MOUNTAIN-PLAINS CONSORTIUM

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Evaluation of the Durability of Thin Lift Surface Treatments

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Disclaimer

ABSTRACT

Fourteen Thin Lift Treatments (TLTs) in Utah's Department of Transportation (UDOT) Region 2 were evaluated over a five-year period in order to assess their performance. Surface distress data was quantified using Pavement Condition Indices (PCIs), and Remaining Service Life (RSL) were estimated following procedures utilized by UDOT.

With the first 5 year's evaluation, 2 TLT sections have failed by Wheel Pass (WP) index, and 2 TLT sections have failed by ENV index. I-80.1 and SR-210 failed due to the WP evaluation, and SR-89 and SR-210 failed due to the ENV evaluation with SR-210 failing mainly due to environmental distresses. In total 3 sections have reached failure.

When all of the different treatments are grouped and both environmental and traffic loading were considered, it was found that the average life for the dense graded surface treatments was 7.3 years, while the average life for the open graded surface course was slightly better at 7.9 years. It is estimated that the average life of Stone Matrix Asphalt (SMA)is 11.7 years.

The local TLTs were compared to similar pavements from the Long Term Pavement Performance database. Both UDOT and LTPP roads are seeing a greater number of environmental failures as opposed to structural or wheel path failures.

It was concluded that environmental factors were the main cause of the deterioration of the surface treatments. The TLT's placed on UDOT's Region 2 have a life expectancy of at least 7 years. Based on their performance, it is recommended that, whenever feasible, SMA should be used on high valued roads.

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
DGA	Dense Graded Asphalt
ENV	Environmental
HMA	Hot Asphalt Mix
IRI	International Roughness Index
LNWP	Longitudinal Non-Wheel Path
LTPP	Long Term Pavement Performance
MAE	Maximum Allowable Extent
OGSC	Open Graded Surface Course
PCI	Pavement Condition Index
PG	Performance Grade
PMS	Pavement Management System
PSR	Present Serviceability Rating
RAP	Reclaimed Asphalt Pavement
SMA	Stone Matrix Asphalt
TLT	Thin Lift Treatment
UDOT	Utah Department of Transportation
WP	Wheel Path

EXECUTIVE SUMMARY

Fourteen thin lift treatments (TLTs) in UDOT's Region 2 were evaluated over a five-year period in order to assess their performance. Surface distress data was quantified using the Pavement Condition Index (PCI) and remaining service life (RSL), which were estimated following procedures developed by Baladi as utilized by the UDOT.

With the first five years' evaluation, two TLT sections had failed based on the wheel path (WP) index, and two TLT sections had failed based on the environmental (ENV) index. I-80.1 and SR-210 failed due to the WP evaluation; SR-89 and SR-210 failed due to the ENV evaluation, so in total three sections had reached failure. In the first five years, only SR-210 had completely fail under both environmental and loading related distress. SR-210 failed mainly due to environmental distresses, as the wheel path distress was influenced by the environmental conditions.

When all of the different treatments were grouped, and both environmental and traffic loading were considered, it was found that the average life for the dense graded surface treatments was 7.3 years; the average life for the open graded surface course was slightly better at 7.9 years. The two treatments in which a stone matrix asphalt (SMA) were used were doing extremely well, even though they supported the most traffic. It was estimated that the average life of the SMA will be 11.7 years.

Similarly, for local TLTs, the thin lift overlays from the long term pavement performance (LTPP) database saw a greater number of environmental failures as opposed to structural or wheel path failures. Wheel path failures accounted for 25% of the LTPP thin lift's failures and accounted for only 7% of the TLTs failures in this study. This could possibly be the result of the Marshall Design method not accounting for traffic and climate conditions.

1. INTRODUCTION

1.1 General

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

The decision as to which maintenance treatment to apply is made based on the pavement management system (PMS). The ultimate goal of any PMS is to maximize pavement life while minimizing cost. To do this, pavement condition data is collected and processed through a PMS. Once the data is entered into the database, forecasting techniques are used to estimate the remaining life of a pavement, and then maintenance decisions are based on these forecasts. Figure 1.1 shows a pavement condition curve and three types of maintenance activities: routine, preservation, and rehabilitation (Galehouse et al. 2003). These maintenance activities provide different functions, increasing in cost as pavement condition deteriorates. However, due to the nonlinear relationship between pavement age, condition, and maintenance cost, it is not always clear as to which maintenance activity will maximize pavement life while being the most cost-effective.

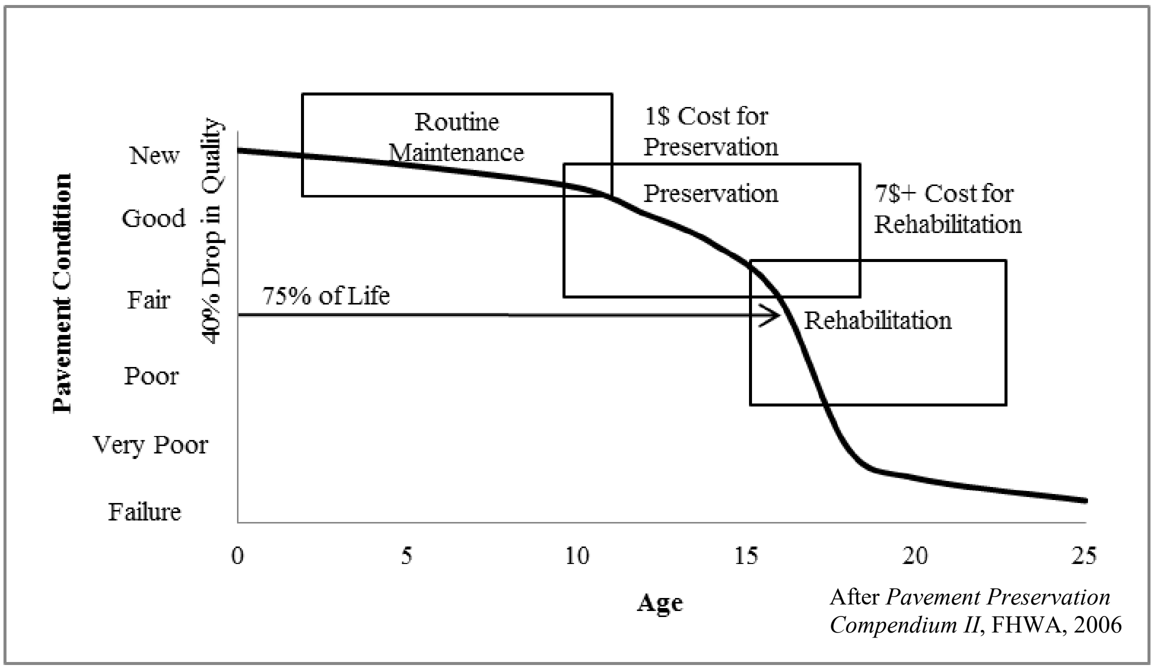


Figure 1.1 Pavement condition curve

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

Preservation treatments, when applied correctly, extend pavement life with minimal costs. 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). Common preservation treatments for asphalt pavements include chip seals, slurry seals, and thin lift overlays or treatments.

TLTs are an important tool within the maintenance preservation toolbox. They 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. Thin lifts treatments (TLTs) are more robust than the other preservation treatments and are more effective across a wider range of climate and distress conditions; however, they are also more expensive because they are thicker than other surface treatments and thus require more material.

The most cost-effective maintenance treatment type during a pavement's life is often uncertain as it depends on many factors (e.g., environment, traffic). The proper choice and timing of the maintenance treatment is challenging to determine. Applying a preservation treatment too soon does not provide a benefit that is worth the cost of a preservation treatment (Morian et al. 1998); however, delaying maintenance for rehabilitation can increase cost by as much as seven times when compared to preservation costs. That said, electing for preservation treatment when rehabilitation treatment 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 where the thresholds within the PMS are so that a pavement engineer can apply the most appropriate treatment at the right time.

1.2 Project Objectives

The objectives of this project are the following:

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

1.3 Scope

Fourteen TLTs applied on state routes in UDOTs Region 2 were evaluated. Data were collected based on image data surveys that were made available on Mandli Communication Roadview Explorer (http://168.178.125.102/UtahRVX3/index.php), and the International Roughness Index (IRI) data was provided by the UDOT. Of the 14 TLTs evaluated, eight were OGSC, four DGA, and two SMA. Out of the 14 TLTs, 12 were constructed in 2012 and the other two in 2013. The location, type, and construction date for these treatments are shown on Table 1.1. A map with the approximate locations of these sections is shown in Figure 1.2. Quantifying the performance of the three different mixture types and predicting the life expectancy of the TLTs are the subject of this report.

Table 1.1 Thin Lift Treatments (TLTs)

Route	Location	MP	TLT	Construction Date
36	Stansbury 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 Silver Creek	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

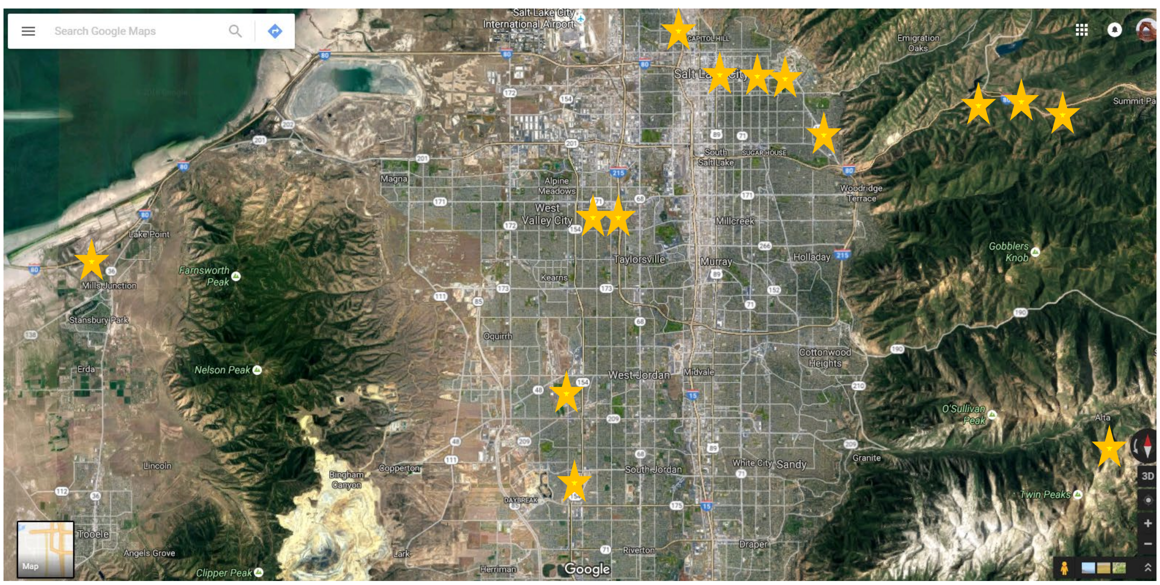


Figure 1.2 General location of projects evaluated

1.4 Outline of Report

This report contains the following chapters:

- Introduction
- Literature Review
- Methodology
- Data Evaluation
- Data Analysis
- Comparison to LTPP data
- Recommendations and Conclusions
- References

2. LITERATURE REVIEW

2.1 Thin Lift Treatments

Thin lift treatments (TLTs), or overlays, are hot-mix asphalt (HMA) products, usually one inch or one-and-half inches thick, that are typically applied to the top of existing flexible pavement. They are a preservation maintenance method that is well accepted by the pavement industry to increase the lifespan of pavements (Morian et al. 1998). UDOT utilizes three mix designs in their TLTs: dense grade asphalt (DGA), open grade surface course (OGSC), and stone matrix asphalt (SMA).

2.1.1 DGA

Dense grade asphalt (DGA) is a commonly used overlay by the UDOT. It is a densely-graded mixture classified by the nominal aggregate size, usually one-half to three-quarters of an inch. DGA overlays protect the pavement structure while adding some support, and it is a lower cost option when compared to a SMA or OGSC. The expected performance of DGA thin lift overlays has been reported to be seven to ten years (Irfan et al. 2009; UDOT 2009C).

2.1.2 OGSC

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

2.1.3 SMA

Stone matrix asphalt (SMA) is an open-graded mixture with a coarse rock skeletal structure designed to maximize stone-on-stone contact to prevent rutting. Similar to an OGSC, the SMA has a higher binder content than densely graded asphalt which allows the SMA to fill void spaces and increase service life. SMA mixtures may also 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. Of the three treatments evaluated, SMA is the most expensive treatment type due to the strict aggregate property requirements and high binder content. SMA is mostly used on high volume facilities, and its life expectancy has been reported to be between seven and ten years (Brown et al. 1997; UDOT 2009C).

2.2 Data Collection

Pavement condition surveys provide necessary data for pavement performance and analysis. Pavement condition data collects involves two main types of collection methods: manual and automatic (Timm and McQueen 2004). Regardless of the method used, the collected data is used for the pavement performance condition evaluation and forecasting, which are critical for anticipating maintenance needs, establishing maintenance priorities, and allocating funding.

Manual data collection is done by a person who walks along a sample section and visually identifies and assesses pavement distresses. Automatic data collection is done by driving a modified survey vehicle, mounted with imaging equipment and a sensor, down the road. The technology on these vehicles includes global positioning systems (GPS), sensory lasers to measure transverse and longitudinal profiles, and a set of high-resolution cameras. Data is captured with the vehicle moving at or near traffic speed (McGhee 2004), and then manually processed into a database. The reason why the automatic data cannot be imported directly into a database from the digital images is because the sensor and the camera only record the distresses' physical measurement such as the width and length; therefore, some interpretation is needed to identify the type and source of the distress. New, more sophisticated algorithms are constantly being developed so in the future human interpretation may not be necessary. An example of the vehicle used is shown in Figure 2.1.

Figure 2.1 Picture of data collection vehicle (from Mandli.com website)

The pavement condition data mostly consists of the Pavement Condition Index (PCI), International Roughness Index (IRI), and skid resistance. Historically, the first type of pavement condition data was the Present Serviceability Rating (PSR). It was defined as the mean user panel rating for rating a pavement condition with a score from 0 to 5. Since the PSR was subjective, it was replaced by the PCI and IRI. The PCI, which was developed by the U.S. Army Corps of Engineers, gives the pavement's initial score a value of 100, which represents a surface in perfect condition. The PCI measures distress of certain types or combines them to represent an overall pavement condition. The distresses are separated into climate and loading related distresses. The PCI is then used with forecasting techniques, which incorporates the rate of deterioration to predict pavement performance and plan maintenance activities (Shahin and Kohn 1981). The IRI is defined as a mathematical property of a two-dimensional road profile. It is the most commonly used roughness index to evaluate the pavement smoothness. Several studies of flexible pavements in the United States show a moderate correlation between IRI and PCI.

