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PERFORMANCE EVALUATION OF TYPICAL UDOT SURFACE TREATMENTS

Prepared For:

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16. Abstract

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) were estimated following procedures utilized by UDOT.

With the first 5 years' evaluation, 2 TLTs sections have failed by WP index, and 2 TLT sections have failed by 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, in total 3 sections have reached failure. SR-210 has failed mainly due to environmental distresses.

When all of the different treatments are grouped and both environmental and traffic loading are considered, it was found that the average life for the dense graded surface treatments is 7.3 years; the average life for the open graded surface course was slightly better at 7.9 years. It is estimated that the average life of SMA's is 11.7 years.

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

It is concluded that environmental factors are the main cause of deterioration of surface treatment. 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 in high valued roads.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
DGA	Dense Graded Asphalt
ENV	Environmental Index
IRI	International Roughness Index
LNWP	Longitudinal Non-Wheel-Path Cracking
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
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 Pavement Condition Indices (PCIs), and Remaining Service Life (RSL) were estimated following procedures developed by Baladi as utilized by UDOT.

With the first 5 years' evaluation, 2 TLT sections have failed by wheel path (WP) index, and 2 TLT sections have failed by the environmental (ENV) index. I-80.1, and SR-210 were failed due to the WP evaluation, SR-89 and SR-210 failed due to the ENV evaluation. In total, three sections have reached failure. In this first five years, only SR-210 has completely failed with both environmental and load-related distress. SR-210 failed mainly due to environmental distresses and the wheel path distress was influenced by the environmental condition.

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) was used are doing extremely well even though they support the most traffic. It is estimated that the average life of SMAs is 11.7 years.

Similarly to local TLTs, the thin-lift overlays from the LTPP database are seeing a greater number of environmental failures as opposed to structural or wheel-path failures. Wheel-path failures accounted for 25% of the LTPP thin-lift failures and account for only 7% of the TLTs failures in this study. This is possibly a result of the Marshall Design method not accounting for traffic and climate conditions.

1.0 INTRODUCTION

1.1 General

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

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 in the database, forecasting techniques are used to estimate the remaining life of a pavement. 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 relation between pavement age, condition, and maintenance cost, it is not always clear which maintenance activity is the most cost effective.

