (Mallick et al. 2000; UDOT 2009C) .

2.3.2 DGA

DGA is the most common overlay. It is a densely graded mixture classified by the nominal aggregate size, half to three quarters of an inch. DGA overlays protect the pavement structure while adding some support. DGA surface treatment is the lower cost option when compared to SMA or OGSC. The expected performance of DGA thin lift overlays is 7 to 10 years (Irfan et al. 2009; UDOT 2009C).

2.3.3 SMA

Stone matrix asphalt is an open graded mixture with a coarse rock skeletal structure designed to maximize stone on stone contact to prevent rutting. Similar to OGSC, SMA has a higher binder content compared to densely graded asphalt in order to fill void space and increase service life. SMA mixtures may have a higher resistance to crack formation, rutting, and raveling. Performance issues with SMA mixes include “fat” spots which are areas of bleeding or splotches of shiny segregated binder resulting from high asphalt content. SMA is the most costly treatment type of the three treatments evaluated due to strict aggregate property requirements and high binder content. SMA is mostly used on high volume facilities. Life expectancy of a SMA is between 7 and 10 years (Brown et al. 1997; UDOT 2009C).

Table 1. Surface Cracking Maximum Allowable Extents for a 528 Feet Section

Distress	MAEs for Severity			Measurement	Possible Cause
	Low	Medium	High		
Wheel Path (WP) Cracking	634	317	158	Area (ft^2)	Load
Longitudinal Non Wheel Path (LNWP) Cracking	528	396	264	Linear (ft.)	Construction
Transverse Cracking	53	40	26	Count (#)	Climate
Block Cracking	528	396	264	Linear (ft.)	Climate

3 RESULT

3.1 Method

Performance of the Thin Lift Treatments (TLTs) was evaluated through the measurement and classification of surface cracking. Surface cracking was measured through reviewing of automatic collection data via Roadview Explorer® (Explorer 2015). Roadview is an interactive online pavement condition data collection software that contains recorded surface images from a vehicle driving along the road. Footage is available in the right lane and in both directions. This allowed the safe evaluation of TLTs from a computer with an internet connection. Roadview utilizes a GPS system for easy route location and records the mileposts of each recorded frame. Roadview was not the only source of evaluation, however. The TLTs were also evaluated manually through site visits. This allowed for confirmation of distress footage and calibration of distress severity, which was not always easy to determine via Roadview.

Deduct values came from UDOT according to distress extent, severity, and Maximum Allowable Extents (MAEs). Distresses were identified according to the Federal Highway Administration's (FHWA) *Distress Identification Manual* for the Long Term Pavement Performance Project (LTPP) (Miller and Bellinger 2014). For each TLT, pre- and postcondition data were measured. UDOT's 2012 Annual Average Daily Traffic (AADT) values and State Route (SR) functional classifications were noted for each route. The decision to use 2012 AADT volume came from 12 of 14 of the TLTs being constructed in 2012. Site visits of the given pavement sections took place between January and February of 2014 and March to April 2015. This consisted of walking along the TLT section, visually assessing condition, and taking photographs of the various distress types. Roadview data were evaluated after performing site visits. This assisted in identifying distresses using Roadview film. Visual assessment by moving vehicle was necessary for sites SR80 and SR215, which are interstate routes and parking is both illegal and hazardous. Even though Roadview film was not available in 2015 during the data collection period of this study, the 2015 site visits were indicative of deterioration of the TLT conditions between 2014 and 2015.

Distress data for the TLTs consisted of Wheel Path (WP), Longitudinal Wheel Path (LWP), Longitudinal Non Wheel Path, (LNWP), transverse, and block cracking. LWP cracks were counted as WP cracks as they occur in the wheel path and result from traffic loading. LNWP cracks, mostly considered joint cracks, are construction related. Bleeding, raveling, and potholes were also noted; however, no deduct values were assigned for these distresses.

Deduct values are based on severity and extent. Road surface markings and automatic data frame lengths were used to estimate distress extents. Assumptions for distress length measurements were a twelve feet lane width, ten feet long painted dashed white lines (which separate lanes), and twenty feet of space between the painted dashed lines. Frame lengths were determined by recorded milepost markings for each frame. Distresses were measured in the right outside lane and considered representative of the entire pavement section. Distress area, for WP cracking, was estimated using tire markings that were assumed eight inches in width. A minimum of three inches was assumed as the width for the distressed area of LWP cracks. This assumption was based upon the travel, or zigzag pattern of the crack, estimating the width between peaks of LWP cracks.

Deduct values comprised the Pavement Condition Index (PCI) scores and consisted of the Environmental (ENV) and Wheel Path (WP) indices. These PCIs divide distress types to reflect environmental- and load-related cracking mechanisms. The ENV index was composed of transverse, block, and LNWP cracks. The WP index consists of load-related distresses such as fatigue cracking and LWP cracking.

The TLT sections were divided into sample units, each a tenth of a mile in length or 528 feet. The starting and ending mile point for each section was rounded up and down to the nearest tenth decimal place. The total number of inspected sample units was 20% of the total number of sample units rounded down. A minimum of two sample units were inspected per section. The spacing interval at which the units were inspected was determined by dividing the total number of sample units divided by the number of inspected units, rounded down. A random start unit was determined by selecting a random number between one and the sample interval.

For each inspected sample unit, the distresses severity, extent, type, and location was recorded. Environmental and WP indices were calculated from each inspected unit and averaged among all the inspected units to represent the condition of the entire section or TLT. The distress severity was indicated by a L (low), M (medium), or H (high) and displayed in the Distress and Pavement Condition Data tables for each TLT. Crack sealed distresses, found in pretreatment condition, were counted as low severity transverse, block, WP, LNWP cracks according to their location and appearance.

The location of treatments and TLT type for each section are shown in Table 2. The table shows the State Route (SR) number for each section, physical description, milepost, and date of treatment. The TLT columns show what treatment type each section received and if milling was performed as part of the treatment application. Milling is the removal of the surface layer prior to placement of the surface treatment. For the routes that were not milled, the TLT was overlaid on the existing surface. Most of the routes received treatment during the summer of 2012. SR171 and SR68, an OGSC and HMA treatment, respectively, were applied summer of 2013. All but three of the routes were milled prior to the TLT application. These were SR36, SR48, and SR80 between Ranch exit and Lambs Canyon, an OGSC, HMA, and SMA route, respectively.

3.2 OGSC

3.2.1 SR36 Stansburry to I-80 MP 62.65 – 65.8

SR36 evaluation occurred between Lake Point and Stansbury Park. SR36 serves as a principle arterial for Stansbury Park and Tooele to I-80. It is a two lane road in each direction. The UDOT 2012 AADT was 25,225, of which 30% were trucks (5% combo, 25% single). The surface treatment for SR36 consisted of a one inch OGSC TLT overlaid on the existing surface. Treatment occurred in July of 2012.

Pretreatment evaluation was in July of 2012, just prior to construction. Greater than 45% of the inspected units had LNWP cracking, which appeared to be located on construction joints (Table 3). Percent distressed was calculated by summing the total amount of distress divided by the total amount of the Maximum Allowable Extent (MAE). About 19% of the cracks were on the wheel path and attributed to loading. No transverse or block cracking showed in any of the inspected units. Posttreatment condition survey in 2014, almost two years after treatment, showed no cracking; however, minor bleeding was seen.

During the 2014 site visit, low severity LNWP joint cracks, similar to pretreatment conditions in manner of appearance and location, are shown in Figure 2. It should be noted that this route was not milled before treatment, possibly accelerating the reappearance of similar distresses. The 2015 survey of this road showed similar conditions to that of 2014. No significant increase in distress extent or type was seen over the 2014-2015 winter. Transverse cracks were not seen during 2015, suggesting good thermal properties for the road.

3.2.2 SR89 Victory Road to Beck Street MP 381.5 – 383.77

SR89 is located in North Salt Lake and runs north and south between I-15 and Limes Canyon. SR89 is a three lane principal arterial that is split into a divided road by I-15. It experienced a 2012 AADT of 20,520; 16% were single unit trucks while 2% were combo unit trucks. Treatment on this route began August 8, 2012. It consisted of a one inch mill with a placement of a one inch OGSC TLT.

Pretreatment conditions showed extensive transverse and block cracking as well as WP cracking at 20%, 39%, and 33% respectively (Table 4). During posttreatment, March of 2014, only one and a half years after construction, WP cracking was found in the same location as pretreatment at MP383.46 (Figure 3 top left and right). This suggests there may be an issue with the road base resulting in rapid deterioration and the reoccurrence of WP cracking. This could possibly be caused by improper drainage from the I-15 overpass. Additionally, pretreatment conditions showed major climate-related stresses. As of spring 2014, 17% of the road is experiencing low severity thermal distresses in transverse and block cracking. A 2015 site visit found increasing thermal distresses in block and transverse cracks throughout the mat as well as some medium severity bleeding (Figure 3 bottom).

3.2.3 SR186 (1) State Street – 700 E MP 2.66 – 3.56

SR186 between MP 2.66 and 3.56 is a three lane principal arterial with a 2012 AADT of 20,945 vehicles (14% single trucks, 3% combo). The surface treatment began on July 9, 2012 and consisted of a one inch mill with a one inch OGSC overlay. The pretreatment survey mainly showed low severity thermal transverse cracking at 32% coverage of the MAE. WP and block cracking, low severity, measured 5% and 4%, respectively, as shown on Table 5.

The 2014 posttreatment pavement condition surveys found 14 low severity transverse cracks adjacent to areas of bleeding and/or raveling. The 2014 site visit showed raveling as well as transverse cracking, depicted in the top of Figure 4. The excessive bleeding and minor raveling found suggests that a substantial volume of the binder may have segregated from the mix during construction (Figure 4). This may have left areas on the mat deficient in binder, possibly accelerating the formation of transverse cracks.

In 2015, a site visit found block cracking as well as the beginning formation of WP cracking (Figure 4 bottom left and right). The block cracking was seen for about a 50 feet section of the mat and across all three lanes. The WP cracking was found in the outside lane. Multiple transverse cracks were seen in all lanes during the site visit. Thermal-related distress types appear to be the main cause of deterioration. From visual inspection between 2014 and 2015, thermal stresses have substantially increased.

3.2.4 SR186 (2) 700 E – 1300 E MP 3.56 – 4.56

This section experienced a 2012 AADT of 20,425 vehicles with 14% single and 3% combo axles. This route received a one inch mill with a one inch OGSC overlay in July 2012. Pretreatment conditions were similar to that west of 700 East and shown in Table 6. Pretreatment occurred a month before the TLT placement. The posttreatment condition data survey was two years after placement.