The PCI is separated into environmentally related distresses and loading related distresses in the wheel path. The Environmental Index (ENV) and Wheel Path Index (WP) are used to represent the surface condition based on the extent of the different distresses; both index numbers result in deduct values that are subtracted from the initial PCI. This process allows for the uniform quantification of the pavement condition as a function of time. The ENV is composed of transverse, longitudinal wheel path (LNWP) and block cracks, which are considered to be related to the environment and construction. The WP index only considers the cracks existing on the wheel path area, such as fatigue cracking, alligator cracking, and longitudinal cracking, which are caused by the loading. As previously mentioned, an initial pavement condition score starts at 100, which represents a pavement in the perfect condition; from this initial value, the deduct quantities are subtracted. Deduct values are assigned to distresses based on the extent, severity, and type of the distress which is measured from the image data. The severity level of each type of crack is based on the UDOT Distress handout.

2.3 Environmental (ENV) Index

The ENV index is used to determine the condition of the pavement from distresses caused by climatic factors. Environmental distress is highly related to changing temperatures, rain, and snow amounts. These natural elements will cause the pavement to develop longitudinal cracking, transverse cracking, and block cracking. Those cracks are measured according to their severity and are recorded to calculate the ENV index.

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

Construction related distresses are the result of poor compaction during construction. They are seen in LNWP cracks and are usually more prevalent on asphalt pavement joints. Additional environment-related distresses include raveling, which is the weathering of asphalt concrete that results in a loss of bond strength and separation between the asphalt and the aggregate. However, raveling was not recorded in this study and is not considered in scoring the climate condition index. The calculation for the ENV index for a 528 foot section is as follows (UDOT 2009A):

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

Where:

"Low", "Med", and "High" represents the severity level of the distress;
Trans = extent of Transverse Cracks (count);
Long = extent of Non-Wheel path Longitudinal Cracks (ft);
Block = extent of Block Cracks (ft).

2.3.1 Transverse Cracking

Transverse cracks, also known as low temperature cracking, are predominantly perpendicular to the pavement centerline. It is caused by the shrinkage of the mixture due to temperature changes. This kind of crack is recorded as the count number of transverse cracks on the section at each severity level. Figure 2.2 shows an example of a typical transverse crack. The transverse crack maximum allowable extent (MAE) for the low severity is one for every ten feet, or 53 cracks for a 528-foot sample section, for medium severity it is 75%, and for high severity it is 50%.

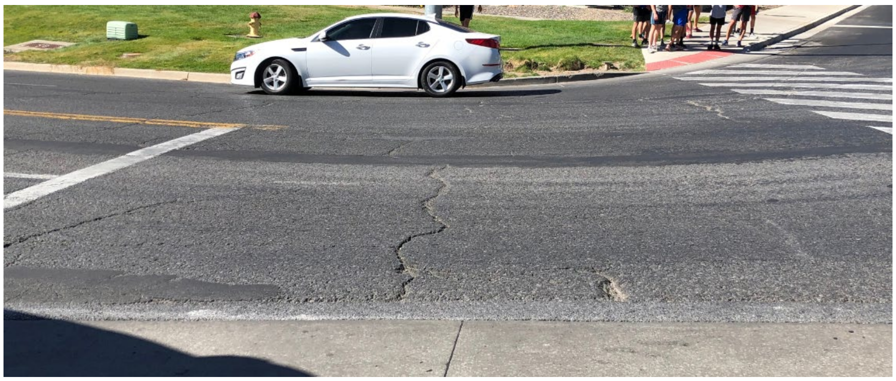


Figure 2.2 Transverse Crack

The severity level of the transverse crack is shown in Table2.1.

Table 2.1 Transverse Crack Severity Level

Severity level	Mean Width
Low	0 mm < & ≤ 6 mm
Moderate	6 mm < & ≤ 19 mm
High	> 19 mm

2.3.1 Block Cracking

Block cracking is the pattern of cracks that divides the pavement into approximately rectangular pieces, with sizes ranging between 0.1 and 10 m^2 (Federal Highway Administration). The MAE of the block crack for a 528 feet sample section at the low severity is 528 feet in total, at the medium severity level is 75%, and the high severity is 50%. Figure 2.3 shows an example of block cracks.

Figure 2.3 Block Crack

The severity level of the clock cracks is shown on Table 2.2.

Table 2.2 Block Crack Severity Level

Severity level	Mean Width
Low	0 mm < & ≤ 6 mm
Moderate	6 mm < & ≤ 19 mm
High	> 19 mm

2.3.2 Longitudinal Non-Wheel Path Cracking

Cracks predominantly parallel to the pavement centerline and located within the lane, but not on the wheel path, are classified as longitudinal non-wheel path (LNWP) cracks, while longitudinal cracking in the wheel path area is considered as the wheel path (WP) cracking. The LNWP crack is recorded as the length with sealant in good condition at each severity level. The MAE for the low severity LNWP is 528 feet of one, 528 feet sample sections, which is 100% of the section. The medium and high severity level are 75% and 50% of the surveyed section respectively. Figure 2.4 shows a picture of longitudinal cracking.

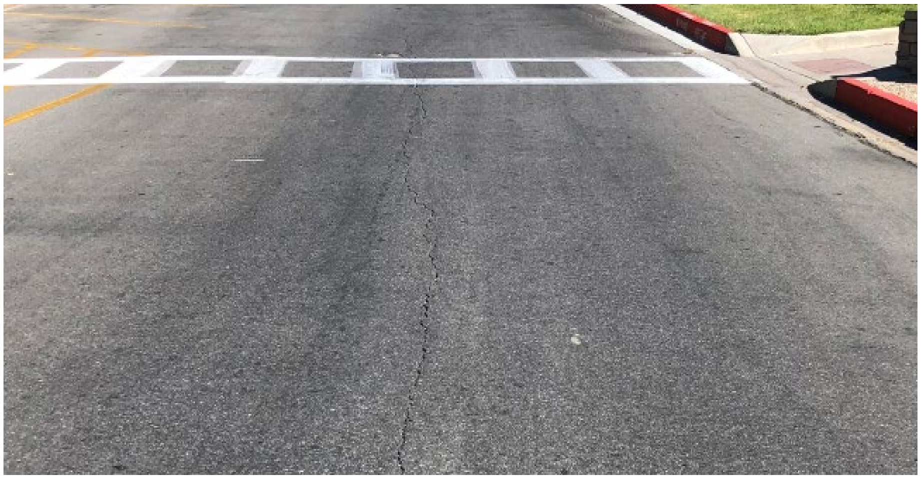


Figure 2.4 Longitudinal Crack

The severity level of the Longitudinal Non-Wheel Path Cracking is shown on Table 2.3.

Table 2.3 Longitudinal Crack Severity Level

Severity level	Mean Width
Low	0 mm < & ≤ 6 mm
Moderate	6 mm < & ≤ 19 mm
High	> 19 mm

2.4 WP Index

The WP index is a measurement of the fatigue and loading related distresses. The WP only calculates the wheel path cracking area of the surveyed section. The equation for one, 528 feet sample section is shown next.

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

Where:

WP = extent of Wheel path Cracks (ft)

The wheel path cracking is mainly caused by the asphalt concrete fatigue, with some longitudinal cracking existing on the wheel path area.

2.4.1 Wheel Path Cracking

WP cracking is also known as alligator cracking or fatigue cracking. The crack is mainly caused by the repeated traffic loadings in the wheel path area and some minor longitudinal crack on the construction joint. The WP crack is recorded as length but calculated as area, since it considers the WP as 1.5 feet wide in both wheel paths for the 528 feet sample section. The maximum allowable extent for a 528 feet long sample section is 40% of 1,584 square feet for the low severity level, 20% for medium severity, and 10% for high severity.

Low severity WP cracks are longitudinal cracks in the wheel path with few secondary cracks. Medium severity has interconnected cracks resembling an alligator's back. High severity is interconnected cracks with moderate to high severity spalling between them. WP cracking is primarily considered loading related (Miller and Bellinger 2014; UDOT 2009A). The normal longitudinal crack on the wheel path is counted as low-level WP cracking. A picture of this type of distress is shown on Figure 2.5.

Figure 2.5 Wheel Path Crack

2.5 International Roughness Index

The International Roughness Index (IRI) is defined as the primary factor for representing the ride quality of pavement in the Pavement Management System (PMS). It was developed by the World Bank's correlation experiment in Brazil in 1982 to mathematically represent the movement reaction of a single tire on a vehicle suspension, and it is used worldwide as an index for comparing pavement smoothness. Basically, the IRI is computed from a single longitudinal profile recorded by a moving quarter car, with this two-dimensional data representing the vertical movement of an object along the road profile. The value of the IRI ranges from 0 to 95 inch/mile representing the surface or pavement in good condition, from 95 to 170 inch/mile for fair condition, and any number higher than 170 inch/mile for poor condition.

The UDOT provided the IRI data from 2010 to 2017. This data was incorporated in this surface performance evaluation study.

3. METHODOLOGY

3.1 Pavement Surface Image Data Processing

Images of road surface conditions were collected and uploaded by Roadview Explorer® (Explorer 2018). The single-unit frame data contained the front view, which was taken by three mounted cameras on top of the moving vehicle. The image was recorded as a high-resolution quality image which allowed the viewer to enlarge the picture for detailed examination. The sensors recorded the surface condition and transformed the information into an organized top-view picture frame-by-frame which showed all of the measurable cracks as well as identified the severity level with a label. The visible distresses in the image data were identified according to the Federal Highway Administration's (FHWA) Distress Identification Manual for the Long-Term Pavement Performance (LTPP) project (Miller and Bellinger 2014). This top-view data provided the measurement function, which increased the reading accuracy of the distress data. The vehicle recorded the data in both directions for every pavement, and the GPS information was assigned to each single frame, making it easy to match the footage to the current route mileage system. A screen shot of the software is shown in Figure 3.1.

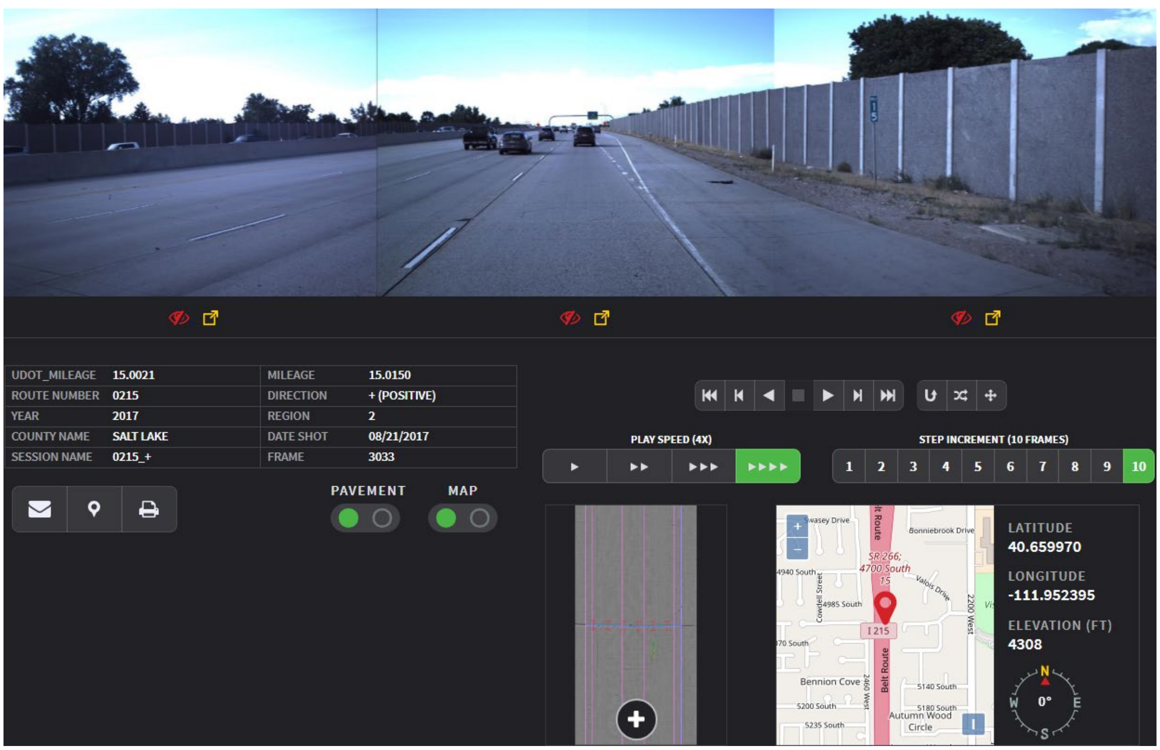


Figure 3.1 Screenshot of Roadview Explorer software

The image data for the entire treated TLT sections were collected, but the evaluated and inspected sample surface was only 1/5 of the original TLT sections, which is 528 feet per half mile. A single unit of the TLT section (1 mile per unit) was divided into ten sample sections (0.1 mile per sample), and two inspected sections (0.2 miles) were required as the minimum number for each single mile TLT section. TLT sections which were less than one mile also required a minimum of two inspected sections. The mileage starting point of the section could be rounded into the next closest two decimal mileage point within the TLT section.

The spacing interval between each inspected section was calculated by using the following equation:

$$\frac{Total\ Sample\ Sections\ Number}{Total\ Inspected\ Sections\ Number} * 0.1\ mile$$

The starting point of one inspected sample section always matched the TLT section starting mileage point unless the image data was incorrect.

Every inspected sample section data was recorded according to crack type, severity level, and cracking extent based on the identification manual; moreover, detailed information such as the location of each single crack was also recorded on the data sheet. Since the ENV and WP indexes are calculated based on different pavement distresses, it was necessary to classify each cracking by group, which helped with data quality control and quality assurance in the analysis. All of the cracks, or distresses, from the inspected section were indicated by different severity levels as L (low), M (medium), or H (high), and then the final amount of distress extents from all inspected sample sections were averaged to reach a number that represented the condition of the entire TLT section's condition.

The deduct value was then calculated based on the recorded cracking dimension. Deduct values came from the UDOT according to distress extent, severity level, and maximum allowable extents. The distress length, or area, was measured by using the measurement tool provided in the Roadview Explorer online software. The accuracy of the measurement tool was 1 millimeter, so the recorded length unit of the crack was recorded in millimeters and then converted into feet for calculating the deduct value. The measured surface was the right outside lane and represented the entire pavement section. This was done because most of the trucks travel on this lane. Finally, only one direction of the section was measured.