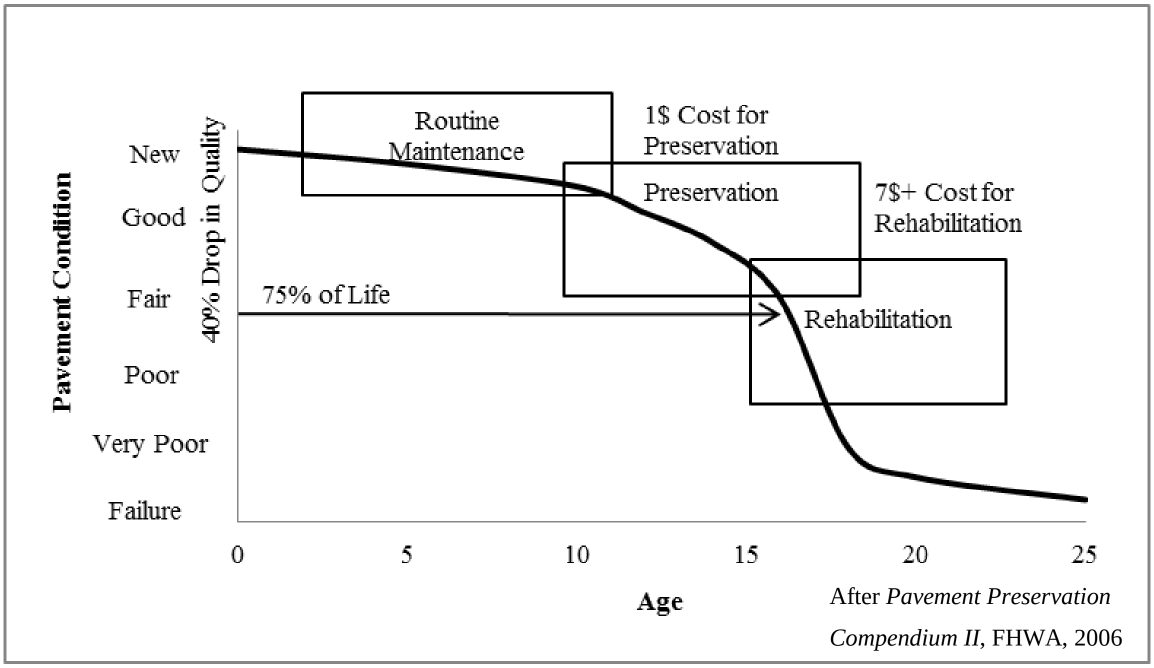

Figure 1-1. Pavement condition curve.

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; 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 a bituminous layer applied 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 it is indicative of structural failure. Rehabilitation applies to the base layers of a pavement and may involve increasing pavement thickness to correct structural deficiencies.

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

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

1.2 Project Objectives

The objectives of this project are 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;*
- *evaluate the performance of three types of TLTs: OGSC, HMA, and SMA, based on the assessment method; and*
- *identify early failures among these treatment types.*

1.3 Scope

Fourteen TLTs applied on state routes in UDOT's Region 2 were evaluated. They were an Open-Grade Surface Course (OGSC), Dense-Graded Asphalt (DGA), and Stone Matrix Asphalt (SMA). Of the 14 TLTs evaluated, eight were OGSC, four DGA, and two SMA. Out of the fourteen, twelve were constructed in 2012 and the other two in 2013.

The location, type, and construction date for these treatments is shown on Table 1-1; Figure 1-2 shows a map with the approximate locations of these sections.

Data was collected based on image data surveys that were made available on Mandli Communication Roadview Explorer (http://168.178.125.102/UtahRVX3/index.php), and IRI data was provided by UDOT. Thus, quantifying the performance of the three different mixture types, and predicting the life expectancy of the TLTs is 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