Low severity bleeding, WP, transverse, and block cracking were found 2014 and 2015 posttreatment. Figure 5 depicts distress conditions in 2015. This section of road appears to be resisting thermal distresses slightly better than that west of 700 East. While block and transverse cracks are occurring, their extent or severity is not the same as between State St. and 700 East. Similar to the block and transverse cracking, bleeding in this section was not as severe as the previous section.

3.2.5 SR269 I-15 to 200 W MP0/0.46-Eastbound and 1.348/1.798-Westbound

SR269 is a principal arterial that connects traffic directly to and from I-15. It is a one way road heading eastbound along 600 South and westbound on 500 South. The surface treatment covered I-15 (approximately 500 West) to 200 West eastbound as well as 200 West to I-15 westbound. Construction began August 6, 2012. The treatment consisted of a one inch mill with a one inch OGSC placement. Eastbound the 2012 AADT was 41,540 with 21% single axle trucks and 3% combo axle trucks. Westbound the AADT was 31,515 with 21% single and 3% combo axles.

Pretreatment pavement condition data were measured two months before treatment. The majority of the pretreatment distresses were low severity joint and WP cracking (Table 7). Posttreatment, 2014, condition data, one and a half years after construction showed the reappearance of WP and transverse cracks with extent almost equaling or exceeding that of pretreatment. Joint cracking was not seen during the 2014 posttreatment pavement condition survey.

The 2015 site visit showed an increase in construction-, climate-, and load-related distresses. Transverse cracks were found near the intersections of 500 and 300 West, which spanned the entire width of the road (Figure 6 top left). Block cracking was seen at three different locations, depicted in Figure 6 top right. A medium severity pothole was found and is shown in Figure 6 bottom left. The bottom right of Figure 6 shows common WP cracking found on the mat. Additionally, minor bleeding and minor raveling along with some minor spot bleeding were noted.

3.2.6 SR80 (1) Fire Station to Silvercreek MP145.5 – 147.5

The UDOT 2012 AADT for this section was 32,125 vehicles with 17% single and 25% combo trucks. Construction occurred on June 4, 2012. It received a one inch mill with and a one inch OGSC surface layer. Pretreatment condition consisted of mainly WP and block cracking measuring at 27% and 34% extent of the MAEs, respectively (Table 8). Delamination with WP cracking was found in the direction of decreasing mileage at MP146.49. Pretreatment condition data were from approximately one year before treatment. Thus, pretreatment conditions were likely worse than what was reported.

Posttreatment condition was measured two years after construction. The main distresses seen included bleeding and raveling, however; they were minor in severity and extent (Figure 7). It appears that the bleeding may be occurring along or near a construction joint.

3.2.7 SR80 (2) High Ute Ranch to Fire Station MP143.07 – 145.18

This section of I-80 has a 2012 AADT of 47,075 vehicles with 18% single and 22% combo unit trucks. Construction occurred on June 4, 2012 consisting of a one inch mill and a one inch OGSC surface layer. Pretreatment footage was filmed a year before treatment began. During the evaluation of Roadview footage between 2012 and 2014, it was evident that distresses seen in 2012 were not seen in 2014. It is likely that either this section received another type of treatment or the distresses "self healed".

The 2011 pretreatment evaluation showed low severity distresses. Joint cracking was at 49% coverage, WP cracking covered 6% of the inspected units, and transverse cracks at 12% extent (Table 9). From 2012 to 2014, the distresses decreased, suggesting a treatment of some type or self healing occurred. The 2012 survey only showed 32% joint cracking, 2% WP cracking, and 2% transverse cracking. Posttreatment survey, performed in 2014, saw only 1% extent of transverse cracks and some minor bleeding (Figure 8).

3.2.8 SR171 Redwood Rd. to 700 W MP 8.032 – 9.426

Treatment on this route occurred July 12, 2013. It received a one inch mill with a one inch OGSC surface overlay. SR171 is a principal arterial that connects directly to I-15. The 2012 AADT was 28,920 vehicles with 21% single truck and 3% combo truck. As construction occurred in July 2013, this treatment is the youngest of the OGSC treatments surveyed.

Pretreatment condition measured low severity WP, LNWP, and transverse cracking at 2%, 11%, and 9%, respectively, of their MAEs (Table 10). The pretreatment survey was from one year before treatment. The posttreatment condition, less than one year after treatment, showed low severity LNWP and transverse cracking at 10% and 1%, respectively. On the bridge spanning the Jordan River, a transverse crack crossed the width of the road (Figure 9 top right). This is a similar distress as seen in the pretreatment survey (Figure 9 top left). Possibly settlement or deflection from the bridge may be resulting in these distresses.

An increase in thermal stresses was noticeable during the 2015 site visit compared to 2014. The 2015 site visit showed some minor bleeding spots in the outside lane, westbound, near 500 West. In this area, a significant increase in thermal distresses in low severity block and transverse cracking occurred (Figure 9 bottom). The distressed area encompasses approximately 50 feet of the mat and spans across all three lanes. Similar distresses are not occurring in eastbound. Low severity LWP cracking, not joint/construction related, was seen during the 2015 site visit.

3.3 DGA

3.3.1 SR48 Milepost1.2 to 9000 S MP 1.2 – 4.44

This route received a one and a half inch DGA overlay on May 10, 2012. This route was not milled prior to treatment. SR48 is a minor arterial with a 2012 AADT of 2,775 vehicles of 23% single unit trucks and 5% combo units. The pretreatment condition survey was from 2010 Roadview footage, almost two years before treatment. Two posttreatment condition surveys were performed: one in June 2012 and the other in August 2014, two years and a month after treatment.

Pretreatment survey conditions found an excessive amount of tar sealed cracks. These cracks appear to be either transverse, block, or WP cracks. Medium severity fatigue cracking was also found. The pretreatment condition survey measured block cracking at 87% of MAE and medium severity WP cracking at 17% (Table 11).

The posttreatment condition survey performed two months after treatment showed no distresses. Posttreatment, at two years, showed a significant number of thermal distresses. The extent of transverse cracking for this road in 2014 was only 7%; however, 6% is coming from only one out of the six inspected sample units. This single sample unit was already at 36% of MAE in less than two years, which is considered failure for environmental conditions. These transverse cracks are occurring at the beginning of the route (eastbound) near the town of Copperton.

Site visits were performed in 2014 and 2015. They found similar distresses seen in the postcondition survey. An additional distress seen during the site visit was some minor raveling. The unusual nature to this treatment was the localization of the occurring transverse cracks. Their manner of appearance and consistency suggests they are being reflected from PCC joints below (Figure 10 left). Pretreatment conditions were evaluated at this location, using Roadview, and similar cracks in location and appearance (tar sealed) were discovered (Figure 10 right). It is noted that this route was not milled prior to overlay treatment. The localization and rapid appearance of these transverse cracks suggests underlying structural and/or base issues. The localization of distresses is occurring between MP1.2 – MP1.4. During the 2015 site visit, because of the low traffic volume, the widths of the transverse cracks were measured at one half inch at the widest opening (Figure 10 bottom).

3.3.2 SR154 13800 South to Bangerter MP 0 - 0.467

SR154 was milled with the placement of a one and a half inch DGA overlay on July 20, 2012. It serves as a major collector and has a 2012 AADT of 16,630 vehicles with 6% single and 4% combo axle trucks. The pretreatment was measured less than one month before treatment occurred. Posttreatment evaluation was almost two years after treatment.

Pretreatment condition survey measured 11% and 26% of block and WP cracking (Table 12). Significant raveling was also seen in the wheel paths for about 60 feet during the pretreatment survey. Niether joint nor transverse cracks were seen pretreatment. Posttreatment condition in 2014 showed no climate or structural distresses.

During site visits in 2014 and 2015, LNWP cracking, raveling, and potholes were found (Figure 11). The number of potholes increased from two in 2014 to three in 2015. They are roughly 4 to 6 inches in diameter. Minor raveling was also noticed to be occuring on the construction joints. This could be a result of increased porosity near the joints allowing for greater water infilitration and subsequential removal of material. The LNWP joint crack was found in the direction of decreasing mileage and was approximately 75 feet in length and low severity. No thermal or WP cracks were seen posttreatment.

3.3.3 SR210 Alta Bypass MP 12.6 – 13.6

SR210 is located up Little Cottonwood Canyon with its highest elevation point at approximately 8,480 feet. The surface treatment consisted of a mill with a 1.5 inch DGA overlay on August 13, 2012. The route is classified as a minor arterial with a 2012 AADT of 175 vehicles, of which 2% were single and 1% combo axles. Pretreatment survey was filmed two years before treatment. Two postcondition surveys were performed: one month and two years after treatment.

Pretreatment condition survey data showed transverse and block cracking at 46% and 14%, respectively. WP cracking measured 5% of MAE (Table 13). Posttreatment, two years, showed transverse cracking at 29% of MAE for the total inspected area. Pretreatment condition showed that the majority of the distresses were climate related. Thermal stresses appear to be the main driving mechanism for failure on this road which is expected due to the high altitutde.

A site visit in 2014 found severe delamination (Figure 12). Moderately severe raveling and thermal distresses were found throughout this section and are also shown in Figure 12. The rapid formation and severity of stresses on this road suggest that the drainage may not be adequate for the road for the freezing conditions. It is likely, due to the location, that water infilitration has deteriorated the structural and base conditions of the road. Frost heave is likely contributing to the deterioration as well. A full depth reclamation (FDR) treatment may be needed to treat base conditions. The drainage conditions of the road should be evaluated for improvement.

3.3.4 R68 1000 N to Davis County Line MP 60.1 – 62.8

SR68 received mill with a one and a half inch DGA overlay. Construction began on June 3, 2013. The 2012 AADT for this principal arterial route is 13,130 vehicles with 8% and 6% single and combo axles, respectively. Pretreatment survey film was from almost one year before treatment. Posttreatment data were obtained almost one year after treatment.

Pretreatment condition survey data consisted of a majority of thermal-related distresses. This road was excessively treated with a crack sealant prior to TLT application. Table 14 shows pretreatment distress extent for transverse, LNWP, WP, and block cracking was 23%, 0%, 14%, and 27% respectively. Post treatment survey conditions less than one year after treatment showed no visible cracking.

Site visits were performed on this route in 2014 and 2015. During these site visits, the only noticeable distress was some minor raveling in the wheel path (Figure 13).

Thermal distress extent did not appear to increase between 2014 and 2015. No joint cracking was seen, suggesting good construction methods. The TLT is in excellent condition as of 2015 which may be attributed to favorable base conditions and thermal properties for the road.