3.2 Data Points

The first data point was estimated as the approximate construction end date around 2012 and given a PCI value of 100. The second data point was collected two years after the surface treatment was applied, around 2014. More measurements followed in 2015 and 2017 for a total performance evaluation period of five years.

3.3 Traffic and Loading

Environmental data were analyzed based on a time scale, while load-related data was analyzed based on traffic, specifically, the available traffic counts (average annual daily traffic, [AADT]) were multiplied by the percent trucks. This value was then multiplied by three to represent the average number of axles. The data were interpolated and prorated based on the time scale.

4. DATA EVALUATION

4.1 Overview

Using the evaluation method described previously, the examination scores collected over the five years for the ENV index and WP index for each TLT section are presented in the following subsections. The IRI analysis was added after the evaluation, and a detailed description with a short conclusion for each surface section is provided as well.

The ENV index in each table was ordered by the observation date, and the WP index was ordered by the traffic load count. All of the data points shown in the summary table were post-treatment values, as the initial index values at the surface treatment construction time were assumed to be 100 and not listed in the tables. The IRI data for each TLT section is also shown as the average value with the standard deviation.

The group analysis for the WP, ENV, and IRI data is presented after the result review. The result review is divided by the types of TLT surfaces: OGSC, HMA, and SMA; the surface performance and predicted lifetime were summarized by the types of surface materials.

4.2 Open Graded Surface Course (OGSC) Sections

4.2.1 SR-36 Stansbury to I-80, MP 62.65 – 65.8

SR-36 section was constructed in July of 2012 and is located between Lake Point and Stansbury Park. It is a two lane road in both directions that serves the traffic between I-80 and Tooele. The AADT for SR-36 at this section was 25,225 for 2012 and 29,673 for 2016.

The total inspected sample section for SR-36 was 3168 feet long, which was six sections. There were no serious distresses found in September of 2015, only some low level WP and LNWP cracks, and only 0.63% of the transverse crack was found in the whole TLT section. In 2017, the surface condition was examined using both the WP and the ENV indexes; neither showed a significant increase. This information is shown in Table 4.1.

Table 4.1 SR-36 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	1.89%	100	99.09	97.61
		M	0.0%			
		H	0.0%			
	LNWP (ft)	L	2.58%			
		M	0.31%			
		H	0.0%			
	Block (ft)	L	0.0%			
WP	WP (ft^2)	L	6.7%	100	98.25	96.65
		M	0.0%			
		H	0.0%			
	Cumulative Loads Reps			4,858,633	9,218,945	15,970,571

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	51	50	38	-	46	49	52
	Stand. Dev	20	33	15	-	27	31	30

4.2.2 SR-89 Victory Rd. to Beck St., MP 381.5-383.8

The SR-89 section was constructed in August of 2012 and located in North Salt Lake. It runs north and south between I-15 and Limes Canyon and connects I-15 at Beck St; it is a three-lane arterial road in both directions. The AADT for SR-89 at this section was 20,520 in 2012 and 22,000 in 2016.

Four sample sections were evaluated from SR-89, with the total length of the inspected sections being 2,112 feet. Environmental distresses were observed in most of the surfaces on these sections. Its ENV index dropped from 92 to 67 in one year, primarily due to transverse cracks. The severity level of the transverse cracks measured in the four sections reached 64.29% of the MAE. According to the pre-treatment evaluation, transverse and block cracks were a majority of distresses on the surface before SR-89 received the treatment. The extent of transverse cracking was 20% and block cracking was 39%. It is possible that these pre-treatment distresses may have reflected on the post -treatment surface.

In contrast to the environmental distresses, the WP distresses did not show up as quickly. Most of the wheel path distresses were wheel path longitudinal cracks, and no obvious fatigue cracking was observed. This information is shown on Table 4.2.

Table 4.2 SR-89 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	47.64%	91.83	67.91	50.27
		M	11.88%			
		H	2.88%			
	LNWP (ft)	L	25.85%			
		M	9.96%			
		H	0.0%			
	Block (ft)	L	1.5%			
WP	WP (ft^2)	L	20.19%	99.41	97.08	89.29
		M	1.22%			
		H	0.0%			
	Cumulative Loads Reps			2,153,730	4,425,229	6,897,248

	Year	2010	2011	2012	2013	2014	2015	2017
IRI	AVE	86	95	90	-	79	91	106
	Stand. Dev	31	31	39	-	22	23	31

4.2.3 SR-186.1 State St. to 700 East, MP 2.7-3.6

The SR-186.1 section was constructed in July of 2012, and new utility construction was initiated on SR-186.1 before 2015. The right lane of this route had some construction work done on it, and some road sections received a new surface treatment which may have resulted in a slight increase in the ENV index.

The section from MP 2.7 to MP 3.6 is located between State Street and 700 East in the Salt Lake City downtown area. It is a three-lane arterial road in both directions. The AADT for SR-186 at this section was 20,945 in 2012 and 23,000 in 2016.

In total, two sections were evaluated for this route which is 1,056 feet long in total. The load-related and environmental distress extents did not exceed 8% for both performance results. The most obvious distress on SR-186.1 was bleeding, and this glass-like surface was found in the wheel path area all the way from the beginning point to the end, with some minor patches. However, since bleeding is not the considered a distress for the WP or ENV evaluation, both indexes remained constant from 2014 to 2017, as shown in Table 4.3.

Table 4.3 SR-186.1 Condition Data

	Cracking type	Severity	Extent (2017)	Index					
				2014		2015		2017	
ENV	Transverse (#)	L	6.6%						
		M	1.25%						
		H	0.0%						
	LNWP (ft)	L	0.0%	93.37		97.40		95.65	
		M	0.84%						
		H	0.0%						
	Block (ft)	L	0.0%						
WP	WP (ft^2)	L	3.43%						
		M	0.0%	100		99.89		98.28	
		H	0.0%						
	Cumulative Load Reps			1,643,004		3,410,859		5,416,855	
IRI	Year		2010	2011	2012	2013	2014	2015	2017
	AVE		153	191	167	-	169	182	164
	Stand. Dev		47	75	33	-	39	43	42

4.2.4 SR-186.2 700 East to 1300 East, MP 3.6-4.6

The SR-186.2 section was resurfaced in July of 2012. The section from MP 3.6 to MP 4.6 is located between 700 East and 1300 East in Salt Lake City and is a three lane arterial road in both directions. The AADT for SR-186 at this treatment section was 20,245 in 2012, and 27,000 in 2016. The pre-treatment evaluation show that the SR-186.2 had a value of 86 on the ENV index and 91 on the WP index.

Two sections were inspected on SR-186.2, and the most common distresses on SR-186.2 were LNWP and transverse cracks. The reason for the LNWP cracks on SR-186.2 seemed to be due to the quality of the construction joint. The LNWP crack was uniform and straight, and it followed the pathway on the right lane going through the wheel path at some points. The final results of the ENV and WP indexes were similar to the evaluation scores of the pre-treatment evaluation. This indicated that the distresses had reflected through the treatment. Table 4.4 shows the data for this section.

Table 4.4 SR-186.2 Condition Data

	Cracking type	Severity	Extent (2017)	Index					
				2014		2015		2017	
ENV	Transverse (#)	L	16.04%	99.53		95.72		85.55	
		M	1.25%						
		H	5.77%						
	LNWP (ft.)	L	0.46%						
		M	3.05%						
		H	2.34%						
	Block (ft.)	L	0.0%						
WP	WP (ft^2)	L	6.15%	98.38		99.64		96.41	
		M	2.09%						
		H	0.0%						
	Cumulative Load Reps			2,177,045		4,625,633		7,376,736	
IRI	Year		2010	2011	2012	2013	2014	2015	2017
	AVE		165	161	181	-	143	157	162
	Stand. Dev		50	41	49	-	59	64	57

4.2.5 SR-269 I-15 to 200 West, MP 0-0.5 & 1.4-1.8

The SR-269 section was constructed in August of 2012 and is a four lane, one-way arterial road on both sections. The sections from MP 0.0 to MP 0.5 and MP 1.4 to MP 1.8 are located between 300 West and State Street in Salt Lake City on both 500 South and 600 South. SR-269 on 600 South handles eastbound traffic from I-15, and SR-269 on 500 South handles westbound traffic from I-15. The AADT for SR-269 at this section was 41,540 in 2012 and 49,000 in 2016.

Two sections were evaluated on SR-269; each eastbound and westbound portion had one inspected sample section. Both the ENV and WP indexes had a significant drop from a good condition to almost failure condition in just two years because of the longitudinal cracks. The majority of the deterioration that was seen on the wheel path were longitudinal cracks. In addition, the traffic on SR-269 by 2017 had already reached twenty million load repetitions as shown in Table 4.5.

Table 4.5 SR-269 Condition Data

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cracking type</th><th rowspan="2">Severity</th><th rowspan="2">Extent (2017)</th><th colspan="6">Index</th></tr>
<tr><th colspan="2">2014</th><th colspan="2">2015</th><th colspan="2">2017</th></tr>
<tr><td rowspan="7">ENV</td><td rowspan="3">Transverse (#)</td><td>L</td><td>11.95%</td><td colspan="2" rowspan="7">96.69</td><td colspan="2" rowspan="7">93.39</td><td colspan="2" rowspan="7">78.83</td></tr>
<tr><td>M</td><td>3.33%</td></tr>
<tr><td>H</td><td>1.28%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td>L</td><td>17.59%</td></tr>
<tr><td>M</td><td>6.46%</td></tr>
<tr><td>H</td><td>0.0%</td></tr>
<tr><td>Block (ft)</td><td>L</td><td>0.31%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft^2)</td><td>L</td><td>29.36%</td><td colspan="2" rowspan="3">94.67</td><td colspan="2" rowspan="3">95.79</td><td colspan="2" rowspan="3">79.32</td></tr>
<tr><td>M</td><td>3.94%</td></tr>
<tr><td>H</td><td>8.06%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">6,289,214</td><td colspan="2">12,070,284</td><td colspan="2">20,283,460</td></tr>
<tr><td rowspan="3">IRI</td><td colspan="2">Year</td><td>2010</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td><td>2017</td></tr>
<tr><td colspan="2">AVE</td><td>116</td><td>128</td><td>-</td><td>-</td><td>107</td><td>110</td><td>127</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>19</td><td>35</td><td>-</td><td>-</td><td>29</td><td>27</td><td>65</td></tr>
</table>

4.2.6 I-80.1 Fire Station to Silver Creek, MP 145.5-147.5

The I-80.1 section from MP 145.5 to MP 147.5 was constructed in June of 2012. This section is located between Salt Lake City and Summit County and is a three lane highway in both directions. The AADT for SR-80 at this section was 32,125 in 2012 and 40,000 in 2016.

For section I-80.1, a TLT utilizing OGSC was complete in June of 2012. A total of four sample sections were evaluated. The most recognizable distress on I-80.1 was the wheel path longitudinal cracks. This TLT section had significant longitudinal cracks on the wheel path area, which brought the WP index below the 75 threshold value after 2017. It is believed that the reasons for these cracks were either the high traffic volume or pre-treatment distresses that reflected through the treatment, or perhaps both. This interstate highway was one the busiest in Utah with 40,000 AADT in 2016, with 39% of those vehicles being trucks as shown on Table 4.6.

Table 4.6 I-80.1 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014		Index 2015		Index 2017	
ENV	Transverse (#)	L	5%	100		95.51		92.33	
		M	1%						
		H	0%						
	LNWP (ft)	L	3%						
		M	6%						
		H	1%						
	Block (ft)	L	0%						
WP	WP (ft^2)	L	68%	100		91.97		66.05	
		M	0%						
		H	0%						
	Cumulative Load Reps			9,046,952		16,989,213		27,802,986	
IRI	Year		2010	2011	2012	2013	2014	2015	2017
	AVE		59	74	53	-	49	57	65
	Stand. Dev		13	27	12	-	10	14	19

4.2.7 I-80.2 High Ute Ranch to Fire Station, MP 143.0-145.2

The I-80.2 section was resurfaced in June of 2012 just like I-80.1. This section extended from MP 143.0 to MP 145.2 is located between High Ute Ranch and the Fire Station on I-80 and is a three lane highway in both directions. The AADT for I-80 at this section was 47,075 in 2012 and 59,000 in 2016.

A total of four sample sections were evaluated. Based on the visual survey, I-80.2 had a better surface condition than I-80.1. It had fewer cracks and a darker surface color. From the pre-treatment evaluation result, I-80.2 contained approximately 49% LNWP cracks and only 6% WP cracks. The post-treatment result showed that I-80.2 had fewer LNWP cracks than WP cracks, with wheel path results in the twenty-fourth percentile of MAE and LNWP only in the ninth percentile. This is shown on Table 4.7.

Table 4.7 I-80.2 Condition Data

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cracking type</th><th rowspan="2" colspan="2">Severity</th><th rowspan="2">Extent (2017)</th><th colspan="4">Index</th></tr>
<tr><th colspan="2">2014</th><th colspan="2">2015</th><th>2017</th></tr>
<tr><td rowspan="7">ENV</td><td rowspan="3">Transverse (#)</td><td colspan="2">L</td><td>16%</td><td colspan="2" rowspan="7">99.29</td><td colspan="2" rowspan="7">92.06</td><td rowspan="7">84.47</td></tr>
<tr><td colspan="2">M</td><td>6%</td></tr>
<tr><td colspan="2">H</td><td>1%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td colspan="2">L</td><td>4%</td></tr>
<tr><td colspan="2">M</td><td>5%</td></tr>
<tr><td colspan="2">H</td><td>0%</td></tr>
<tr><td>Block (ft)</td><td colspan="2">L</td><td>0%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft^2)</td><td colspan="2">L</td><td>13%</td><td colspan="2" rowspan="3">99.94</td><td colspan="2" rowspan="3">99.25</td><td rowspan="3">91.88</td></tr>
<tr><td colspan="2">M</td><td>2%</td></tr>
<tr><td colspan="2">H</td><td>1%</td></tr>
<tr><td colspan="4">Cumulative load reps</td><td colspan="2">4,932,948</td><td colspan="2">13,959,839</td><td>26,314,134</td></tr>
<tr><td rowspan="3">IRI</td><td>Year</td><td colspan="2">2010</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td><td>2017</td></tr>
<tr><td>AVE</td><td colspan="2">59</td><td>63</td><td>62</td><td>-</td><td>48</td><td>49</td><td>60</td></tr>
<tr><td>Stand. Dev</td><td colspan="2">12</td><td>13</td><td>16</td><td>-</td><td>10</td><td>11</td><td>12</td></tr>
</table>

4.2.8 SR-171 Redwood to 700 West, MP 8.0-9.4

Section SR-171 was constructed in July of 2013, which was the most recent construction surface out of the 14 TLT sections in this study. This section extended from MP 8.0 to MP 9.4 and is located between Redwood Road and 700 West. It is a three-lane arterial road in both directions. The AADT for SR-171 at this section was 28,920 in 2012 and 32,000 in 2016.