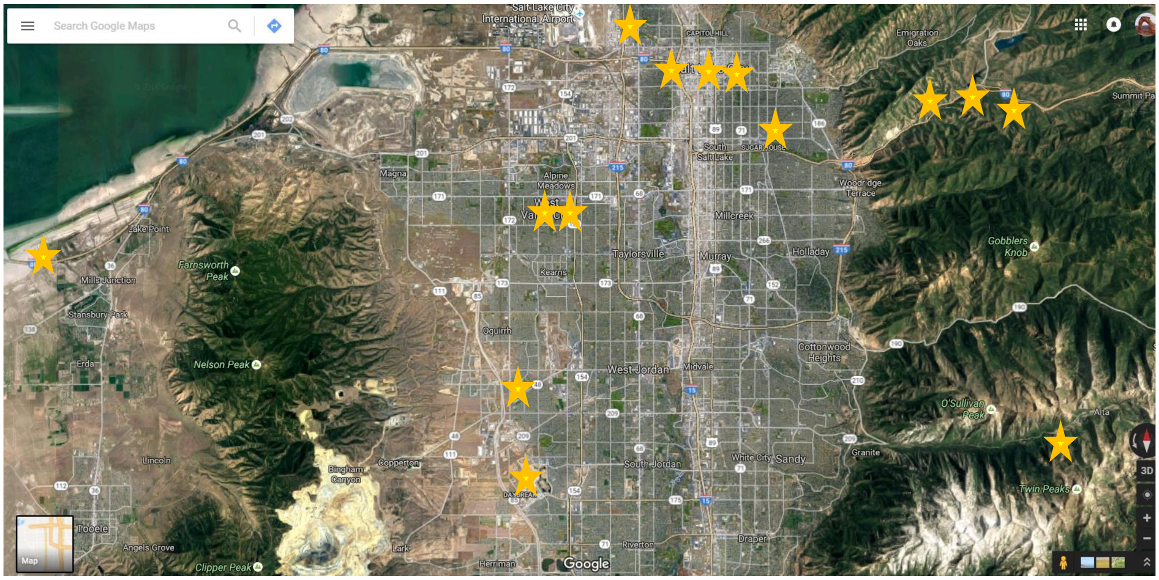

Figure 1-2. General location of projects evaluated

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

2.0 Literature Review

2.1 Thin-lift overlays

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

2.1.1 DGA

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

2.1.2 OGSC

Open-Grade Surface Course (OGSC) mixes differ from densely graded mixtures by decreasing the number of fines (passing No. 4 sieve) and increasing the coarse aggregate. The porous structure resulting from the course aggregate reduces water spray, decreases hydroplaning, reduces noise pollution, and improves wet surface friction. Richer binder quantity provides increased surface reflection, promoting safer nighttime travel and increased longevity. OGSC treatments are more expensive than DGA due to a higher binder content but cost less than

SMA treatments due to less binder content and increased aggregate requirements. Performance issues include bleeding, raveling and stripping in underlying asphalt layers. The porous structure may also become clogged by deicing salts and dust. The life expectancy of an OGSC pavement is between 8 and 12 years (Mallick et al. 2000; UDOT 2009C) .

2.1.3 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 OGSC, SMA has a higher binder content compared to densely graded asphalt in order to fill void space and increase service life. SMA mixtures may have a higher resistance to crack formation, rutting, and raveling. Performance issues with SMA mixes include “fat” spots which are areas of bleeding or splotches of shiny segregated binder resulting from high asphalt content. SMA is the costliest treatment type of the three treatments evaluated due to strict aggregate property requirements and high binder content. SMA is mostly used on high-volume facilities. Life expectancy of an SMA has been reported to be between 7 and 10 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 from two main types of collection methods: manual and automatic (Timm and McQueen, 2004). Regardless of the method used, the collected data is then used for the pavement performance condition evaluating and forecasting. This is critical to anticipate maintenance needs, establish maintenance priorities, and allocate funding.

The manual data collection is done by a human who walks along a sample section and visually identifies and assesses pavement distresses. The automatic data collection is done using a modified survey vehicle with the mounted imaging equipment and the sensor driving 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 processed into a database manually. The reason why the data cannot be recorded directly into a database from the digital images is because the sensor and the camera only record the distress's physical measurement such as the width and length and then some interpretation is needed to identify the type and source of the distress. New, more sophisticated algorithms are constantly being developed. An example of the vehicle used is shown in Figure 2-1.

Figure 2-1 Picture of data collection vehicle (from Mandli.com website)

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 to rate a pavement condition from score 0 to 5. Since the PSR was subjective, it was replaced by the PCI and IRI. PCI, as 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. 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. PCI is then used with forecasting techniques which incorporate 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 pavement smoothness. Several studies of flexible pavements in the United States show moderate correlation between IRI and PCI.

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

2.3 Environmental (ENV) Index

ENV index is used to determine the condition of the pavement from distresses caused by climatic factors. The environmental distress is highly related to changing temperatures, precipitation, and snow amount. Those natural elements will cause the pavement to develop longitudinal cracking, transverse cracking, and block cracking. Those cracks are measured according to 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 as the result of low-construction quality. Climate induced distresses result from the time-temperature-dependent behavior properties of asphalt materials. At lower temperatures, the ability for asphalt to dissipate stresses decreases, the material hardens and becomes susceptible to cracking. Cold temperature performance is accounted for in the Superpave performance grade (PG) specifications of AASHTO standard M320, *Performance Graded Asphalt Binder.* While this standard gives criteria in 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 seen in LNWP cracks; they are usually more prevalent on asphalt pavement joints. They are the result of poor compaction during construction.