3.4 SMA

3.4.1 SR80 (3) Ranch Exit to Lambs Canyon MP 131.8 – 136.1

I-80 received a 1.5 inch SMA overlay over the existing surface. This route was not milled prior to placement. Construction began in July 2012. This is an interstate route and has a 2012 AADT of 46,215 vehicles with 23% single and 14% combo unit axles. Pretreatment survey was filmed just before treatment occurred. The posttreatment survey was filmed almost two years after treatment.

Pretreatment condition data showed that the major stress affecting this route was LNWP joint cracking but measured at less than 10% extent. WP cracking was measured at 2% while only one transverse crack was found in all inspected units (Table 15). Joint cracking was the most prominent distress but only accounted for 8% extent of the inspected units. Posttreatment condition data measured LNWP joint cracking at 6%. A low amount of WP cracking was found at less than 1% extent. Roadview screenshots in Figure 14 show the low severity WP and LNWP joint cracking posttreatment. No thermal distresses were visible from the Roadview survey, 2014.

3.4.2 SR215 End of PCCP to 3300 S MP 0.9 – 1.8

SR215 is an interstate route with a 2012 AADT of 69,580 vehicles of which 23% are single and 6% are combo axle trucks. Construction began June 25, 2012 and consisted of a one and a half inch mill with a 1.5 inch SMA overlay. Pretreatment footage was filmed just before treatment occurred while posttreatment was filmed under two years after treatment.

Pretreatment condition data showed 37% extent of MAE for WP cracking, 20% for LNWP joint cracking, and only 1% transverse cracking (Table 16). Posttreatment survey showed non-visible signs of cracking. Figure 15 depicts medium severity fatigue cracking found during pretreatment conditions. The treatment appears to be handling the climate and traffic conditions well. A drive through of this section on August 3, 2015 showed no additional distresses visible. The only visible distresses seen on this road during the drive through was some low severity bleeding patches less than 6 inches in diameter.

3.5 Summary

Table 17 summarizes the PCIs pre- and posttreatment as well as the major failure mechanism as determined by climate, construction, or loading distresses. Climate distresses include block and transverse cracks. Construction includes longitudinal non wheel path cracking (LNWP) and loading refers to wheel path (WP) cracks. The 2012 average annual daily traffic (AADT), elevation at the beginning milepost, and age of the treatment during postcondition rating are also shown.

From Table 17, it is seen that after approximately two years, six out of the 14 TLTs main distress mechanism are most likely climate related: SR89, SR186 (1), SR80 (2), SR48, and SR210. Two routes, SR186 (2) and SR269, show loading as the major distress mechanism and two show construction-related distresses, SR171 and SR80 (3). Five show no significant failure mechanisms two years after construction: SR36, SR80 (1), SR154, SR68, and SR215. It should be noted, however, that LNWP cracking was seen during the site visits of SR36 and that SR154 and SR68 are very low volume roads. Additionally, from site visits in 2014 and 2015, increased climate distresses in transverse and block cracks were found on SR269 and SR171. These distresses are not represented in the pavement condition data. Thus, it seems likely that climate will be the main distress causing mechanism for almost 50% of the routes within the next year.

Table 2. Thin Lift Treatments (TLTs)

Route	Location	MP	TLT	Construction Date
36	Stansburry to I-80	65.7-68.1	1” OGSC Overlay	7/30/2012
89	Victory Rd. to Beck St.	381.5-383.8	1” Mill/1” OGSC	8/8/2012
186	State to 700 East	2.7-3.6	1” Mill/1” OGSC	7/9/2012
186	700 East to 1300 East	3.6-4.6	1” Mill/1” OGSC	7/11/2012
269	I-15 to 200 West	0-0.5 & 1.4-1.8	1” Mill/1” OGSC	8/6/2012
80	Fire Station to Silvercreek	145.5-147.5	1”Mill/1” OGSC	6/4/2012
80	High Ute Ranch to Fire station	143.0-145.2	1” Mill/1” OGSC	6/4/2012
171	Redwood to 700 West	8.0-9.4	1” Mill/1” OGSC	7/12/2013
48	MP 1.2 to 9000 South	1.2-4.4	1.5” HMA Overlay	5/10/2012
154	13800 South to Bangerter	0.0-0.5	1.5” Mill/1.5” HMA	7/20/2012
210	Alta Bypass	12.5-13.6	1.5” Mill/1.5” HMA	8/13/2012
68	1000 North to Davis County line	60.8-62.9	1.5” Mill/1.5” HMA	6/3/2013
80	Ranch Exit to Lambs	131.7-136.1	1.5” SMA Overlay	7/13/2012
215	End PCCP to 3300 South	0.8-1.8	1.5” Mill/1.5” SMA	6/25/2012

Table 3. SR36 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 7/11/2012					
ENV	77	Transverse, L (#)	0	316.8	0
		LNWP, L (ft)	1430	3168	45
WP	91	WP, L (ft^2)	717	3802	19
		Block, L (ft)	0	3168	0
Posttreatment: 4/16/2014					
ENV	100	Transverse, L (#)	0	316.8	0
		LNWP, L (ft)	0	3168	0
WP	100	WP, L (ft^2)	0	3802	0
		Block, L (ft)	0	3168	0

Figure 2. SR36: WP crack, possibly reflected, and typical bleeding seen in the wheel paths throughout the section (March 2015).

Table 4. SR89 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 7/1/2012					
ENV	69	Transverse, L (#)	42	211.2	20
		LNWP, L (ft)	80	2112	4
WP	78	WP, L (ft^2)	812	2534	32
		WP, M (ft^2)	165	1267	13
		Block, L (ft)	815	2112	39
Posttreatment: 3/22/2014					
ENV	92	Transverse, L (#)	27	211.2	13
		LNWP, L (ft)	0	2112	0
WP	99	WP, L (ft^2)	30	2534	1
		Block, L (ft)	75	2112	4

Figure 3. SR89: Top left, 2012 pretreatment fatigue damage. Top right, same location 2014. Bottom left, posttreatment transverse, and longitudinal cracking with spalling. Bottom right, medium severity bleeding (April 2015).

Table 5. SR186 (1) Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/18/2012					
ENV	82	Transverse, L (#)	34	105.6	32
		LNWP, L (ft)	0	1056	0
WP	98	WP, L (ft^2)	58	1267	5
		Block, L (ft)	45	1056	4
Posttreatment: 3/10/2014					
ENV	93	Transverse, L (#)	14	105.6	13
		LNWP, L (ft)	0	1056	0
WP	100	WP, L (ft^2)	0	1267	0
		Block, L (ft)	0	1056	0

Figure 4. SR186 (1): Top left: transverse crack with raveling. Top right: medium severity bleeding. Bottom left: block cracking. Bottom right: WP cracking (April 2015).

Table 6. SR186 (2) Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/18/2012					
ENV	87	Transverse, L (#)	12	105.6	11
		LNWP, L (ft)	0	1056	0
WP	91	WP, L (ft^2)	225	1267	18
		Block, L (ft)	165	1056	16
Posttreatment: 3/10/2014					
ENV	99	Transverse, L (#)	1	105.6	1
		LNWP, L (ft)	0	1056	0
WP	98	WP, L (ft^2)	41	1267	3
		Block, L (ft)	0	1056	0

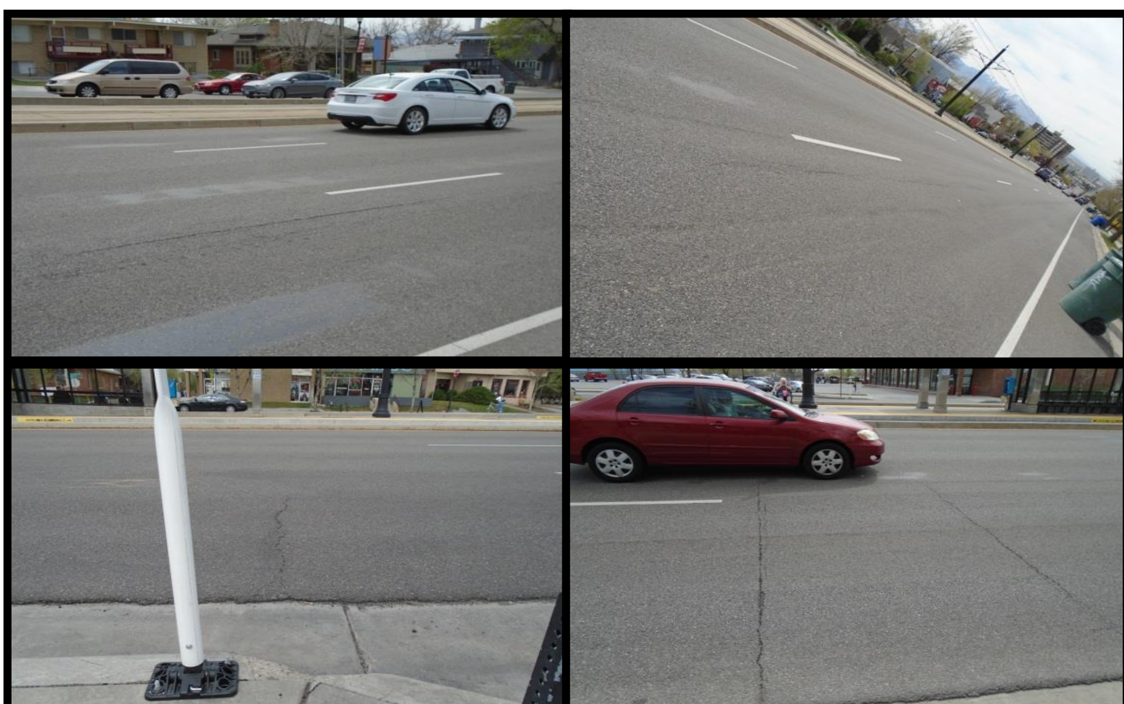

Figure 5. SR186 (2): Starting from top left to right and top to bottom: WP cracking with bleeding, additional WP cracking, transverse cracking, and block cracking (April 2015).

Table 7. SR269 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/17/2012					
ENV	93	Transverse, L (#)	2	105.6	2
		LNWP, L (ft)	130	1056	12
WP	94	WP, L (ft^2)	163	1267	13
		Block, L (ft)	0	1056	0
Posttreatment: 4/16/2014					
ENV	95	Transverse, L (#)	1	105.6	1
		LNWP, L (ft)	30	1056	3
WP	95	WP, L (ft^2)	135	1267	11
		Block, L (ft)	30	1056	3

Figure 6. SR269: Top left clockwise: transverse crack, block crack, WP crack, and medium severity pothole (April 2015).