A total of three sample sections were selected for evaluation. After the examination, the condition of this TLT section was rated good, with both the ENV index and WP index having values higher than 90. No significant distress issues were experienced on this route, and most of the cracks appeared at the intersection or near a drainage well. It was noted that the ENV index increased from 2014 to 2015; this was attributed to changes in the camera systems used in the recording vehicle. Table 4.8 presents this data.

Table 4.8 SR-171 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	6%	94.95	99.06	92.54
		M	4%			
		H	0%			
	LNWP (ft)	L	5%			
		M	0.33%			
		H	0%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	10%	100	99.45	94.79
		M	1%			
		H	0%			
	Cumulative Load Reps			2,065,786	6,147,590	11,527,695

IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	95	84	98	-	90	100	112
	Stand. Dev	44	35	48	-	51	49	51

4.2.9 Summary of OGSC

Eight OGSC TLT sections were evaluated; only one section showed a PCI below 75. Table 4.9 provides a summary of the evaluation.

Table 4.9 Summary of OGSC Evaluation

OGSC		2014	2015	2017
SR-36	ENV	100	99.09	97.61
	WP	100	98.25	96.65
	IRI	46	49	52
SR-89	ENV	91.83	67.91	50.27
	WP	99.41	97.08	89.29
	IRI	79	91	106
SR-186.1	ENV	93.37	97.4	95.65
	WP	100	99.89	98.28
	IRI	169	182	164
SR-186.2	ENV	99.53	95.72	85.55
	WP	98.38	99.64	96.41
	IRI	143	157	162
SR-269	ENV	96.69	93.39	78.83
	WP	94.67	95.79	79.32
	IRI	107	110	127
I-80.1	ENV	100	95.51	92.33
	WP	100	91.97	66.05
	IRI	49	57	65
I-80.2	ENV	99.29	92.06	84.47
	WP	99.94	99.25	91.88
	IRI	48	49	60
SR-171	ENV	94.95	99.06	92.54
	WP	100	99.48	94.79
	IRI	90	100	112

4.3 Dense Graded Asphalt (DGA) Sections

4.3.1 SR-48 MP 1.2 to 9000 South, MP 1.2-4.4

SR-48 (marked as SR-209 after 2015) DGA section was resurfaced in May of 2012. This TLT section extended from MP 1.2 to MP 4 and is located from MP 1.2 to 9000 South; it is a single lane road in both directions. The AADT for SR-48 at this section was 3,750 in 2012 and 4,400 in 2016.

This DGA thin lift treatment had six inspected sections. After no real changes in the WP index from 2012 to 2015, the WP index dropped sharply after 2015. In 2017 the WP index dropped to 74.65, which is just below the wheel path index threshold value. Most of the distress on SR-48 were wheel path cracks primarily caused by load and asphalt fatigue. A large area of the alligator cracks was seen on both the left and right wheel path areas. Other minor, longitudinal cracking occurred along the wheel path as well as some asphalt fatigue cracks. Table 4.10 shows this data.

Table 4.10 SR-48 Condition Data

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cracking type</th><th rowspan="2">Severity</th><th rowspan="2">Extent (2017)</th><th colspan="6">Index</th></tr>
<tr><th colspan="2">2014</th><th colspan="2">2015</th><th colspan="2">2017</th></tr>
<tr><td rowspan="7">ENV</td><td rowspan="3">Transverse (#)</td><td>L</td><td>8%</td><td colspan="2" rowspan="7">95.53</td><td colspan="2" rowspan="7">92.97</td><td colspan="2" rowspan="7">80.33</td></tr>
<tr><td>M</td><td>3%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td>L</td><td>15%</td></tr>
<tr><td>M</td><td>13%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td>Block (ft)</td><td>L</td><td>0%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft²)</td><td>L</td><td>40%</td><td colspan="2" rowspan="3">100</td><td colspan="2" rowspan="3">97.48</td><td colspan="2" rowspan="3">79.70</td></tr>
<tr><td>M</td><td>2%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">1,132,590</td><td colspan="2">1,766,468</td><td colspan="2">2,868,003</td></tr>
<tr><td rowspan="3">IRI</td><td colspan="2">Year</td><td>2010</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td><td>2017</td></tr>
<tr><td colspan="2">AVE</td><td>110</td><td>116</td><td>129</td><td>-</td><td>135</td><td>130</td><td>144</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>53</td><td>64</td><td>69</td><td>-</td><td>52</td><td>61</td><td>86</td></tr>
</table>

4.3.2 SR-154 13800 South to Bangerter, MP 0.0-0.5

SR-154 section was resurfaced in July of 2012 and runs from MP 0.0 to MP 0.5, or physically from 13800 South to Bangerter highway. It is a two-lane arterial road in both directions. The AADT for SR-154 at this section was 16,630 in 2012 and 20,000 in 2016.

Two sample sections were selected for this route evaluation. Both the ENV and WP indexes were still slightly above their threshold value, which meant that the section had not failed yet. The main distress on this section was longitudinal cracking along the road, with more than half of thecracking observed in the wheel path area. This data is shown on Table 4.11.

Table 4.11 SR-154 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	5%	100	86.51	72.84
		M	0%			
		H	0%			
	LNWP (ft)	L	31%			
		M	18%			
		H	0%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	31%	100	90.39	83.85
		M	2%			
		H	0%			
	Cumulative Load Reps			1,023,536	2,013,436	3,290,537

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	131	126	138	-	114	129	113
	Stand. Dev	27	23	13	-	23	29	33

4.3.3 SR-210 Alta Bypass, MP 12.5-13.6

SR-210 TLT section was resurfaced on August of 2012 and extends from MP 12.5 to MP 13.6, which provides access to the Alta Mountain Resort. It is a single lane, two directions bypass road. The AADT for SR-210 at this section was 175 in 2012 and 1,900 in 2016. This route was a special case for this surface performance evaluation study due to the unique elevation of this route of 8,500 feet.

The average annual snowfall for this area is 514 inches, while the average annual snowfall for the Salt Lake Valley is only 82 inches. This is believed to be the primary reason for the the negative value on the ENV index for SR-210. The cracks on SR-210 were deep and wide; 87% of the LNWP cracks were high severity level, and 93% of the transverse cracks were also high-severity level. SR-210 has the lowest traffic load, but was the first section with an ENV index value below the threshold. It is evident that the reason SR-210 had such a low value on the WP index was partially due to environmental distresses. This is presented on Table 4.12.

Table 4.12 SR-210 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	6%	85.22	40.45	-13.54
		M	16%			
		H	71%			
	LNWP (ft)	L	3%			
		M	14%			
		H	117%			
	Block (ft)	L	7.9%			
WP	WP (ft^2)	L	6%	99.92	89.79	24.42
		M	89%			
		H	57%			
	Cumulative Load Reps			3,411	17,456	50,840

IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	173	190	141	-	156	159	193
	Stand. Dev	38	44	25	-	33	33	52

4.3.4 SR-68 1000 North to Davis County line, MP 60.8-62.9

The SR-68 section was resurfaced on July of 2013. It is a single lane arterial road in both directions that extends from MP 60.8 to MP 62.9, which is from 1000 North to Davis County line. The AADT for SR-154 at this section was 13,130 in 2012 and 12,000 in 2016.

SR-68 performed well on both the ENV and WP indexes; four sections were evaluated, and, according to the data, there were not any serious cracks on it, except from MP 62.7 to 62.8. This section had a construction joint crack that went from right to left along the TLT section. The cause of this crack is believed to be due to poor shoulder construction quality and cannot be simply counted as wheel path cracking. It was included in the percentage of the extent of cracking type based on the amount of LWP and LNWP on the surface. Table 4-13 shows this information.

Table 4.13 SR-68 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	2%	100	95.87	95.77
		M	0%			
		H	0%			
	LNWP (ft)	L	1%			
		M	6%			
		H	0%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	10%	100	93.96	94.82
		M	1%			
		H	0%			
	Cumulative Load Reps			541,977	1,644,504	2,586,614

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	68	97	98	-	70	79	77
	Stand. Dev	11	25	27	-	11	20	20

4.3.5 Summary of DGA

A total of four sections were evaluated for DGA. Of those four sections, one failed. Table 4.14 provides a summary of the evaluation of the DGA TLTs.

Table 4.14 Summary of DGA Evaluation

DGA		2014	2015	2017
SR-48	ENV	95.53	92.97	80.33
	WP	100	97.48	79.7
	IRI	135	130	144
SR-154	ENV	100	86.51	72.84
	WP	100	90.39	83.85
	IRI	114	129	113
SR-210	ENV	85.22	40.45	-13.54
	WP	99.92	89.79	24.42
	IRI	156	159	193
SR-68	ENV	100	95.87	95.77
	WP	100	93.96	94.82
	IRI	70	79	77

4.4 Stone Matrix Asphalt (SMA) Sections

4.4.1 I-80.3 Ranch Exit to Lambs, MP 131.7-136.1

The I-80.3 section, a three lane highway in both directions, was resurfaced in July of 2012 and was treated with stone matrix asphalt (SMA) from MP 131.7 to MP 136.1. The AADT for this section was 45,960 in 2012 and 58,000 in 2016.

I-80.3 section TLT is the first SMA TLT surface on I-80, and a total of eight sample sections were evaluated. Both of the ENV and WP indexes showed good performance from for 2015 and 2017, especially the WP index, which still maintained a value of 99 after 25 million load repetitions. The major cracks on I-80.3 were low severity level LNWP cracks, with the extent reaching 14% of the MAE which made the ENV index drop to 90. This is summarized on Table 4.15.

Table 4.15 I-80.3 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	1%	97.16	95.63	90.06
		M	0%			
		H	0%			
	LNWP (ft)	L	14%			
		M	3%			
		H	2%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	1%	99.89	99.92	99.42
		M	0%			
		H	0%			
	Cumulative Load Reps			8,406,869	15,422,559	25,072,601

IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	77	76	87	-	54	56	62
	Stand. Dev	22	18	32	-	10	11	13

4.4.2 I-215 End PCCP to 3300 South, MP 0.8-1.8

The I-215 section was resurfaced in June of 2012. This section was treated from MP 0.8 to MP 1.8, which is from the Belt Route and I-80 intersection to 3300 South. It is a two lane highway ramp from MP 0.8 to 1.2, and a three lane highway from MP 1.2 to 1.8 in both directions. The AADT for I-215 at this section was 69,580 in 2012 and 75,000 in 2016.

Only two sections were available for evaluation. Similar to the treated section on I-80.3, this SMA treated surface showed good performance on both the ENV and WP indexes, in spite of having the highest traffic volume of all sections. According to the evaluated sample sections, only 1% of the MAE of the wheel path crack was discovered on the treatment surface in year 2017. This is shown in Table 4.16.

Table 4.16 I-215 Condition Data

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cracking type</th><th rowspan="2">Severity</th><th rowspan="2">Extent (2017)</th><th colspan="6">Index</th></tr>
<tr><th colspan="2">2014</th><th colspan="2">2015</th><th colspan="2">2017</th></tr>
<tr><td rowspan="7">ENV</td><td rowspan="3">Transverse (#)</td><td>L</td><td>5%</td><td rowspan="7" colspan="2">100</td><td rowspan="7" colspan="2">96.20</td><td rowspan="7" colspan="2">91.95</td></tr>
<tr><td>M</td><td>1%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td>L</td><td>8%</td></tr>
<tr><td>M</td><td>2%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td>Block (ft)</td><td>L</td><td>0%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft^2)</td><td>L</td><td>9%</td><td rowspan="3" colspan="2">100</td><td rowspan="3" colspan="2">94.81</td><td rowspan="3" colspan="2">95.55</td></tr>
<tr><td>M</td><td>1%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">12,596,690</td><td colspan="2">26,001,407</td><td colspan="2">40,451,170</td></tr>
<tr><td rowspan="3">IRI</td><td colspan="2">Year</td><td>2010</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td><td>2017</td></tr>
<tr><td colspan="2">AVE</td><td>83</td><td>87</td><td>77</td><td>-</td><td>73</td><td>75</td><td>80</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>32</td><td>32</td><td>19</td><td>-</td><td>17</td><td>23</td><td>26</td></tr>
</table>

4.4.3 Summary of SMA Sections

Two SMA sections were evaluated, both of them performed well. The results are shown in Table 4-17.

Table 4.17 Summary of SMA Evaluation

SMA				
		2014	2015	2017
I-80.3	ENV	97.16	95.63	90.06
	WP	99.89	99.92	99.42
	IRI	54	56	62
I-215	ENV	100	96.2	91.95
	WP	100	94.81	95.55
	IRI	73	75	80

4.5 International Roughness Index

The International Roughness Index (IRI) consists of localized information on the smoothness of road sections; given the level of detailed information, some variability is expected. Unlike the surface condition index, IRI is a measurement describing the surface changing rate along the whole road profile. IRI values start at zero; a higher IRI value represents a rougher road surface. In this study, all of the TLT sections had a unique IRI starting point because of their local surface condition; in other words, the same treatments on several different road sections could have totally different IRI values even though the road conditions for those sections were similar. Thus, a quantitative value of the road condition index number does not correlate well to the scale of the IRI since the measurement method for both are completely different. Only some minor correlations between the IRI and the condition index were found to exists.

As expected, all of the TLTs had a lower IRI after they received the treatment. An increase in the IRI is expected as the road is damaged by the environment and traffic. More distresses on the road are expected to cause a higher IRI. A larger standard deviation is also expected due to the increased variability of the road surface condition. For the yearly IRI average value, a clear drop was observed between 2012 and 2013, and the standard deviation also decreased after the surface was treated. The lower standard deviation represents a more consistent IRI result for the entire treated road section. The TLTs offered a newer surface with less variability, and thus a lower IRI number and standard deviation were expected after the treatment. However, the road continually supports loads, so the damage increases and the surface gets more distressed every year; therefore, it is anticipated that the IRI and its standard deviation will also increase with time.

5. ANALYSIS

5.1 Evaluation

The thin lift treatment performance evaluation analysis was separated into two deterioration distress types, environmental distress (ENV) and loading-related distress (WP) in the wheel path. The ENV index was analyzed based on the time since the application of the TLT, given that the weather and temperature are time-dependent factors. The WP index was analyzed based on the traffic loading count as explained in Section 3.3. It was assumed that the condition of the treated surface right after the TLT was ideally perfect, and thus the ENV and WP index were both 100 at this point.