Table 8. SR80 (1) Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/1/2011					
ENV	78	Transverse, L (#)	8	211.2	4
		LNWP, L (ft)	130	2112	6
WP	86	WP, L (ft^2)	683	2534	27
		Block, L (ft)	728	2112	34
Posttreatment: 7/30/2012					
ENV	98	Transverse, L (#)	0	211.2	0
		LNWP, L (ft)	100	2112	5
WP	100	WP, L (ft^2)	6	2534	0
		Block, L (ft)	0	2112	0
Posttreatment: 4/8/2014					
ENV	100	Transverse, L (#)	0	211.2	0
		LNWP, L (ft)	0	2112	0
WP	100	WP, L (ft^2)	0	2534	0
		Block, L (ft)	0	2112	0

Figure 7. SR80 (1): Minor raveling and bleeding, Roadview Explorer (April 2014).

Table 9. SR80 (2) Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/1/2011					
ENV	69	Transverse, L (#)	26	211.2	12
		LNWP, L (ft)	1040	2112	49
WP	95	WP, L (ft^2)	152	2534	6
		Block, L (ft)	0	2112	0
Posttreatment: 7/30/2012					
ENV	83	Transverse, L (#)	5	211.2	2
		LNWP, L (ft)	680	2112	32
WP	99	WP, L (ft^2)	63	2534	2
		Block, L (ft)	0	2112	0
Posttreatment: 4/8/2014					
ENV	99	Transverse, L (#)	3	211.2	1
		LNWP, L (ft)	0	2112	0
WP	100	WP, L (ft^2)	3	2534	0
		Block, L (ft)	0	2112	0

Figure 8. SR80 (2): Two minor transverse crack formations depicted on the left with minor bleeding in the center of the outside lane on the right (April 2014).

Table 10. SR171 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/17/2012					
ENV	91	Transverse, L (#)	14	158.4	9
		LNWP, L (ft)	170	1584	11
WP	99	WP, L (ft^2)	32	1901	2
		Block, L (ft)	0	1584	0
Posttreatment: 4/16/2014					
ENV	95	Transverse, L (#)	1	158.4	1
		LNWP, L (ft)	150	1584	10
WP	100	WP, L (ft^2)	0	1901	0
		Block, L (ft)	0	1584	0

Figure 9. SR171: Top left: transverse crack posttreatment (2012). Top right: same location (2015). Bottom left: block and transverse cracking. Bottom right: LWP cracking (April 2015)

Table 11. SR48 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 5/27/2010					
ENV	56	**Transverse, L (#)**	1	316.8	0
		LNWP, L (ft)	0	3168	0
WP	91	**WP, L (ft^2)**	43	3802	1
		WP, M (ft^2)	316	1901	17
		Block, L (ft)	2769	3168	87
Posttreatment: 6/18/2012					
ENV	100	**Transverse, L (#)**	0	316.8	0
		LNWP, L (ft)	0	3168	0
WP	100	**WP, L (ft^2)**	0	3802	0
		Block, L (ft)	0	3168	0
Posttreatment: 8/28/2014					
ENV	96	**Transverse, L (#)**	22	316.8	7
		LNWP, L (ft)	0	3168	0
WP	100	**WP, L (ft^2)**	0	3802	0
		Block, L (ft)	0	3168	0

Figure 10. SR48: Transverse cracks, upper left proceeding clockwise: posttreatment (2014), pretreatment (2012), posttreatment (2015), 0.5 inch wide.

Table 12. SR154 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/16/2012					
ENV	94	**Transverse, L (#)**	0	52.8	0
		LNWP, L (ft)	0	528	0
WP	87	**WP, L (ft^2)**	162	634	26
		Block, L (ft)	60	528	11
Posttreatment: 3/22/2014					
ENV	100	**Transverse, L (#)**	0	52.8	0
		LNWP, L (ft)	0	528	0
WP	100	**WP, L (ft^2)**	0	634	0
		Block, L (ft)	0	528	0

Figure 11. SR154: One of three potholes in the wheel path (left) and (right) LNWP joint crack (September 2014).

Table 13. SR210 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/22/2010					
ENV	70	Transverse, L (#)	49	105.6	46
		LNWP, L (ft)	0	1056	0
WP	98	WP, L (ft^2)	59	1267	5
		Block, L (ft)	150	1056	14
Posttreatment: 9/8/2012					
ENV	100	Transverse, L (#)	0	105.6	0
		LNWP, L (ft)	0	1056	0
WP	100	WP, L (ft^2)	1	1267	0
		Block, L (ft)	0	1056	0
Posttreatment: 5/17/2014					
ENV	85	Transverse, L (#)	31	105.6	29
		LNWP, L (ft)	2	1056	0
WP	100	WP, L (ft^2)	2	1267	0
		Block, L (ft)	0	1056	0

Figure 12. SR210: Delamination (top), raveling, and transverse cracking with raveling (April 2015).

Table 14. SR68 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 7/17/2012					
ENV	75	**Transverse, L (#)**	48	211.2	23
		LNWP, L (ft)	0	2112	0
WP	93	**WP, L (ft^2)**	363	2534	14
		Block, L (ft)	570	2112	27
Posttreatment: 4/3/2014					
ENV	100	**Transverse, L (#)**	0	211.2	0
		LNWP, L (ft)	0	2112	0
WP	100	**WP, L (ft^2)**	0	2534	0
		Block, L (ft)	0	2112	0

Figure 13. SR68: Raveling in the wheel path (top). Pretreatment conditions showing many tar sealed cracks (bottom).

Table 15. SR80 (3) Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 7/30/2012					
ENV	95	**Transverse (#)**	1	422.4	0
		LNWP, L (ft)	280	4224	7
		LNWP, M (ft)	70	3168	2
WP	99	**WP (ft^2)**	95	5069	2
		Block (ft)	0	4224	0
Posttreatment: 4/8/2014					
ENV	97	**Transverse (#)**	0	422.4	0
		LNWP (ft)	240	4224	6
WP	100	**WP (ft^2)**	11	5069	0
		Block	0	3168	0

Figure 14. SR80 (3): Low severity WP cracking (left) and LNWP joint crack (right) (April 8, 2014).

Table 16. SR215 Distress and Pavement Condition Data

Indices		Crack	Extent	Total Amount	% Distressed
Pretreatment: 6/17/2012					
ENV	89	Transverse, L (#)	1	105.6	1
		LNWP, L (ft)	180	1056	17
		LNWP, M (ft)	30	790	4
WP	80	WP, L (ft^2)	444	1267	35
		WP, M (ft^2)	30	634	5
		Block, L (ft)	0	1056	0
Posttreatment: 3/10/2014					
ENV	100	Transverse, L (#)	0	105.6	0
		LNWP, L (ft)	0	1056	0
WP	100	WP, L (ft^2)	0	1267	0
		Block, L (ft)	0	1056	0

Figure 15. SR215: Medium severity fatigue cracking, found in pretreatment condition, Roadview Explorer (June 17, 2012).

Table 17. TLTs Pre- and Postconditions with Major Distress Mechanism

SR	TLT	2012 AADT	Elevation (ft.)	Age (years)	ENV	WP	Pre ENV	Pre WP	Major Distress Mech.
36	OGSC	25,225	4,250	1.7	100	100	77	91	None
89	OGSC	20,520	4,190	1.6	92	99	69	78	Climate
186 (1)	OGSC	20,945	4,240	1.7	93	100	82	98	Climate
186 (2)	OGSC	20,425	4,350	1.7	99	98	87	91	Loading
269	OGSC	41,540	4,190	1.6	95	95	93	94	Loading
80 (1)	OGSC	32,125	6,380	1.8	100	100	78	86	None
80 (2)	OGSC	47,075	6,330	1.7	99	100	69	95	Climate
171	OGSC	28,920	4,190	0.8	95	100	91	99	Const.
48	HMA	2,775	5,190	2.3	96	100	56	91	Climate
154	HMA	16,630	4,390	1.7	100	100	94	87	None
210	HMA	175	8,320	1.8	85	100	70	98	Climate
68	HMA	13,310	4,170	0.8	100	100	75	93	None
80 (3)	SMA	46,215	5,670	1.7	97	100	95	99	Const.
215	SMA	69,580	4,820	1.7	100	100	89	80	None

4 ANALYSIS

The state routes were organized by treatment and distress type. The distress extents as percentages of the Maximum Allowable Extents (MAEs) of the sample units were plotted for each state route for pretreatment and posttreatment condition surveys (Figures 16 and 17). Transverse and block cracking extents were summed to plot climate distresses together. From the graph, it is apparent that the majority of distresses in OGSC and HMA mixes, in pre- and posttreatment conditions, are climate related. No thermal cracking was seen on the two SMA routes. Additionally, SR269 appears to be suffering from significantly WP cracking only two years after treatment. SR210 is suffering heavily from climate-related distresses; however, this is not surprising given its elevation at 2,000 feet higher than the other TLTs surveyed.

The 2012 AADT volume was plotted in Figure 18 for each SR in order to assess traffic condition impacts for each TLT. Figure 18 shows similar groupings of traffic volume per TLT sections. This is a result of prioritizing the TLT types for traffic volume. The lower volume routes (below 20,000) are receiving the DGA mixtures. Medium to high volume (20,000 – 45,000) see OGSC mixtures which provide additional safety benefits in reduced water spray and hydroplaning. The SMA mixtures are seen on high volume interstate routes (45,000+). The traffic volume prioritization makes it difficult to assess traffic volume impacts on the TLTs. For instance, three out of the four DGA mixtures are performing well with little distresses; however, they are all on low volume roads. It is unclear why SR80 (2) received an OGSC treatment and SR80 (3) an SMA. SR80 (2) is both greater in 2012 AADT and elevation compared to SR80 (3). However, SR80 (2) seems to be performing sufficiently well with only minor climate-related distresses.

An analysis was performed on the traffic volume and effect on load-related distresses (i.e. WP cracking). Figure 19 shows the 2012 AADT and WP condition index for both pre- and posttreatment. For early performance, no correlation is apparent between traffic volume and the WP index for neither pre nor post treatment. Pretreatment does show a decreasing trend. However, comparison is limited due to the TLT mix designs which are targeted for certain traffic volumes.

4.1 Remaining Service Life

The RSL of the pavements was calculated using the pavement condition indices, deterioration rate, and threshold values. A threshold value represents a pavements' condition that has reached its designed life. The design life for flexible pavements is 30-35 years. UDOT assigns a pavement condition index at a value of 50 to represent a pavement which has reached its' design life. For example, a RSL of zero represents a pavement with a PCI at the threshold level. A pavement condition score of 50, or RSL of zero, reflects a pavement that is in need of either major rehabilitation or reconstruction.

Thin lift treatments (TLTs) are surface layers and do not represent the condition of the entire pavement. Thus, another value needs to be determined to evaluate them. The estimated life spans of the DGA and SMA treatments are 7-10 years and 8-12 years for OGSC. UDOT's pavement management system (PMS) adds years to the RSL for pavements depending upon treatment type. These are called treatment resets. For the OGSC treatment, nine years is added to the RSL estimate. The DGA and SMA thin lifts add eight years. These reset values were used as the design lives for the TLTs.

Furthermore, treatment triggers, determined by pavement condition, are used by UDOT to schedule maintenance. Different levels of maintenance treatments are assigned different treatment triggers. The treatment triggers, as set by UDOT, for environmental (ENV) and wheel path (WP) cracking is 70 and 75, respectively. These triggers were used as threshold values for the TLTs. Thus, failure for the TLTs is defined as a section having either a WP index of 75 or an ENV index of 70 before reaching design life.

Figure 20 shows the RSL calculations. The RSLs were calculated using the lower pavement condition index value. The dashed line represents the failure conditions, red for wheel path and blue for environmental. From examining Figure 20, out of the 14 treated sections, it seems likely that four will trigger a treatment type for environmental distresses before their design life. Because pavement condition experiences an exponential decline over time, early performance estimates are overestimated.

Early failures due to environmental distresses are likely for SR210, SR171, SR89, and SR186 (1). Possibly one SR will trigger treatment conditions for WP cracking before reaching its' design life, SR269. Of these SRs, four are OGSC treatments: SR171, SR89, SR186 (1), and SR269, one is DGA (SR210). Both SMA treatments are performing well after two years. The SMA routes, three of the HMA routes, and four of the OGSC seem likely to meet or exceed their design life.

4.2 Summary

Out of the 14 TLTs monitored over two years, five are likely to experience premature failure. Therefore, based on the condition data, over 35% of the TLTs monitored are likely to fail prematurely. This results in 50% of the OGSCs, 25% of the HMA, and 0%

of the SMA likely not reaching their design lives. Additionally, the high expected rate of failure for the OGSCs justifies additional examination into their expected design lives. OGSC treatments are more expensive than DGA treatments and seem not to be meeting design specifications. It should be noted, however, that OGSCs provide a safety benefit of reducing standing water, which reduces water spray and hydroplaning. This safety benefit increases on high trafficked roads.

Thermal distresses are the main failure mechanisms for these treatments, accounting for twice of the early failures when compared to either structure- or construction-related distresses. Additionally, from 2015 site visits, thermal distress extent seemed to increase significantly on both SR269 and SR171, which may lead to increased early thermally related failures. Thermal distresses are an issue due to increased pathways for water ingress, which will lead to increased structurally related distresses such as WP cracking and more expensive treatment measures. A low temperature mixture test, such as the Bending Beam Rheometer, has shown to identify HMA mixtures susceptible to thermal cracking (Marasteanu et al. 2009; Romero et al. 2011). Incorporation of such a test may provide great benefit in improving the life span of these TLTs. Furthermore, due to the rapid formation of WP cracking on SR269, an evaluation of roadbase conditions may be warranted. Possibly, a TLT was not sufficient for this road and rehabilitation maintenance may be justified. Continued monitoring of this section will provide greater insight into justification of more serious maintenance measures.

Neither SR36, SR48, nor SR80 (3) received milling prior to treatment application. For all three of these treatments, similar pretreatment distresses seem to be reoccurring. Longitudinal non wheel path (LNWP) cracks are seen on both SR36 and SR80(3) while

SR48 is seeing similar transverse cracks to pretreatment conditions. In all instances, the cracks are in similar locations and appearance to pretreatment.

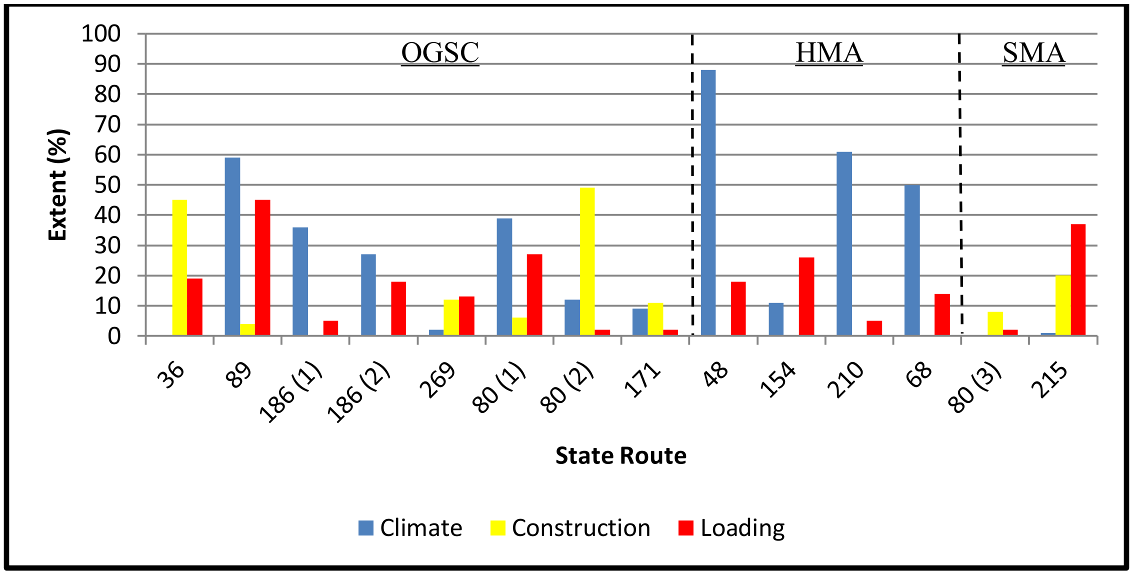

Figure 16. Pretreatment distress extent for each state route and treatment type

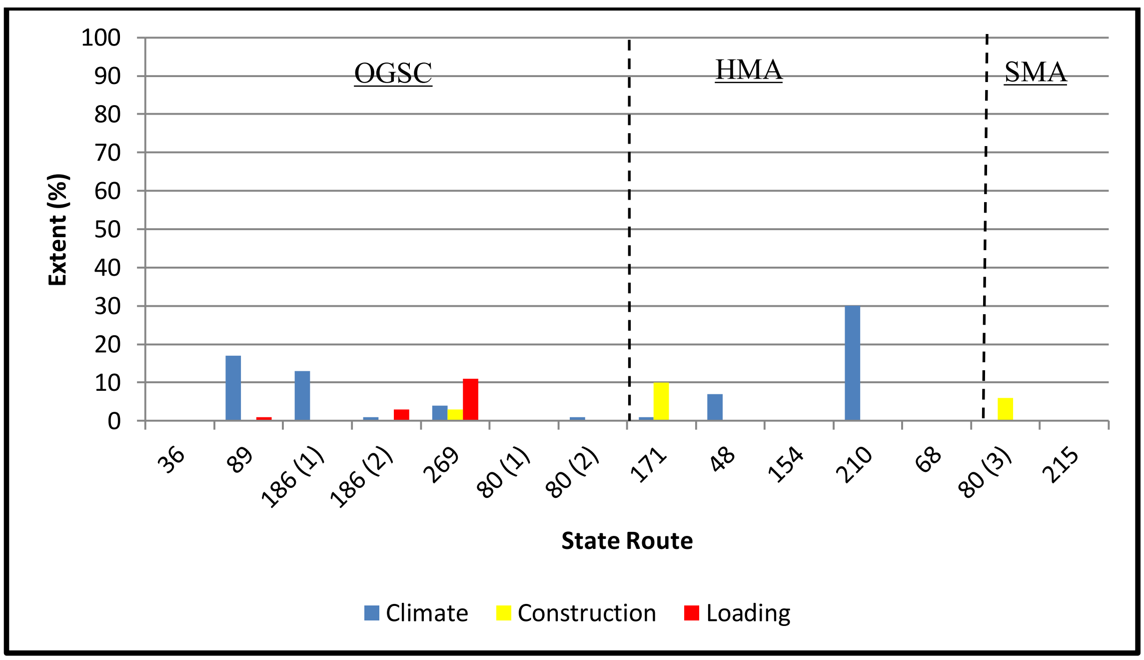

Figure 17. Posttreatment distress extent for each state route and treatment type.

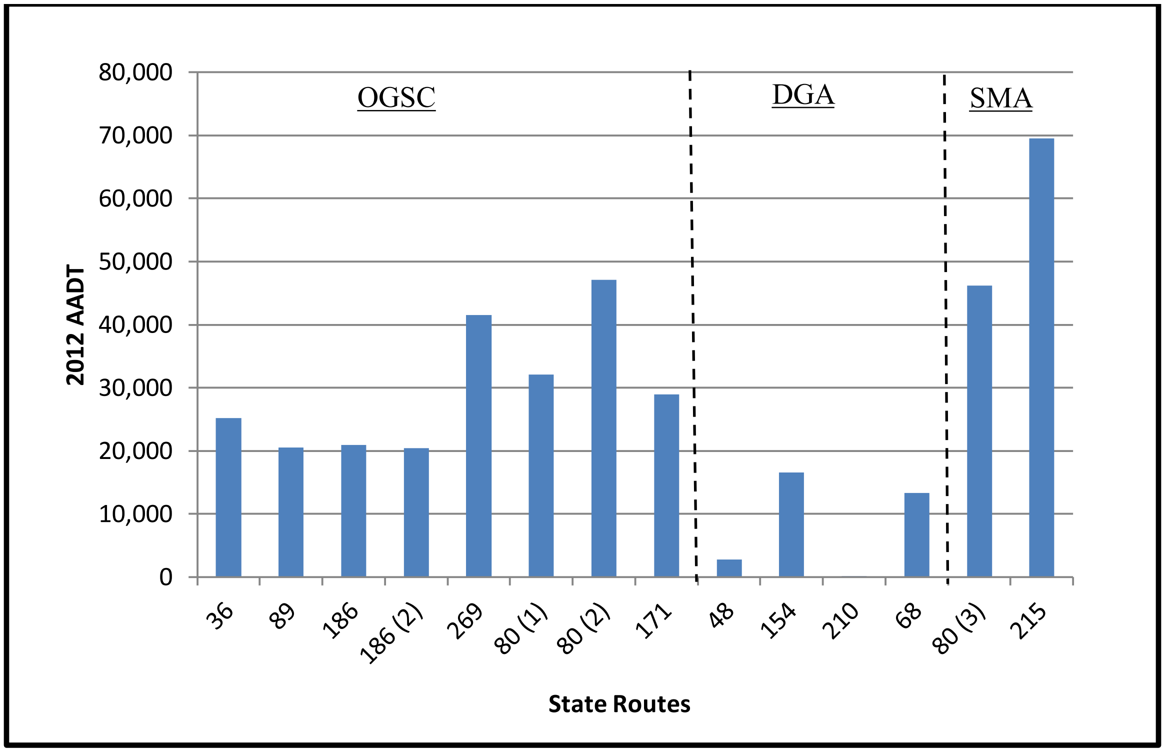

Figure 18. 2012 AADT per SR and TLT grouping.