5.2 Life Expectancy Estimates

The life expectancy of a TLT is estimated by the crossing point of the pavement condition curve with the threshold line. The performance curve of each section could be extended based on the general condition curve with each unique decreasing trend. By extending the decreasing trend in a reasonable manner, the intersection with the threshold line can then be used to estimate the life of the TLTs based on the ENV or WP evaluation.

5.3 Environmental Factors

Figure 5.1 is a summary of all 14 TLT surface ENV index data points. As was discussed in the previous chapter, many factors contribute to environmental distresses. Given that all of the sections except for one were located in approximately the same geographic region, factors such as temperature, precipitation, sunshine, snow, etc. are considered to be relatively equal. Therefore, based on the assumption that the weather factors for most of these sections were approximately the same, the time dependent relationship graph was created.

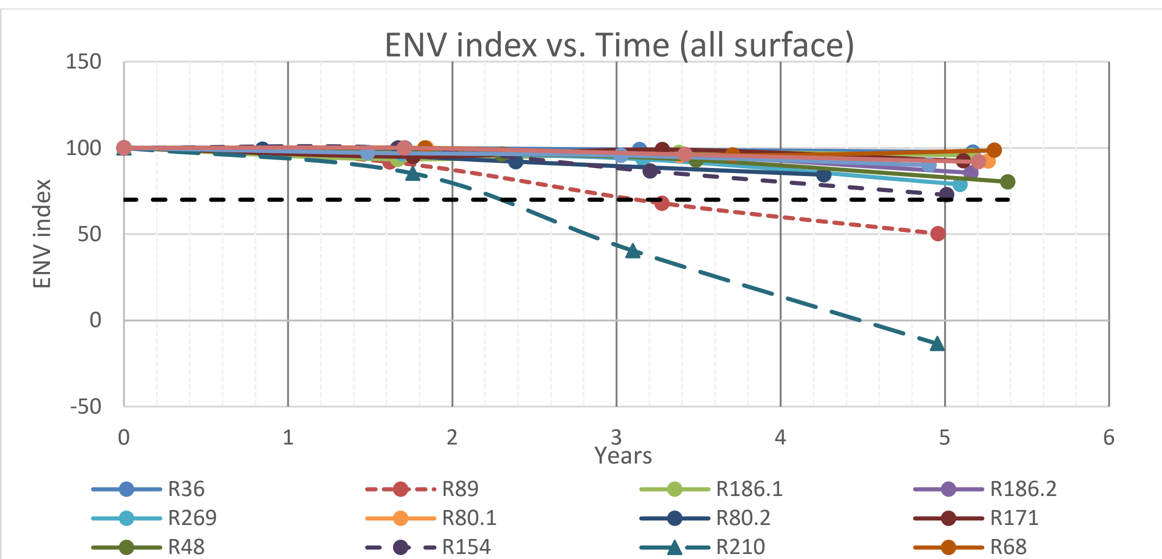


Figure 5.1 ENV Index Summary Plot

The ENV index summary plot shows the expected decreasing trend at an increasing rate for most TLT sections. SR-210 and SR-89 failed at year two and three, respectively. The remaining TLTs surfaces have an estimated life that ranges from six to 11 years. Half of the TLT sections had more LNWP cracks in comparison to other distresses; this is a common problem due to low density at the pavement surface joint. The other half of the TLT sections had significant transverse cracks caused by the low temperature environmental condition. Most of the TLT surface treatments followed the expected life predictions, with the exception of SR-210 and SR-89.

5.3.1 DGA ENV study

In order to better understand the performance of each type of TLT, the data was separated into treatment types. Figure 5.2 shows the ENV index of the DGA surface only. SR-154, SR-68, and SR-48 have a fairly constant deterioration rate after two-and-half years, but SR-210 did not follow this pattern, and instead deteriorated much more quickly over the same timeframe.

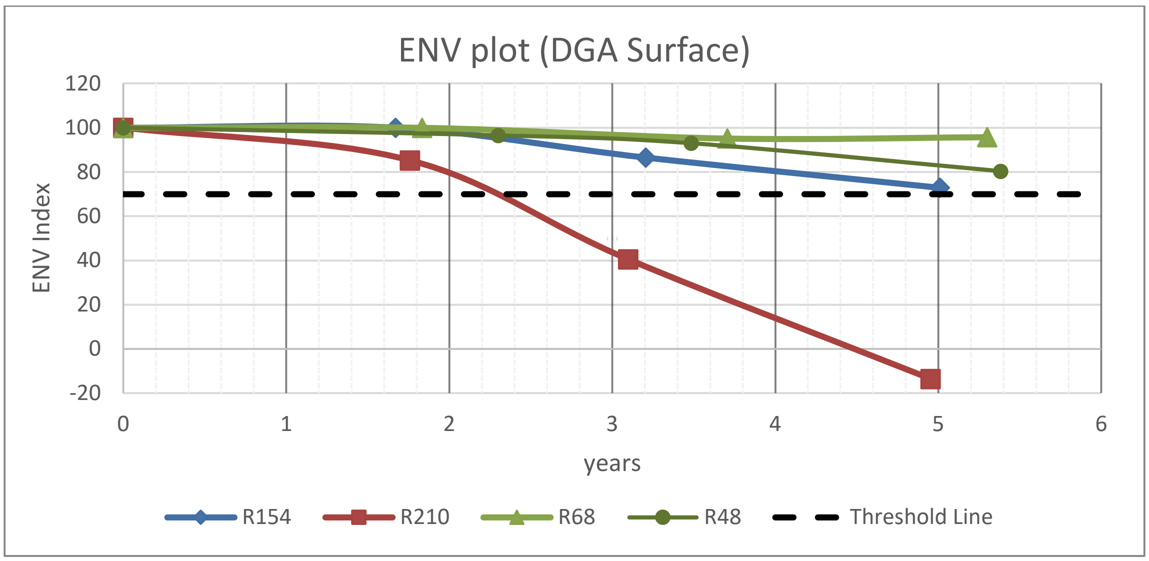


Figure 5.2 DGA TLTs ENV plot

As was discussed in Section 4.3.3, SR-210 is the route going to Alta and the Snowbird Mountain Resort, thus it is subjected to harsh winter conditions. The average elevation of SR-210 is 8000 feet from the sea level, which is 3800 feet higher than Salt Lake City. As shown in Table 5.1, this higher elevation leads to an average temperature for SR-210 section that is about 10 degrees lower than greater Salt Lake area (NOAA Data), and the snowfall in the Alta area is ten times more than that in the Great Salt Lake area. This environment is believed to be a critical issue for the SR-210 TLT section as it led the surface to start rapidly deteriorating before 2015. As a result, this route has the worst performance score out of the 14 treatments evaluated; however, it can be argued that the observed performance is an outlier and not representative of DGAs.

Table 5.1 Environmental Data Summary

	SR-210	Salt Lake City
Average Lowest T (C°)	-10	-3
Average Highest T (C°)	22	32
Average Maximum Snowfall (Dec) (mm)	2017.1	289.1
Average Maximum Rainfall (Apr) (mm)	165.4	59.1

The other three DGA treatments studied have a better score than SR-210. By following the data point decreasing trend, the lifetime for each section was estimated and the result is shown on Table 5.2.

Table 5.2 DGA Environmental Lifetime Estimation

State Route	Estimated life (years)	Already past (years)	Remain life (years)	Total life Average (years)
48	6.8	5.4	1.4	7.4
154	5.5	5.0	0.5	
210	2.3	5.0	-2.7	
68	10.0	5.3	4.7	

SR-210 failed at 2.3 years due to the ENV performance. Excluding that section, the average lifetime of DGA thin lift treatment increased to 9.2 years.

5.3.2 OGSC ENV study

The OGSC surface treatment comprised the largest sample group in this study. The ENV indexes for all of the OGSCs are shown in Figure 5.3. Seven sections had reasonable decreasing trends, but SR-89 stands out from the group. The estimated life ranges for OGSC surface treatment due to the ENV index condition is between six and 11 years, with the average of being 7.2 years, SR-89 being the exception since it failed at 3.3 years.

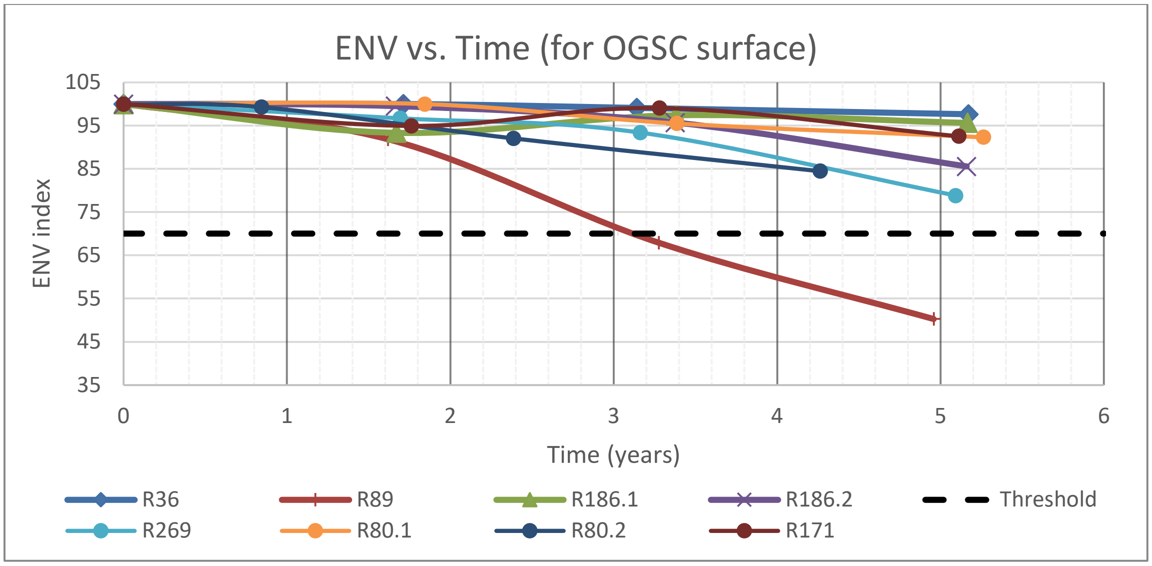


Figure 5.3 OGSC TLTs ENV Index Plot

After five years, the ENV index for a majority of the OGSC surface treatments ranged from 78 to 97 (SR-89 was out of range). As Figure 5-3 shows, the ENV index value of SR-171, SR-186, and I-80 increased moderately from 2014 to 2015. Physically this is unlikely, although the "self-healing" of asphalt pavement has been reported. Self-healing is still a challenging issue for pavement engineering because it is a complicated mechanism that is not well understood and was not considered for this study. Thus "self-healing" will not be discussed or evaluated under this performance evaluation section. Instead, the increase will be considered an anomaly observation.

The estimated life for each single OGSC TLT is shown in Table 5.3. The average lifetime for the OGSC thin lift treatment is about 7.2 years. SR-89 failed after 3.2 years, and SR-269 is expected to fail in the next half year. The other sections remain in good or fair condition, which means that these sections, on average, have about three years of life remaining. These results match the expectation from other general studies.

Table 5.3 OGSC Environmental Lifetime Estimation

State Route	Estimated life (years)	Already past (year)	Remain life (years)	Total Life AVE (years)
36	10.4	5.2	5.2	7.2
89	3.2	5.0	-1.8	
186.1	8.7	5.2	3.6	
186.2	6.9	5.2	1.7	
269	5.7	5.1	0.6	
80.1	7.4	5.3	2.1	
80.2	7.7	4.3	3.4	
171	8.0	5.1	2.9	

5.3.3 SMA ENV Study

The SMA treatment consisted of only two sections, I-215 and I-80.3. As shown in Figure 5.4, both SMA sections have a high ENV index. After five years, both sections still have a value above 90. The extended trend line shows the estimated lifetime for I-215 as ten years and for I-80.3 as 11 years. On average, the lifetime is estimated as ten years for the SMA surface treatment.

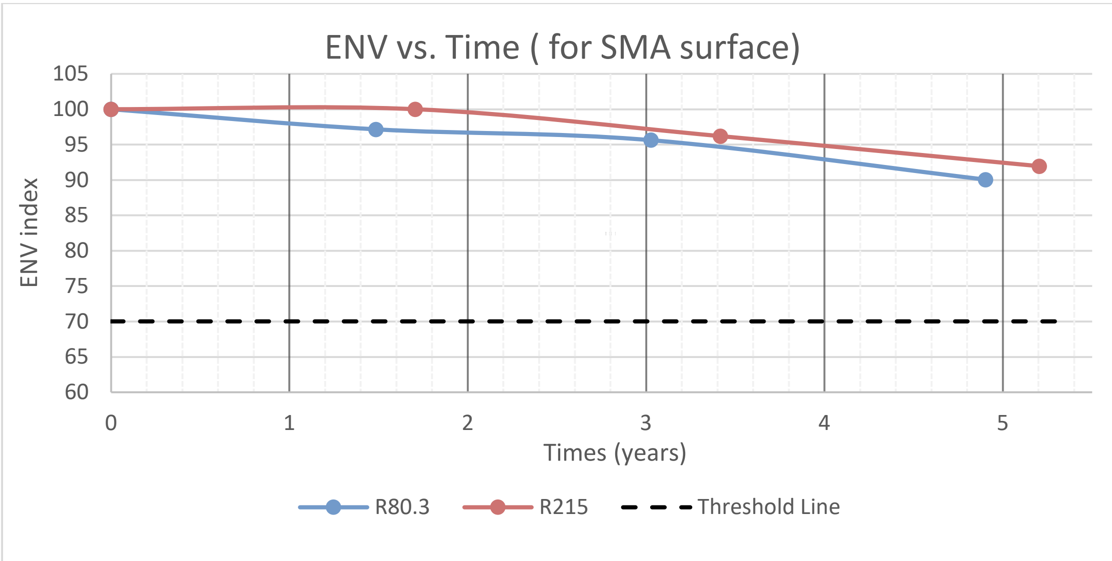


Figure 5.4 SMA TLTs ENV Plot

While only based on two surface sections, the SMA shows good performance. The evaluation of SMAs resulting in higher condition indices on both ENV and WP. Since the deterioration rate of SMA is still not in the secondary stage, the life estimate is not reliable. Nevertheless, based on all the limitations cited, the estimated lifetime of the SMA thin lift treatment is shown in Table 5-4.