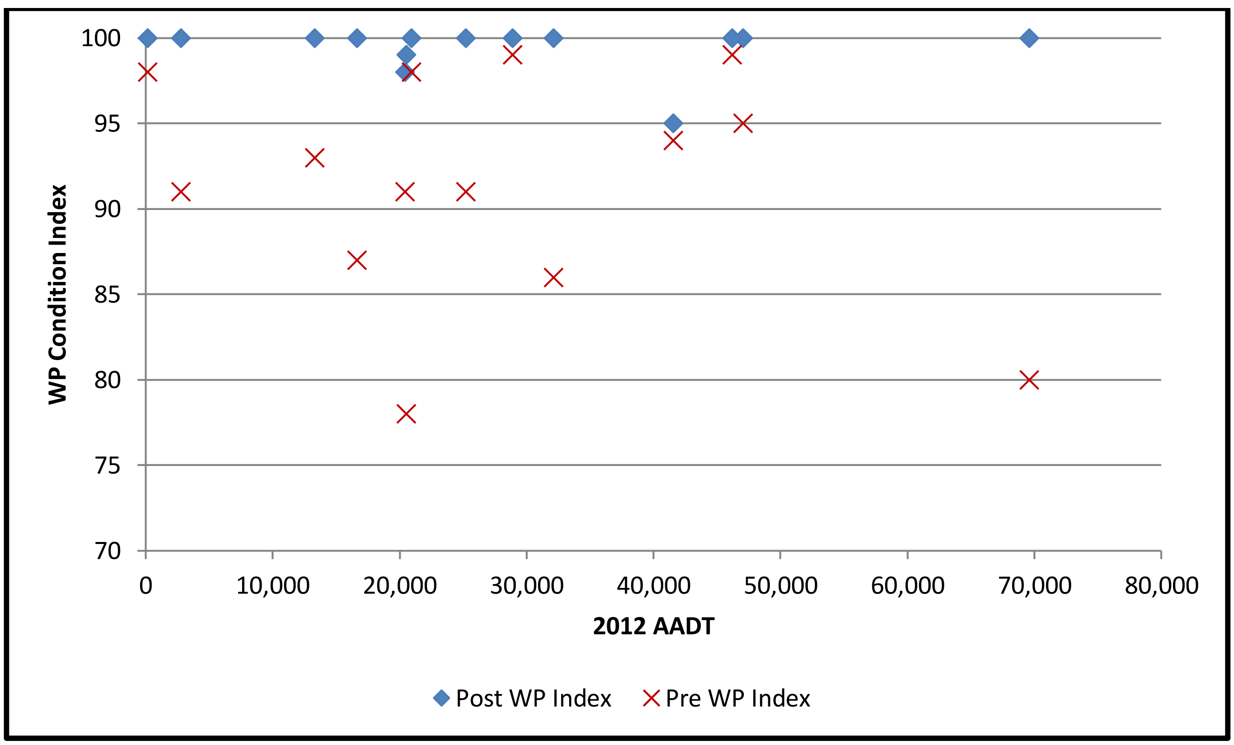

Figure 19. WP condition index and 2012 AADT for pre- and posttreatment.

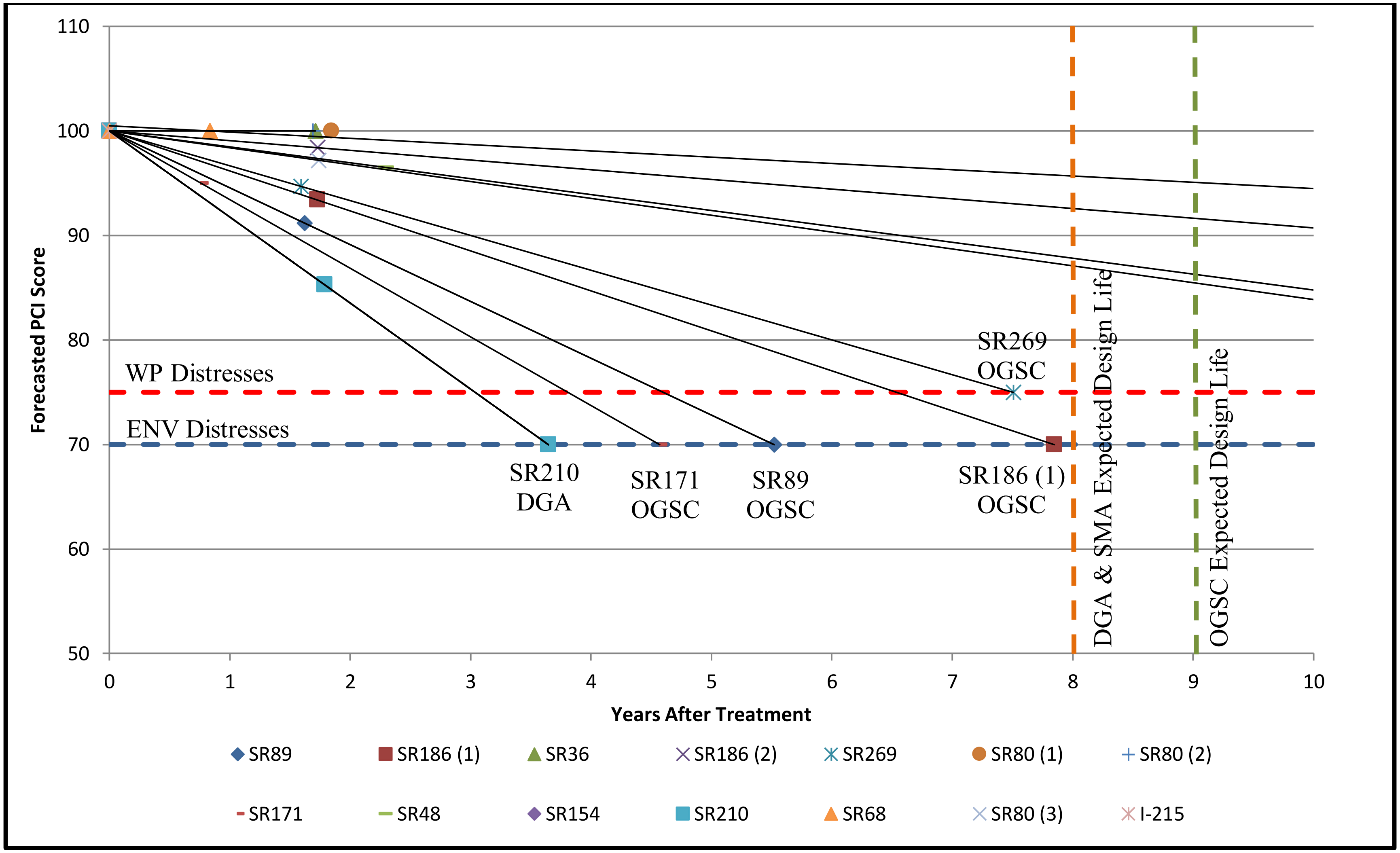

Figure 20. Remaining Service Life Estimations

5 COMPARISON TO LTPP DATA

The Strategic Highway Research Program (SHRP), as an effort to track performance of both rigid and flexible pavements, pioneered the Long Term Pavement Performance (LTPP) database in 1987. In 1992, the LTPP program came under the control of the Federal Highway Administration (FHWA). The program included participation of state highway agencies in all 50 US states, District of Columbia, Puerto Rico, and 10 providences in Canada. The program has monitored over 2,500 sections of pavements. The database includes information on pavement performance, age, traffic volumes, weather, and materials.

The LTPP database consists of several studies; each study refers to a specific pavement type (i.e. rigid, flexible, overlays, etc.) One such study is the SPS-3 (Special Pavement Study) on the preventative maintenance of asphalt concrete pavements. This five-year study occurred through 1990-1995 and measured performance of thin hot mix asphalt overlays (approximately one inch or less), slurry seals, crack seals, and chip seals. Additionally, each site was characterized according to moisture conditions, temperature, subgrade type, traffic loading, and previous pavement condition. Thin lift sections, identified in the SPS-3 study, with similar climate and moisture conditions to Utah, were used to compare the performance of local TLTs to that of thin lift overlays nationwide.

5.1 Discussion of Data

The SPS-3 study monitored 445 asphalt concrete pavement sections across 29 states and four Canadian providences. The number of sections was reduced to 92 by restricting sections to a dry freeze climate. These 92 sections were further reduced to 16 by selecting only those sections that had received a thin lift overlay treatment. Determining which sections received a thin lift overlay can be accomplished in two ways: viewing the Section Summary Report on the LTPP website for each section and noting which sections received an asphalt overlay or by using the Construction Number (CN) event code to locate HMA overlays in the data file. CN codes were assigned to maintenance treatments to quickly identify desired sections in a large database. For instance, the CN codes for preventative maintenance treatments are 1 crack sealing, 19 asphalt concrete overlays, 31 aggregate seal coat, and 33 slurry seal coat. Unique identifiers for each section were created by combining the state ID with the section ID. Using the CN code and the unique section identifier, the pavement condition data for each thin lift section were easily extracted from the dataset for the given sections.

Pavement condition for each section is 500 feet long and includes distress data for WP, LNWP, transverse, and block cracking. Additional distress data are available for rutting and the International Roughness Index (IR); however, these data were not used in this study. The 16 sections came from six states and one Canadian providence: Idaho, Nevada, Utah, Washington, Wyoming, Colorado, and Saskatchewan. Three sections came from Idaho, one from Nevada, five from Utah, one from Washington, two from Wyoming, two from Colorado, and two from Saskatchewan. Some sections were monitored after the SPS-3 study was completed in 1995. For some, condition data exist 14 years after initial construction. One section was only monitored the same year that it was constructed.

There are some important differences between the LTPP thin lift and local TLT sections. The LTPP thin lift sections were constructed using the Marshall Mix design method. The TLTs in Utah used the Superpave method. The Superpave method, which stands for Superior Performing Asphalt Pavements, was established in 1993 and is typically considered superior than the Marshall method because it incorporates a Superpave Gyratory Compactor (SGC), temperature-dependent binder specifications, aggregate gradation requirements, and compactive effort based on traffic requirements. Furthermore, the LTPP thin lift sections only utilized one mix design, a dense grade asphalt (DGA).

5.1.1 Analysis

The pavement condition data from the LTPP database were converted to ENV and WP indices as was for the local TLTs. The same design life criterion that was used to evaluate the local TLTs was used to evaluate the LTPP thin lift sections. Because all of the thin lift overlays were DGA mixes, a design life of eight years was considered. The treatment trigger values, as explained in the Method section, of 75 and 70 for WP and ENV distresses, respectively, were used as failure thresholds. The evaluated sections, corresponding states, estimated life spans, and age of the treatment at last survey are shown in Table 18. Traffic volume data for the sections were only available for some of the sections. The ENV and WP life columns show the year of a failure for each section. The value of eight plus (8+) was used if failure was not seen during the surveyed period for the given index. From the table, it is noticeable that ten sections failed for ENV distresses before WP and four WP before ENV at 62% & 25% of the total sections, respectively.

Two plots were made, one for WP and one for ENV distresses. These plots are shown in Figures 21 and 22, respectively. Out of the 16 sections, seven appear to be failing for WP cracking. Figure 22, ENV index versus age, shows some interesting behavior in the measurement of the ENV index for the sections. For instance, on section 8B310, the ENV index dips below 70 after one year and picks back up to 76 half a year later. Other sections that experienced this same behavior were 90A310, 8A310, and 49B310. This could possibly be attributed to self healing of thermal distresses or possibly the evaluator rated the distress types differently over the survey time period. Self healing is the closure of cracks due to the liquid behavior of asphalt which increases at higher temperatures (Little and Bhasin 2007). Out of the 16 sections, ten appear to be failing for ENV distresses. This high number may be an indication of the Marshall Mix design method not considering temperature affects in binder selection.

The effect that temperate and climate had on these overlay treatments was substantial. Obviously, colder climates will exacerbate distress formation. In order to show this, the ENV and WP indices for each route were plotted, in Figure 23, against the annual freezing index for these sections. The freezing index, as defined by the National Snow & Ice Data Center, is the total annual of cumulative number of degree days when temperatures are below zero degrees Celsius. Noticeable from Figure 23 is the general downward trend in the ENV index scores with increasing freezing index. For the WP index, this trend is not noticeable as the data are more scattered. However, as ENV cracking increases, it is expected for WP cracking to increase proportionately. This is primarily from increased water ingress into the pavement and subsequent structural damage to supporting layers.

5.2 Results

Similar to local TLTs, the thin lift overlays from the LTPP database are seeing a greater number of environmental failures as opposed to structural or wheel path failures. However, LTPP thin lift overlays saw a significant higher number of sections experiencing environmental distress-related failures: 63% opposed to 28% that are likely for the TLTs. This is possibly a result of the Marshall Design method not accounting for climate conditions in the binder selection. Wheel path failures accounted for 25% of the LTPP thin lifts and may likely account for only 7% of the TLTs monitored in this study. However, it should be noted that this was an early performance evaluation of the TLTs and a lot of variability exists in estimating performance at such an early stage. Furthermore, this study could only identify one early environmental failure for the DGA mix design of the TLTs, which represented only 25% of the DGA sections surveyed. This compared to the 63% environmental failures for the LTPP sections that are all DGA mixes. It is likely that this is due to the adoption of the Superpave Design method that selects asphalt binder based on local climate and shows the benefits of Superpave over the Marshall method.

5.3 Summary

The Long Term Pavement Performance database was accessed to extract pavement condition data for 16 thin lift treatment sections from a dry freeze climate and analyzed for performance. These thin lift treatments were constructed in 1990 using the Marshal Design method and whose performance was monitored anywhere from one year to 14 years. These sections were evaluated using the same method that was used for the TLTs. Additionally, the LTPP sections were analyzed for distress performance by freezing index showing decreased environmental performance with increasing freezing index. As was seen in the

TLT evaluation, environmental distresses are the main failure mechanism for these sections. Better performance is noticeable in the TLTs evaluated and is likely attributed to the use of the Superpave Design method.

Table 18. LTPP Thin Lift Treatments and Measured Life Spans

Unique ID	State	ENV life (years)	WP life (years)	Age at last survey (years)
16A310	Idaho	8+	8+	13.9
16B310	Idaho	6	8+	13.8
16C310	Idaho	1.5	8+	6.8
32B310	Nevada	8+	2	6.6
49A310	Utah	1	2.5	8.0
49A361	Utah	1.5	5	8.0
49B310	Utah	8	6.5	10.8
49B361	Utah	8+	8+	3.0
49C310	Utah	7	8+	12.2
53B310	Washington	6	8+	9.6
56A310	Wyoming	8+	6.5	6.8
56B310	Wyoming	0.5	8+	11.7
8A310	Colorado	8+	1	8.0
8B310	Colorado	1	2	1.3
90A310	Saskatchewan	0.5	8+	5.1
90B310	Saskatchewan	0.5	5.5	8.8

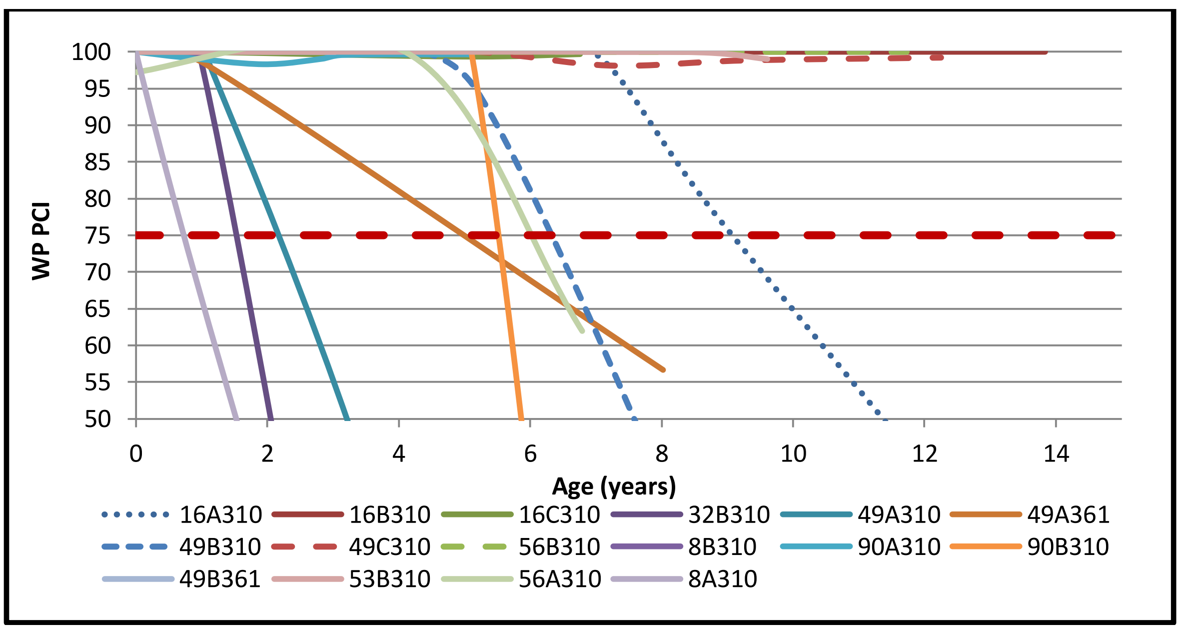

Figure 21. Wheel path pavement condition index with failure line.

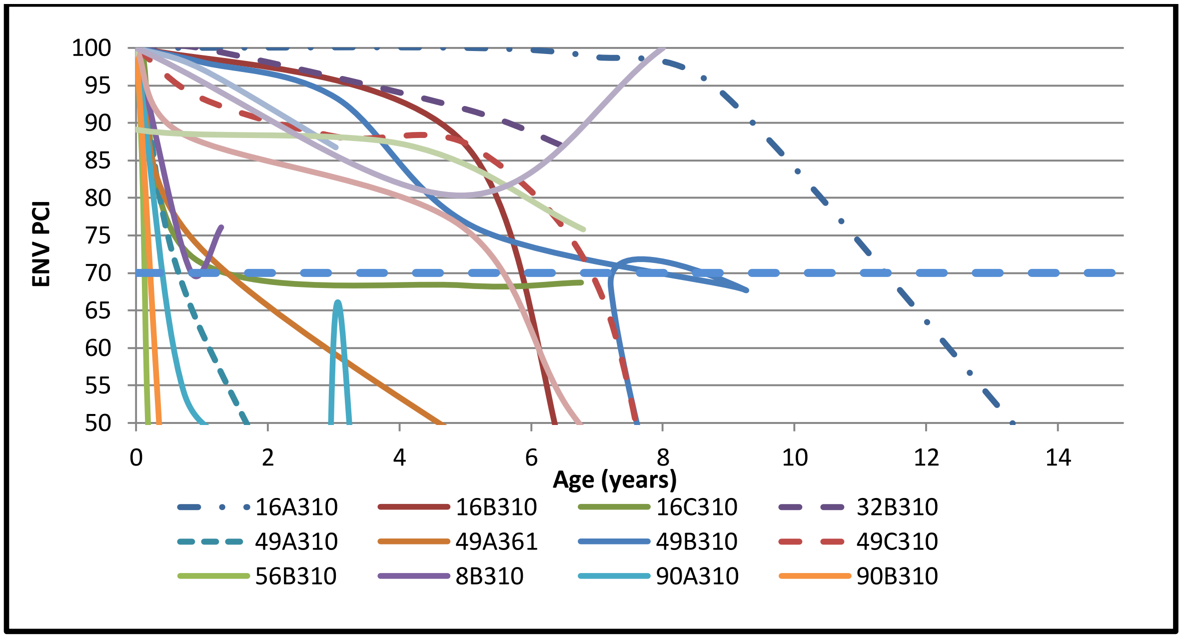

Figure 22. Environmental pavement condition index with failure line.