Table 5.4 SMA Environmental Lifetime Estimation

State Route	Estimated life (years)	Already past (years)	Remain life (years)	Total Life AVE (years)
80.3	9.3	4.9	4.4	10
215	10.4	5.2	5.2	

The average life of the two SMA TLT sections is estimated at ten years. Both SMA TLT sections are still under the “new” or “good” condition, which suggests the extremely high prediction of ten years for the estimated life of the SMA TLT.

5.3.4 Loading and WP Index

The total WP index value versus traffic loading counts for all 14 TLT treatment sections in each observation year were plotted. In general, the results follow the expected curve of the pavement performance versus traffic loading. This is shown in Figure 5.5.

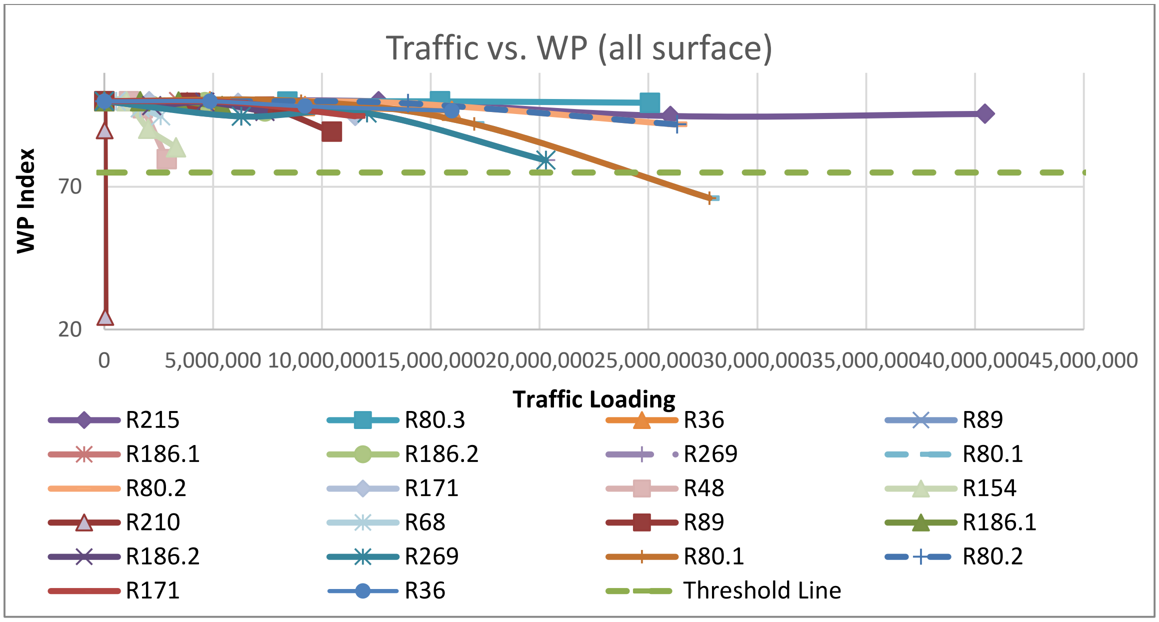


Figure 5.5 WP Index Summary Plot

5.3.5 OGSC WP Analysis

The Open Graded Surface Coarse (OGSC) treatment consisted of eight surface sections. A majority of the OGSC surface treatments followed the general trend of decreasing performance as the rate for traffic load increased. Other studies have determined that the life expectancy of an OGSC pavement under the designed condition to be between eight and 12 years. Based on the current daily traffic amount and growth rate, the estimated life for the OGSC surface treatment in Utah is about 8.5 years. Figure 5.6 shows this information.

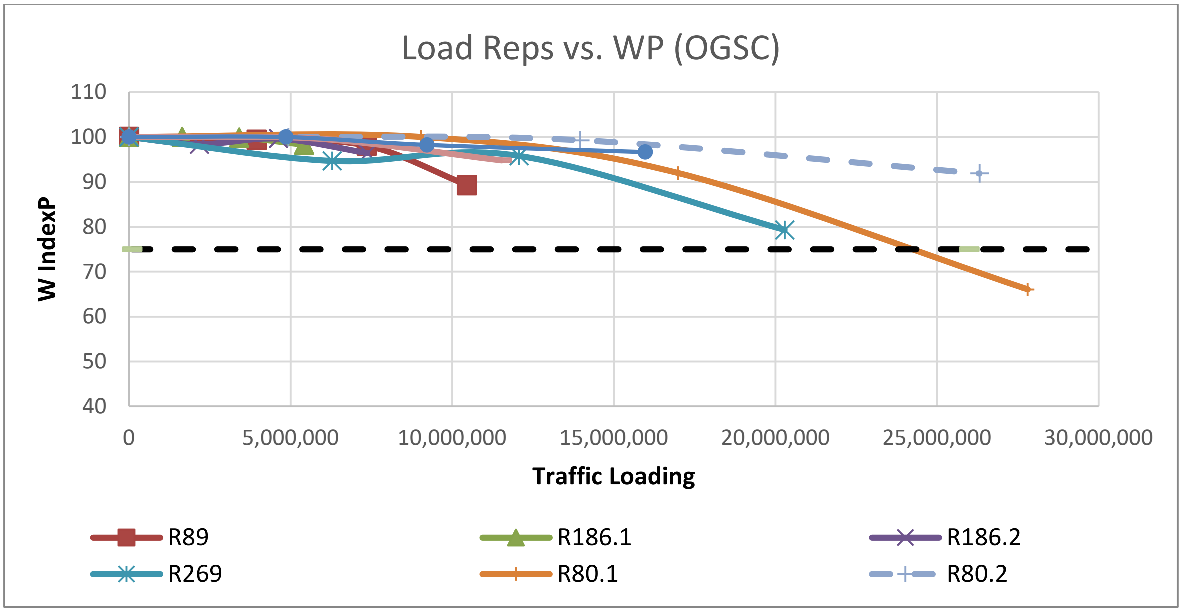


Figure 5.6 OGSC WP Index Plot

The estimated lifetime for the OGSC thin lift treatments is shown in Table 5.5. By extending the data point line, the cross point of the threshold line and the trend line is the estimated lifetime, and the estimated traffic loading is calculated for all sections. The estimated life expectancy for the OGSC surface based on the WP evaluation analysis is about 8.5 years on average. This value is lower than the ENV index estimation result.

Table 5.5 OGSC Loading Lifetime Estimation

State Route	Estimated life (years)	Loaded traffic (axles)	Remain life (years)	Average traffic load (axles)	Average LIFE (years)
SR-36	11.4	15,970,571	6.2	23,451,907	8.5
SR-89	6.2	10,457,803	1.3		
SR-186.1	13.2	5,416,855	8.0		
SR-186.2	11.1	7,376,736	5.9		
SR-269	5.4	20,283,460	0.3		
I-80.1	4.6	27,802,986	-0.7		
I-80.2	7.1	26,314,454	2.9		
SR-171	8.8	11,527,695	3.7		

5.3.6 DGA WP Analysis

The dense graded asphalt (DGA) surface treatment wheel path result shows that SR-154, SR-68, and SR-48 are still above the threshold value, but that SR-210 has failed. The value for the first three sections starts decreasing after three million load repetitions. SR-210 has the most unique situation in DGA study group as it has the most extreme environmental conditions out of all 14 sections. It is believed that the negative ENV score influenced the WP performance. This is shown in Figure5.7.

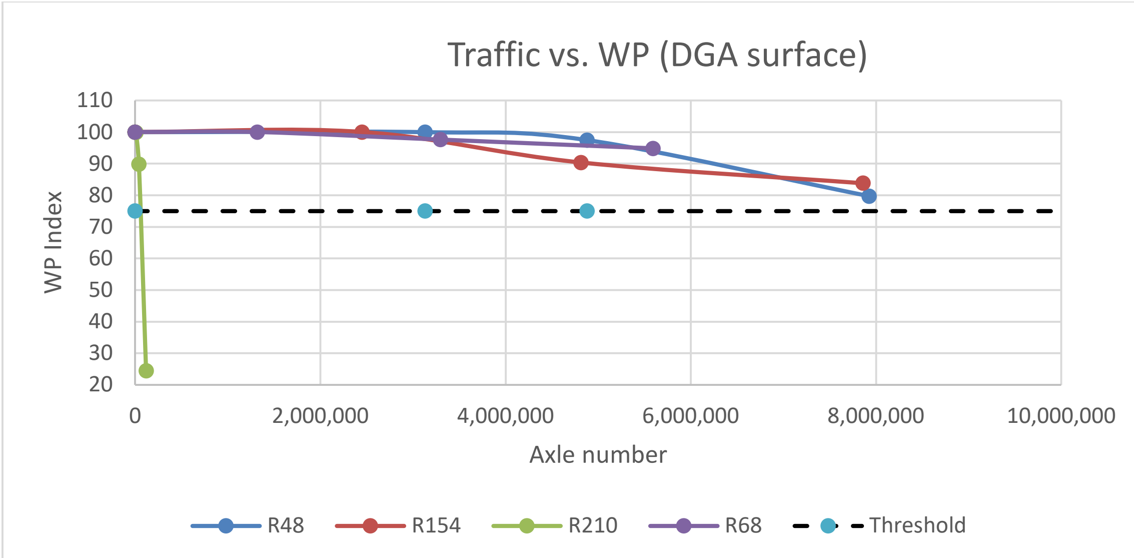


Figure 5.7 DGA WP Index Plot

The average failure point for the DGA TLT is at about 8 million load repetitions, which is approximately 8.5 years, depending on the specific traffic (without SR-210). Table 5.6 shows the life predictions for the DGA treatment.

Table 5.6 DGA Loading Lifetime Estimation

State Route	Estimated life (years)	Loaded traffic (Axles)	Remain life (years)	Average Load Reps	Average Life (without SR-210)
SR-48	5.8	7,924,746	0.4	10,954,565	8.5
SR-154	7.1	7,860,276	2.1		
SR-210	2.8	118,481	-2.2		
SR-68	12.5	5,593,277	7.2		

5.3.7 SMA WP Analysis

The stone matrix asphalt (SMA) has the best performance among the three types of surface treatments studied. The plot shows the high quality of the SMA for the WP index evaluation after five years of use. Even though there were only two routes that were resurfaced with the SMA treatment, the data, shown in Figure 5.8, shows excellent performance results.

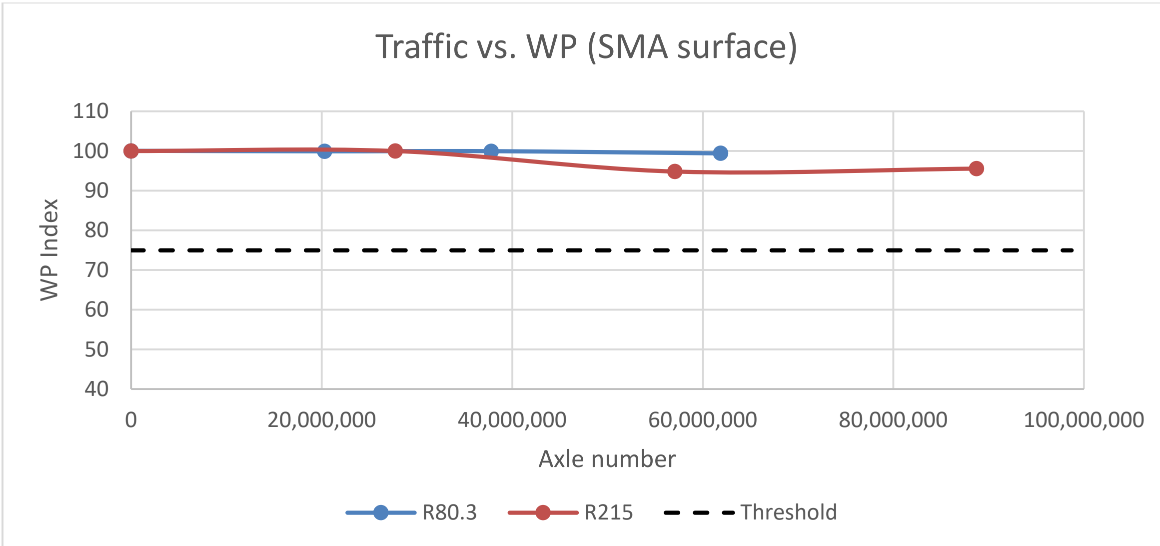


Figure 5.8 SMA WP Index Plot

The SMA surface shows no WP index drop during the five years of this study. Both of the treated surfaces have a final WP index higher than 95 and no obvious decreasing trend or WP distress in spite of the high traffic volume. SR-215 has the highest traffic loading of all of 14 TLT sections, with 40 million load repetitions on it, yet the wheel path shows no serious damage. SR-80.3 has the second highest traffic load repetitions, and it has a WP index of 99, the best performance evaluation on the WP index. This results in an estimated lifetime of 13.5 years as shown on Table 5.7.

It is speculated that the reason that SMA treatments have such good performance evaluation results is because of its higher binder content. In many ways, the SMA is similar to the OGSC but, in order to fill more void space between the stone mix, SMA uses more binder than OGSC. Since more binder has been put in the asphalt mix, the fat spot and bleeding should be the main distress of the SMA treatment. However, according to the observation, both SR-215 and SR-80.3 did not experience the large scale of shiny asphalt surface issue.

Table 5.7 SMA Loading Lifetime Estimation

State Route	Estimated life (years)	Loaded traffic (axles)	Remain life (years)	Average load (axles)	Average life (years)
80.3	15.6	61,850,534	10.7	194,833,208	13.5
215	11.3	88,707,017	6.1		

5.4 IRI Evaluation with the WP and ENV

The IRI data for the 14 different TLT sections were collected. In general, the IRI for all of the sections dropped (smoother surface) following the treatments, and then they started to increase again. “The International Roughness Index is a time-dependent data,” and thus long-term monitoring of the IRI is required (Syed Waqar Haider). The time based IRI analysis from 2010 to 2017 was used to find out the TLTs’ impact on the roughness before and after the treatment.

5.4.1 IRI Evaluation with the WP and ENV

Figure 5.9 shows the relationship between the IRI and the sum of WP + ENV. The IRI value was expected to increase when the amount of distress increased, and the total distresses should be the total number of ENV and WP. However, as can be seen, there is not a clear trend. Different TLT sections behaved differently, with no obvious trend or rule that could be found from this plot.

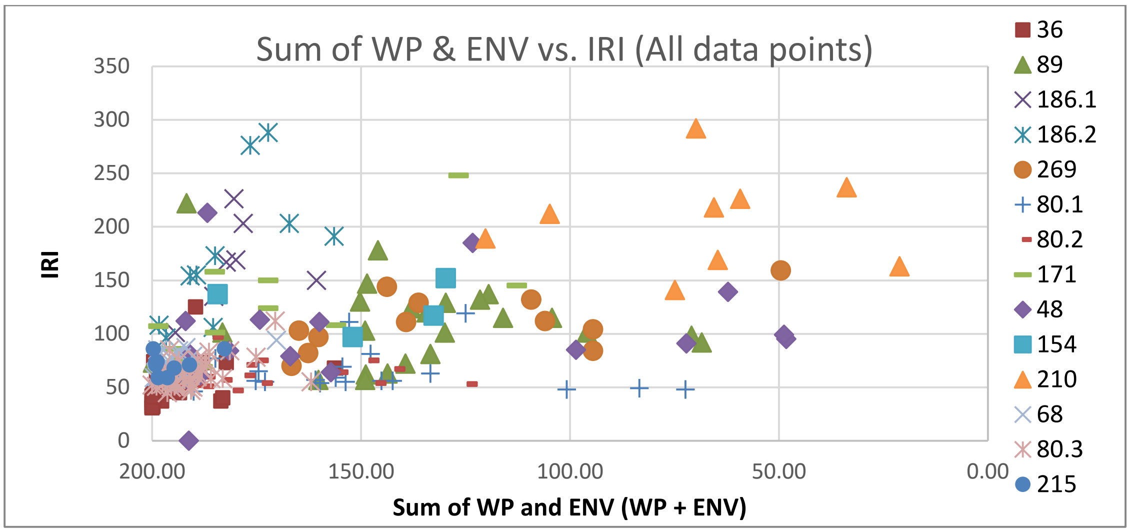


Figure 5.9 IRI Data Summary Plot

The correlation coefficient (R^2) between the IRI and the Surface Condition Index was determined for WP, ENV, and ENV+WP. As shown in Figure 5-10, the correlation coefficient is below 0.08, which indicates that the IRI does not account for or capture the effect of all distresses. For example, cracking is counted based on width, so unless faulting were to occur, such distresses would not make a significant difference in the IRI. The large spread area and high concentration of points on the good condition side does not establish a relationship function for the IRI and the condition index, so the surface condition indices may not relate to the IRI. In other words, contrary to what some previous research has reported, one value cannot be used as a predictor of the other or as an alternative to the other.

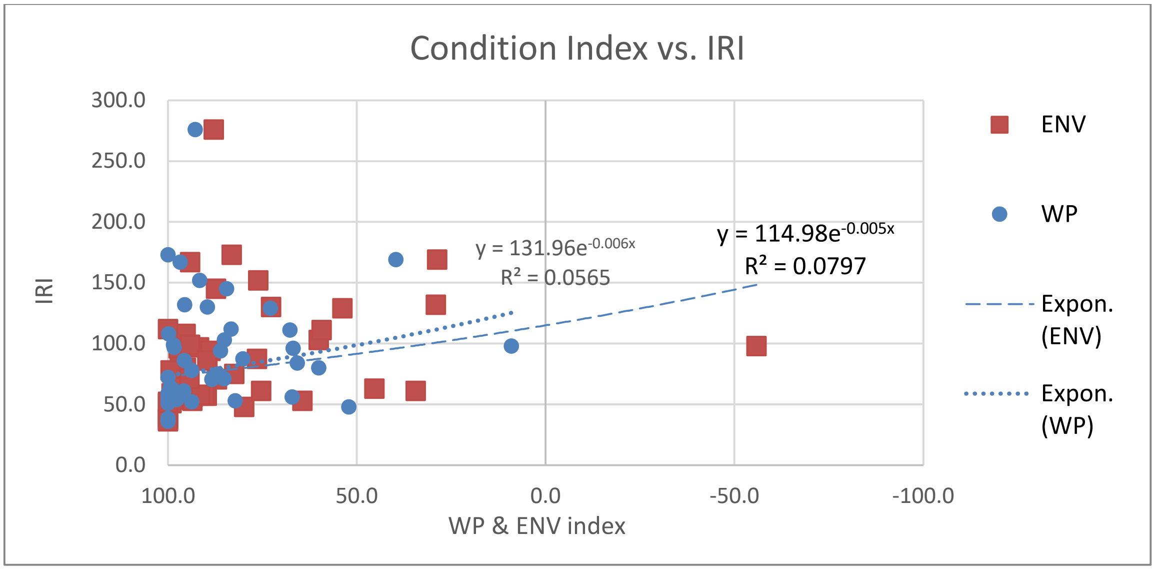


Figure 5.10 TLTs' IRI Data Plot

Even though there is no established correlation between the IRI and WP + ENV, the roughness of the sections could be estimated based on the probability that a certain WP and ENV index exists. The IRI does not follow the WP, ENV, or Sum of WP and ENV; however, the proportion of the data points based on the different performance levels could be determined. All TLT sections have the IRI data recorded at every 0.1-mile. By examining all of the TLT surface sections, 253 performance data points were collected. From those data points, the surface condition was divided into nine different categories, which were integrated with three surface condition levels and three IRI levels as shown in Table 5.8.

Table 5.8 Surface Condition Definition

		Sum of WP & ENV		
		200-150	**150-100**	**100-0**
IRI	**>170**	**Poor**	**Failed**	**Extreme Failed**
	95-170	**Fair**	**Failed**	**Failed**
	0-95	**Good**	**Fair**	**Failed**

The IRI data points proportion was calculated based on each condition level. In the "Good" condition WP+ENV is greater than 150, and 79.8% of the sections have an IRI less than 100; in other words, it can be said that a section with WP+ENV > 150 has an 80 percent change of being smooth (IRI < 100). When the WP+ENV is between 150 and 100, 50% of the sections have an IRI between 95 and 170, which falls into the "Failed" category; in other words, if theWP+ENV is less than 150 but greater than 100 there is a 50% probability that the IRI is between 95 and 170. Finally, if the WP+ENV is less than 100, 67% of the sections will have an IRI greater than 100 and only about 33% of the sections have the IRI less than 95. While this does not necessarily represent causation, it would be expected that those sections having a high WP+ENV index (i.e., have few distresses) will have lower roughness. This is shown graphically on Figure 5.11.

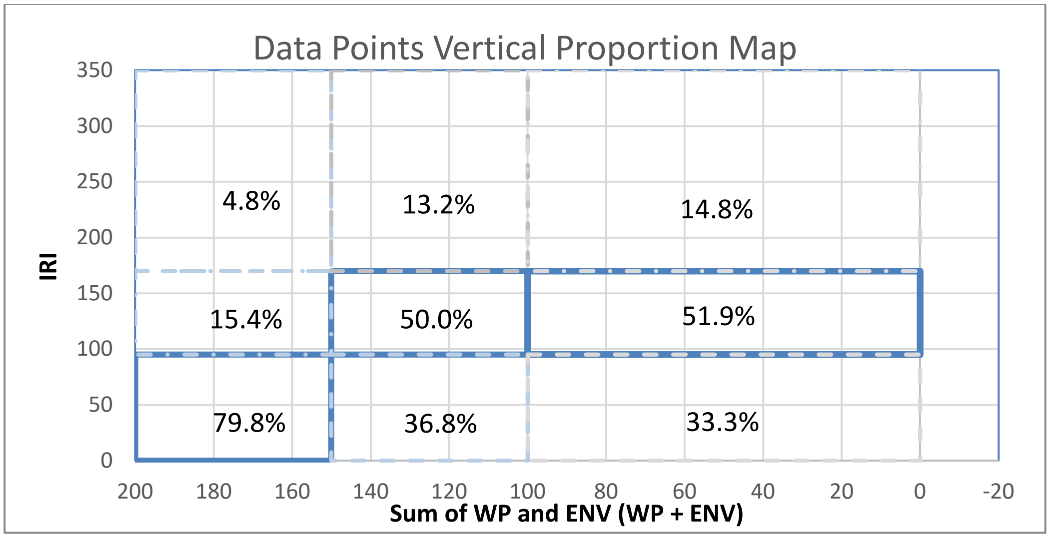


Figure 5.11 IRI Data Points Concentration Plot

5.4.2 Time Dependent IRI Analysis

As previously discussed, the IRI data depends on the local profile and the surface condition of the road; each road section has its unique IRI result. Three different TLTs have three different results because they have a different sample number on the inspected sections. The summary plots about SMA, DGA, and OGSC are shown in Figure 5.12 through 5.14.

The IRI plot of the SMA treatment, Figure 5.12, shows the clearest trend. It shows an increase in IRI with time (2010-2012) then a drop after the treatment (2012-2013) followed by a small increase in the IRI of 2.62 in/mile per year with time (2014-2017). SMA TLTs were only used on two roads, which led to a small data set, so no significant conclusions can be made.

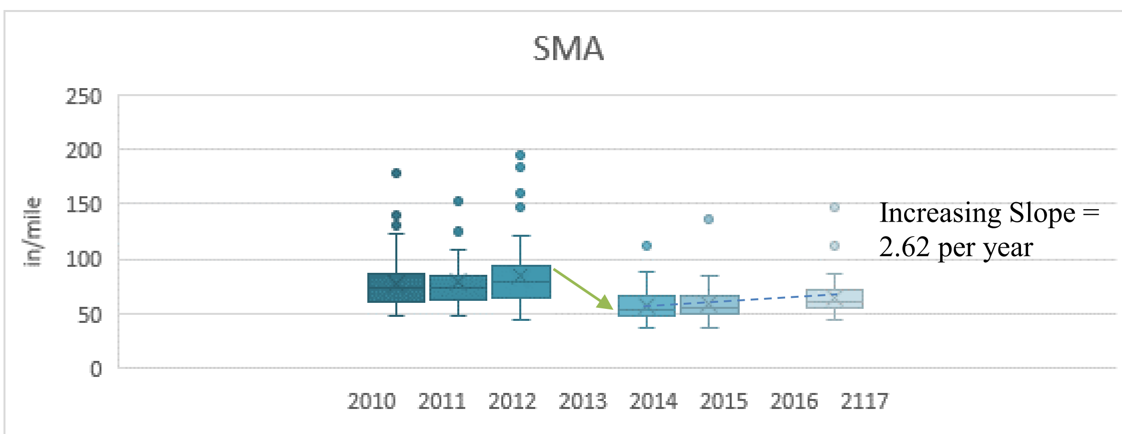
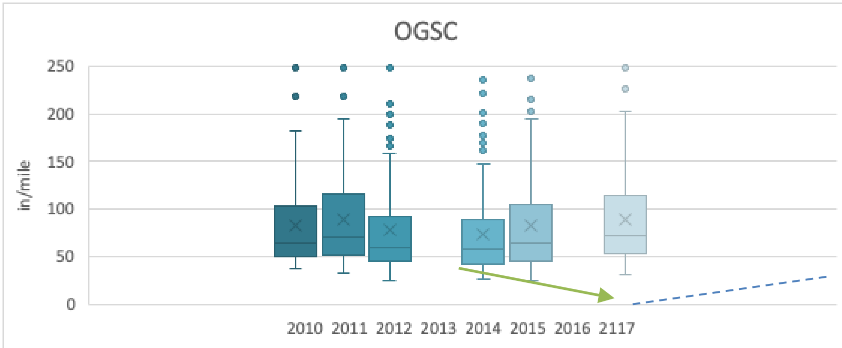


Figure 5.12 SMA IRI Box Plot

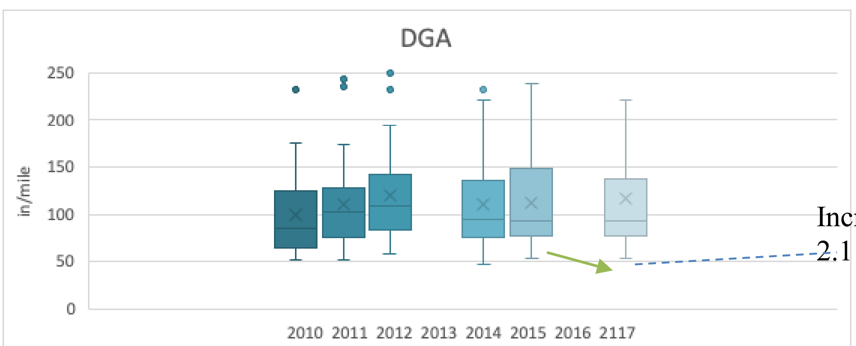
The OGSC surface has a larger data set when compared to the other two treatments. As shown in Figure 5.13, the surface conditions of all of the OGSC sections have a lower IRI on both average and data range after they received the TLT in 2012, but less concentrated data points indicate the large variability of OGSC IRI data. Also, a constantly increasing trend of OGSC roughness index of 5.17 in/mile per year is found from 2014 to 2017.



Increasing Slope = 5.17 per year

Figure 5.13 OGSC IRI Box Plot

As seen in Figure 5.14, the DGA IRI has the highest value out of the three TLT results, starting above 100 after the treatment. The DGA surface also shows more improvement from the treatment as reflected by a drop in its IRI index from 2012 to 2014. The roughness number increased from 2014 to 2017 at a rate of 2.1 in/mile per year, which is less than the other treatment; however, the IRI values are, as a whole, higher than other surfaces.



Increasing Slope = 2.1 per year

Figure 5.14 DGA IRI Box Plot

The IRI study is general enough to show the characteristics of the surface roughness number. Even though there is no strong connection between the IRI and the surface condition index, some key points can be summarized:

- The IRI is a highly variable index.
- Roughness comes from different sources, more than just surface distress. In other words, some distresses might not affect the roughness of the road surface.
- The IRI data have an increasing rate, but different road material and road sections have different deterioration rates; OGSC has the highest increase rate of 5.17 in/mile per year, SMA has an increase rate of 2.62 in/mile per year, and DGA has the lowest increasing rate, which is 2.1 in/mile per year.
- The IRI does have some general relationships with the surface condition index. As long as the condition index stays in the threshold number WP+ENV < 150, the IRI will most likely stay below 95.
- The DGA has the highest IRI values of all of the TLT types.

5.5 Summary

Within this performance evaluation study, two TLT sections failed by the WP index, and two TLT sections failed by the ENV index. In total, three sections reached a failure point: I-80.1 and SR-210 failed by the WP evaluation, and SR-89 and SR-210 failed by the ENV evaluation. In the first 5 years, only SR-210 had completely failed from both environmental and load related distresses. It is believed that SR-210 failed mainly due to environmental distresses, and that the wheel path distresses were influenced by the environment condition. All of the result are summarized in Table 5.9.