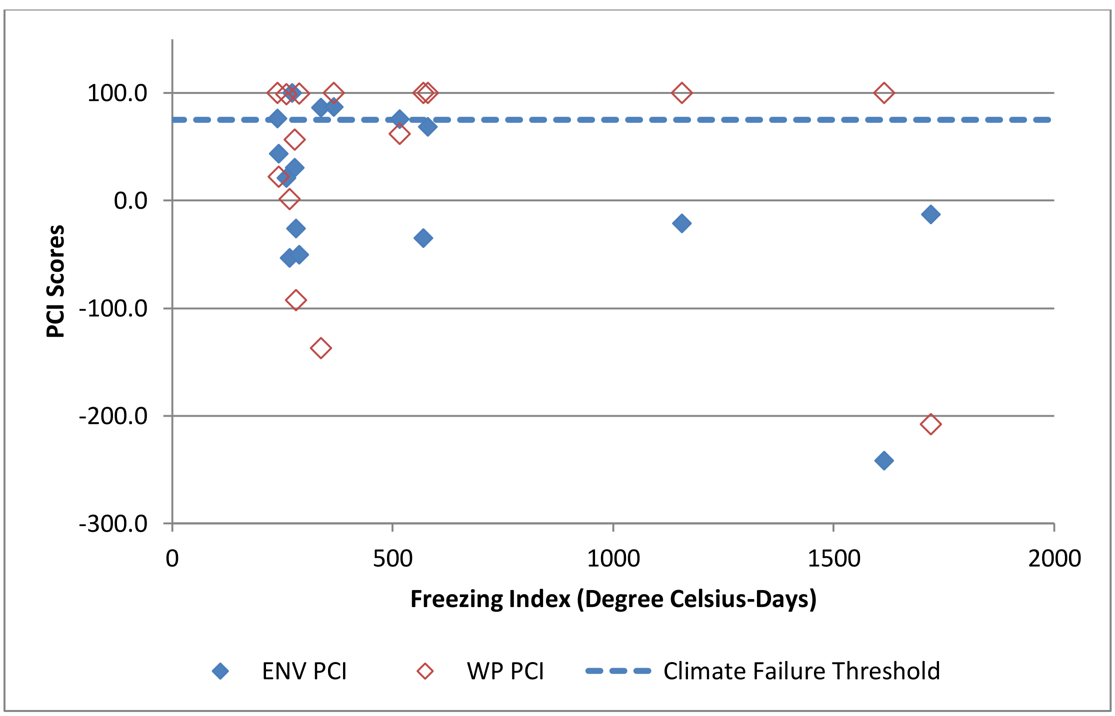

Figure 23. LTPP pavement condition indices and freezing index.

6 CONCLUSION

6.1 Summary of Results

Fourteen Thin Lift Treatments (TLTs) in UDOT's Region II were evaluated between a one- and two-year period in order to assess their early performance. Surface distress data were quantified using Pavement Condition Indices (PCIs) and Remaining Service Life (RSL) was estimated following procedures developed by Baladi as utilized by UDOT. The local TLT performance was then compared to national data using the Long Term Pavement Project (LTPP) database by selecting areas of similar climate conditions to Utah.

For the TLTs, climate-related distresses (transverse and block cracking) appear to be the main failure mechanism for both pre- and posttreatment conditions. Climate failures account for almost half of the early failures by 2015. It should be noted, however, that condition forecasting methods from only two years of data are limited. However, early failures occur for five of the 14 TLTs as indicated from the surface condition data. These routes are SR210, SR171, SR89, SR186 (1), and SR269. Four of these five routes are OGSC and the other is a DGA. The SMA routes, at the time of this assessment, are experiencing no climate- or load-related distresses. Only one of the two, SR80 (3), is experiencing some minor construction-related distresses in joint cracking, which is possibly being reflected from the pavement below.

Wheel path cracking for SR269 has already reached an extent similar to pretreatment conditions at only one and a half years posttreatment. A TLT was the wrong treatment for this section. A better treatment for SR269 is rehabilitation. Additionally from wheel path structural cracking, the visual assessment of SR269, during the 2015 site visit, found a substantial increase in climate distresses from 2014.

From the three sections that were not milled prior to treatment (SR36, SR48, and SR80 3), both SR36 and SR80 (3) are experiencing longitudinal non wheel path (LNWP) cracks similar to pretreatment conditions while SR48 is seeing similar transverse reflective cracking. The locations and appearance of these distresses posttreatment are similar to what was found pretreatment. It may be likely from failing to mill the surface layer before treatment application, that these distresses are being reflected to the surface and resulting in decreased performance for these sections. Additionally, for SR48 a rehabilitation treatment is needed in the area of reflective transverse cracking.

At the time of posttreatment evaluation, traffic volume does not appear to be correlated to performance. Reviewing performance after several years may indicate otherwise. This may be due to structural adequacy for the majority of the surveyed sections as result of an effective maintenance strategy or simply a lack of data from early performance monitoring.

Nationally, thermal distresses for climate conditions similar to Utah (defined as a dry, freeze) are the main failure mechanism for the thin lift overlays. Locally, thermal performance seems to have improved compared to the national overlays. Out of the 16 LTPP sections, 14 experienced early failure when evaluated with the same criteria of the local TLT sections. This is roughly 88% compared to the estimated 35% for the local TLTs. The freezing index, which represents the number of days below freezing, may be the reason of increased national failures as some of the thin lift overlays were placed in areas much colder than Utah. Environmental failures, including thermal distresses, accounted for 62% of the LTPP sections that failed. This will likely account for only 25% failures of the local TLTs.

6.2 Conclusion

The conclusions made from the data analysis of the pavement surface conditions consider that OGSC's are used on medium to high volume roads, DGAs are used on low volume roads, and SMAs are used on high volume roads.

- Not removing the surface layer prior to treatment application seems to reduce TLT performance through reflective cracking.
- Because many early projected failures were seen for the OGSC, a nine-year life expectancy is extremely optimistic. A seven-year lifespan seems to be more realistic.
- Even though few sections are SMA, it seems, due to the high binder content, high quality aggregate, and Superpave designs, are performing well and are crack resistant.
- Clearly environmental-related failures are the most significant problem facing the roads in Utah.
- Compared to national LTPP data, TLTs in Utah are performing better to those of similar climate.

6.3 Recommendations and Future Work

It is recommended to perform a cost analysis for determining the effective treatment application for TLTs. First, a larger database needs to be developed. Conditional factors such as traffic volume and pretreatment condition need to be considered with statistical analysis methods to determine the affect each factor has on TLT performance. An analysis on the safety benefit of OGSC through crash reduction needs to be performed in order to quantify their benefit. Furthermore, monitoring of the TLTs in this study should continue in order to establish increased accuracy in the prediction models.

REFERENCES

Al-Mansour, A. I., Sinha, K. C., and Kuczek, T. (1994). "Effects of routine maintenance on flexible pavement condition." *Journal of Transportation Engineering*, 120(1), 65-73.

Baladi, G. Y., and Novak, E. "Pavement condition index-remaining service life." *Proc., Pavement Management Implementation symposium, 1991, Atlantic City, New Jersey, USA.*

Brown, E. R., Mallick, R. B., Haddock, J. E., and Bukowski, J. (1997). "Performance of stone matrix asphalt (SMA) mixtures in the United States." *Journal of the Association of Asphalt Paving Technologists*, 66(97), 426-457.

Carey Jr, W., and Irick, P. (1960). "The pavement serviceability-performance concept." *Highway Research Board Bulletin*(250).

El-Korchi, R. B. M. a. T. (2013). *Pavement Engineering: Principles and Practice, 2nd Edition*, CRC Press, Boca Raton.

Explorer, R. (2015). Utah Department of Transportation. <http://roadview.udot.utah.gov/> (12/16/2015, 2015).

Galehouse, L., Moulthrop, J. S., and Hicks, R. G. (2003). "Principles of Pavement Preservation: Definitions, Benefits, Issues, and Barriers." *TR NEWS*, 228(September-October), 52.

Haider, S., Baladi, G., Chatti, K., and Dean, C. (2010). "Effect of Frequency of Pavement Condition Data Collection on Performance Prediction." *Transportation Research Record: Journal of the Transportation Research Board*(2153), 67-80.

Ho, C.-H., and Romero, P. (2012). "Asphalt Mixture Beams Used in Bending Beam Rheometer for Quality Control: Utah's Experience." *Transportation Research Record: Journal of the Transportation Research Board*(2268), 92-97.

Irfan, M., Khurshid, M., and Labi, S. (2009). "Determining the Service Life of Thin Hot-Mix Asphalt Overlay by Means of Different Performance Indicators." *Transportation Research Record: Journal of the Transportation Research Board*(2108), 37-45.

Little, D. N., and Bhasin, A. (2007). "Exploring Mechanism of H ealing in Asphalt Mixtures and Quantifying its Impact." *Self healing materials*, Springer, 205-218.

Lytton, R. L., Uzan, J., Fernando, E. G., Roque, R., Hiltunen, D., and Stoffels, S. M. (1993). *Development and validation of performance prediction models and specifications for asphalt binders and paving mixes*, Strategic Highway Research Program.

Mallick, R. B., Kandhal, P., Cooley, L. A., and Watson, D. (2000). "Design, construction, and performance of new-generation open-graded friction courses." *Asphalt Paving Technology*, 69, 391-423.

Marasteanu, M., Velasquez, R., Falchetto, A. C., and Zofka, A. (2009). "Development of a simple test to determine the low temperature creep compliance of asphalt mixtures." *IDEA program final report NCHRP*, 133.

McGhee, K. H. (2004). "NCHRP SYNTHESIS 334." *Automated Pavement Distress Collection Techniques, A synthesis of Highway Practices, National Cooperative Highway Research Program, Washington, DC*.

Miller, J. S., and Bellinger, W. Y. (2014). "Distress identification manual for the long-term pavement performance program." *Report No. FHWA-HRT-13-092.*

Morian, D., Gibson, S., and Epps, J. A. (1998). "Maintaining Flexible Pavements-The Long Term Pavement Performance Experiment SPS-3 5-Year Data Analysis." *Report No. FHWA-RD-97-102.*

Myers, L. A., Roque, R., and Ruth, B. E. (1998). "Mechanisms of surface-initiated longitudinal wheel path cracks in high-type bituminous pavements." *Journal of the Association of Asphalt Paving Technologists*, 67.

Romero, P., Ho, C.-H., and VanFrank, K. (2011). "Development of Methods to Control Cold Temperature and Fatigue Cracking for Asphalt Mixtures." *Technical Report UT-10.08. UDOT.*

Shahin, M. Y. (2005). *Pavement management for Airports, Roads, and Parking Lots*, Springer Science + Business Media, LLC, New York.

Shahin, M. Y., and Kohn, S. D. (1981). "Pavement Maintenance Management for Roads and Parking Lots." *Report No. CERL-TR-M-294. Construction Engineering*. Research Lab, Champaign IL..

Su, K., Sun, L., Hachiya, Y., and Maekawa, R. (2008). "Analysis of shear stress in asphalt pavements under actual measured tire-pavement contact pressure." *Proceedings of the 6th ICPT, Sapporo, Japan*, 11-18.

Timm, D. H., and McQueen, J. M. (2004). "A study of manual vs. automated pavement condition surveys." *Report No. IR-04-01*. Highway Research Center, Alabama, EE. UU: Auburn University.

UDOT (2009A). "Pavement Preservation Manual Part 4." *Pavement Condition Modeling with DTIMS*

UDOT (2009B). "Pavement Preservation Manual Part 2." *Pavement Condition Data*

UDOT (2009C). "Pavement Preservation Manual Part 3." *Preservation Treatments*.