Table 5.9 TLTs Sections' Lifetime Summary

TLTs	State Route	Estimated Time (years)	Already past year	Remain Life-time (years)	Average Time
OGSC	36	10.9	5.2	5.7	7.9
	89	3.2	5.0	-1.8	
	186.1	11.0	5.2	5.8	
	186.2	7.8	5.2	2.6	
	269	5.6	5.1	0.5	
	80.1	6.0	5.3	0.7	
	80.2	7.4	4.3	3.1	
	171	8.4	5.1	3.3	
DGA	48	6.3	5.4	0.9	7.3
	154	5.9	5.0	0.9	
	210	2.3	5.0	-2.7	
	68	11.3	5.3	6.0	
SMA	80.3	12.5	4.9	7.6	11.7
	215	10.9	5.2	5.6	

6. 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, the District of Columbia, Puerto Rico, and ten providences in Canada. The program has monitored over 2,500 sections of pavements. The database includes information on pavement performance, age, traffic volume, 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 from 1990 through 1995 and measured the 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 the thin lift overlays done nationwide.

6.1 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 was accomplished either by 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.

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. Pavement condition for each section were 500 feet long and included distress data for WP, LNWP, transverse, and block cracking. Additional distress data were available for rutting and the International Roughness Index (IR); however, these data were not used in this study. Some sections were monitored after the SPS-3 study was completed in 1995, so for some, condition data existed for 14 years after its initial construction. One section was only monitored for the same year that it was constructed.

There are some important differences between the LTPP thin lift and the 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 to 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).

6.1.1 Analysis

The pavement condition data from the LTPP database were converted to the ENV and WP indices that were utilized 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. Consistent with Section 5.2, the values 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 6-1. Traffic volume data for the sections were only available for some of the sections. The ENV and WP life columns show the year of 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. As indicated in the Table 6.1, ten sections failed for ENV distresses before WP, and four sections failed for WP distresses before ENV at 62% and 25% of the total sections respectively.

Table 6.1 LTPP Thin Lift Treatments & 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

Two plots were made to show the results. Figure 6.1 shows for WP distresses and Figure 6.2 for ENV distresses.

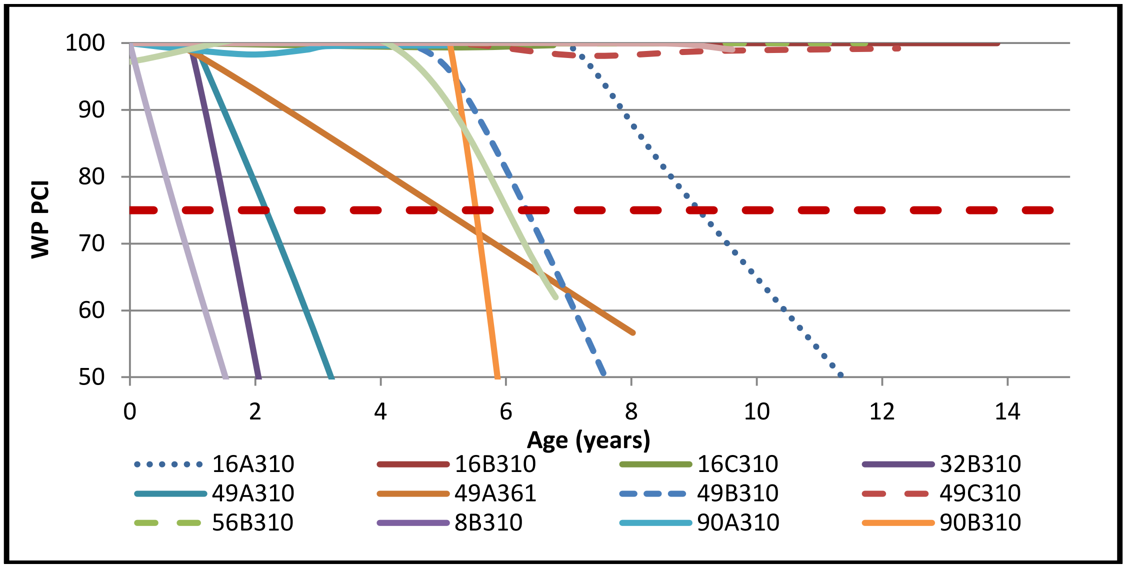


Figure 6.1 Wheel path pavement condition index with failure line

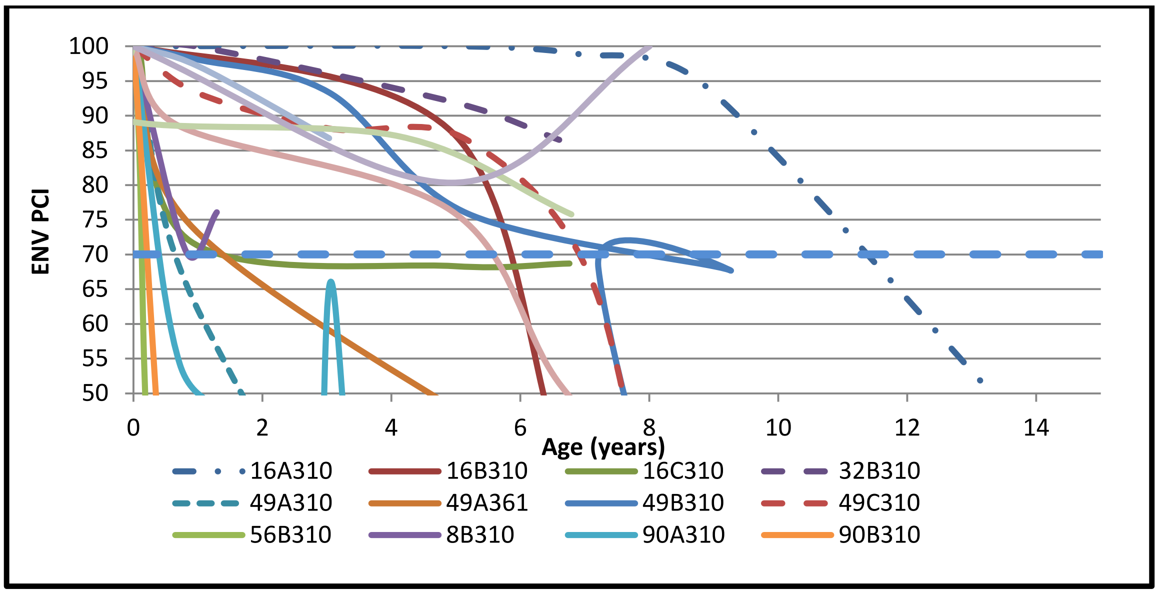


Figure 6.2 Environmental pavement condition index with failure line

Out of the 16 sections, seven appear to be failing for WP cracking. Figure 6-2, the 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 the evaluators rating the distress types differently over the survey time period or to the self-healing of thermal distresses. 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 effects in binder selection.

The effect that temperate and climate had on the 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 6-3 against the annual freezing index for these sections. The freezing index, as defined by the National Snow and Ice Data Center, is the total annual cumulative number of days when temperatures are below zero degrees Celsius. Figure 6-3 indicates a general downward trend in the ENV index scores as the freezing index increases. For the WP index, this trend is not indicated as the data is more scattered. However, as ENV cracking increases, it is expected that WP cracking will increase proportionately. This is primarily due to increased water ingress into the pavement and subsequent structural damage to the supporting layers.

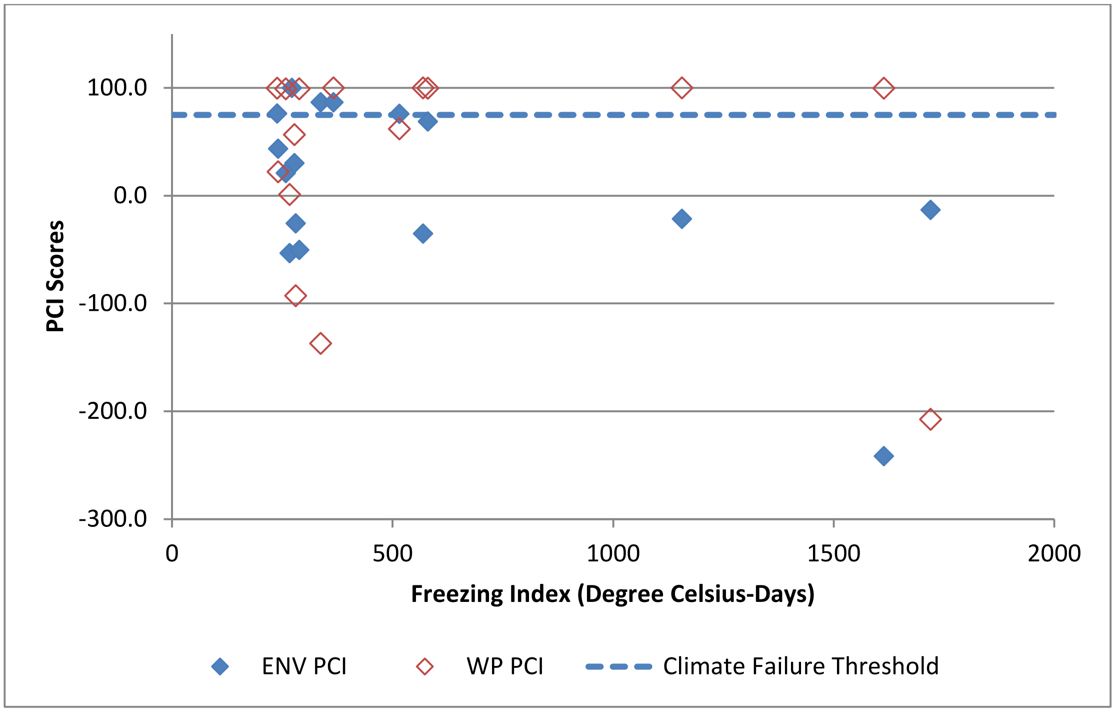


Figure 1.3 LTPP pavement condition indices and freezing index

6.2 Summary of Comparisons

Similar to local TLTs, the thin lift overlays from the LTPP database saw a greater number of environmental failures as opposed to structural or wheel path failures. Wheel path failures accounted for 25% of the LTPP thin lifts, but will likely account for only 7% of the TLTs monitored in this study, due to the adoption of the Superpave Design method that selects asphalt binder based on local climate. The comparison shows the benefits of Superpave over the Marshall method. When comparing the levels of failure due environmental distresses, the LTPP thin lift overlays saw a significantly higher number of sections experiencing environmental distress related failures; 63% as opposed to the 28% that are likely for the local TLTs. This is possibly a result of the Marshall Design method not accounting for climate conditions in the binder selection.

6.3 Summary

The Long Term Pavement Performance database was accessed to extract pavement condition data for 16 thin lift treatment sections located in a dry freeze climate, and then those 16 sections were analyzed for performance. These thin lift treatments were constructed in 1990 using the Marshall Design method, and their performance was monitored anywhere from one to 14 years. These sections were evaluated using the same method that was used to evaluate the TLTs used in Utah. Additionally, the LTPP sections were analyzed for distress performance using the freezing index, which showed decreased environmental performance with an increased 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 TLT sections versus the LTPP sections, and this improved performance is likely due to the use of the Superpave Design method.

7. RECOMMENDATIONS AND CONCLUSION

7.1 Summary of Results

Fourteen thin lift treatments (TLTs) in UDOT's Region 2 were evaluated over a five-year period in order to assess their performance. Surface distress data was quantified using Pavement Condition Indices (PCIs), and Remaining Service Life (RSL) was estimated following procedures developed by Baladi as utilized by the UDOT. For all of the sample sections, image data were transferred into numerical data. Two SMAs, four DGAs, and eight OGSCs treated surface were evaluated. For all of them the WP and ENV indexes were calculated, and the IRI was analyzed. From this, the average life for the different treatments and the impact of environment on the TLTs were examined. Finally, a comparison was done using the IRI results and the PCI results to see if there was a relationship between the indices.

First, the average life for OGSC, DGA, and SMA were estimated. The TLT's life prediction was based on the WP and the ENV index trends. All of the predictions from the ENV index are lower than those from the WP index. The weather condition gives the OGSC and estimated life of 7.2, the DGA and estimated life of 7.4, and the SMA estimated life of 9.9 years. The life estimation based on the WP index for OGSC is 8.5 years, 7.0 years for the DGA, and 13.5 years for the SMA. This indicates that the severe weather variations encountered in Utah are the primary reason roads deteriorate. The data show that the SMA has the highest quality in terms of lower roughness, and its ability to handle the weather and traffic conditions in Utah. Two of the SMA sections have higher traffic flow than any of the other sections that were observed for this study, and the performance results for the SMA show that it is the most durable option under intense traffic.

Next, the impact of environmental factors on the TLTs was examined. The special location of SR-210 demonstrated that the environment has a large impact on road performance. SR-210 is a DGA treatment located in the Alta area. It has the highest elevation, which lead to the worst weather conditions. Both the WP and ENV index evaluations showed failure within three years. SR-210 had the lowest traffic flow, but the cold temperature and heavy snowfall caused incredible damage to the treatment surface; the severe environment was a critical problem for this TLT. For high elevation roads such as SR-210, a better alternative should be considered to maintain the road surface quality.

Finally, the IRI analysis was added to this performance evaluation. The analysis established that PCI and IRI have no strong correlation, although it is clear that roads with a high PCI likely have lower roughness. The TLTs appeared to have a positive impact on road roughness, but based on the limited data, it seems that in comparison to an OGSC, the SMA resulted in a lower rate of increasing in roughness (2.62 in/mile per year vs. 5.17 in/mile per year), while DGA has an even lower increase rate at 2.1 in/mile per year. It should be noted that the DGA also has the highest average roughness.

7.1 Conclusions

Based on the analysis of the results, some key points were made regarding the TLT's performance analysis. First, weather is the main cause for road distress in Utah since the estimated life based on the ENV is shorter than the result from the WP, which seems to imply that the weather condition caused more damage to the road surface than the traffic in Utah. Second, high quality mixes like SMA do result in a longer life and lower increase rate in roughness for the TLTs. In addition, while distresses are not directly correlated to roughness, roads in good condition have a higher chance of being smooth. Finally, the estimated life of TLTs in Utah are comparable to those in other studies.

7.2 Recommendations & Future Work

After this TLTs' evaluation study, the following are recommended:

1. SMA is the best treatment out of the three TLTs studied. When possible, it should be the preferred alternative for high valued roads.
2. SR-210 needs structural reconstruction immediately. Other routes such as SR-89, I-80.1 need some repair to bring the condition back above the threshold. SR-48, SR-154, and SR-269 are very close to the threshold line; therefore, some maintenance needs to be done to improve their condition.
3. Long-term monitoring is required for all sample sections. SR-48 should be recorded as SR-209 (UT-209, New Bingham Highway).
4. Skid data evaluation could be added in a later evaluation study. This study could extend the result to skid and friction so that a complete performance could be described.

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