Additional environment-related distresses include raveling. Raveling is the weathering of asphalt concrete that results in a loss of bond strength and separation between the asphalt and the aggregate. However, raveling was not recorded in this study and is not considered in scoring the climate condition index. The calculation for the Environmental 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" represent 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 are predominantly perpendicular to the pavement centerline. Transverse cracking is also known as low-temperature cracking. 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 the typical transverse crack. The transverse crack Maximum Allowable Extent (MAE) for low severity is one for every ten feet, or 53 cracks for a 528-foot sample section is 100%. Medium severity is 75%, and high severity is 50%.

Figure 2-2. Transverse Crack

The severity level of the transverse crack is shown in Table 2-1.

Table 2-1. Transverse Crack Severity Level

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

2.3.2 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 maximum allowable extent of the block crack for a 528-foot sample section at low severity is 528 feet in total, at the medium severity level it is 75%, and high severity is 50%. Figure 2-3 shows an example of block cracks.

Figure 2-3. Block Crack

The severity level of the block cracks is shown in 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

2.3.3 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) cracking while longitudinal cracking in the wheel-path area is considered as Wheel-Path (WP) cracking. The LNWP crack is recorded as the length with sealant in good condition at each severity level. The MAE for low severity LNWP is 528 feet of one 528-foot sample section, 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 in 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

WP index is a measurement of the fatigue and load-related distresses. The WP index is only calculating the wheel-path cracking area of the surveyed section. The equation for one 528-foot 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)

Wheel-path cracking is mainly caused by 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 repeated traffic loadings in the wheel-path area and some minor longitudinal cracking on the construction joint. The WP crack is recorded as length but calculated as area, since it considers the WP is 1.5 feet wide in both wheel paths for the 528-foot sample section. The maximum allowable extent for a 528-foot long sample section is 40% of 1,584 square feet for 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 load related (Miller and Bellinger 2014; UDOT 2009A). Also, 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

International Roughness Index (IRI) is defined as the primary factor to represent the ride quality of the pavement in the Pavement Management System. It was developed by the World Bank's correlation experiment in Brazil in 1982.

Basically, IRI is computed from a single longitudinal profile by a moving quarter car, and this two-dimensional data represents the vertical movement of an object along the road profile. IRI is used worldwide as an index for comparing pavement smoothness, which is developed mathematically to represent the movement reaction of a single tire on a vehicle suspension. The value of IRI ranges from 0 to 95 inches/mile representing the surface or pavement in good condition, from 95 to 170 inches/mile for fair condition, and any number higher than 170 inches/mile for poor condition.

UDOT provided the International Roughness Index (IRI) data from 2010 to 2017. This data was incorporated in this surface-performance evaluation study.

3.0 Methodology

3.1 Pavement Surface Image Data Processing

Road-surface condition images were collected and uploaded by Roadview Explorer® (Explorer 2018). The single-unit frame data contains the front view which was taken by three mounted cameras on top of the driving vehicle. The image was recorded as a high-resolution quality image which allows the viewer to zoom the picture for detailed examination. The sensor records the surface condition and transforms the information into the organized top-view picture frame by frame that can show all the measurable cracks with identified severity level label. The visible distresses in the image data are identified according to the Federal Highway Administration's (FHWA) Distress Identification Manual for Long-Term Pavement Performance Project (LTPP) (Miller and Bellinger 2014). This top-view data provides the measurement function, which increases the reading accuracy of the distress data. The vehicle records the data in both directions for every pavement and the GPS information is assigned to each single frame making the footage easily matched to the current route mileage system. A screen shot of the software is shown in Figure 3-1.

The image data of the entire treated TLT section was collected, but the evaluated and inspected sample surface is only 1/5 of the original TLT section, which is 528 feet per half mile. A single unit of TLT section (1 mile per unit) is divided into 10 sample sections (0.1 mile per sample), and 2 inspected sections (0.2 mile) are required as the minimum number for each single mile in the TLT section. TLT sections which are less than 1 mile also require a minimum of 2 inspected sections as well. The mileage starting point of the section could be rounded into the next closest two-decimal mileage point within the TLT section.

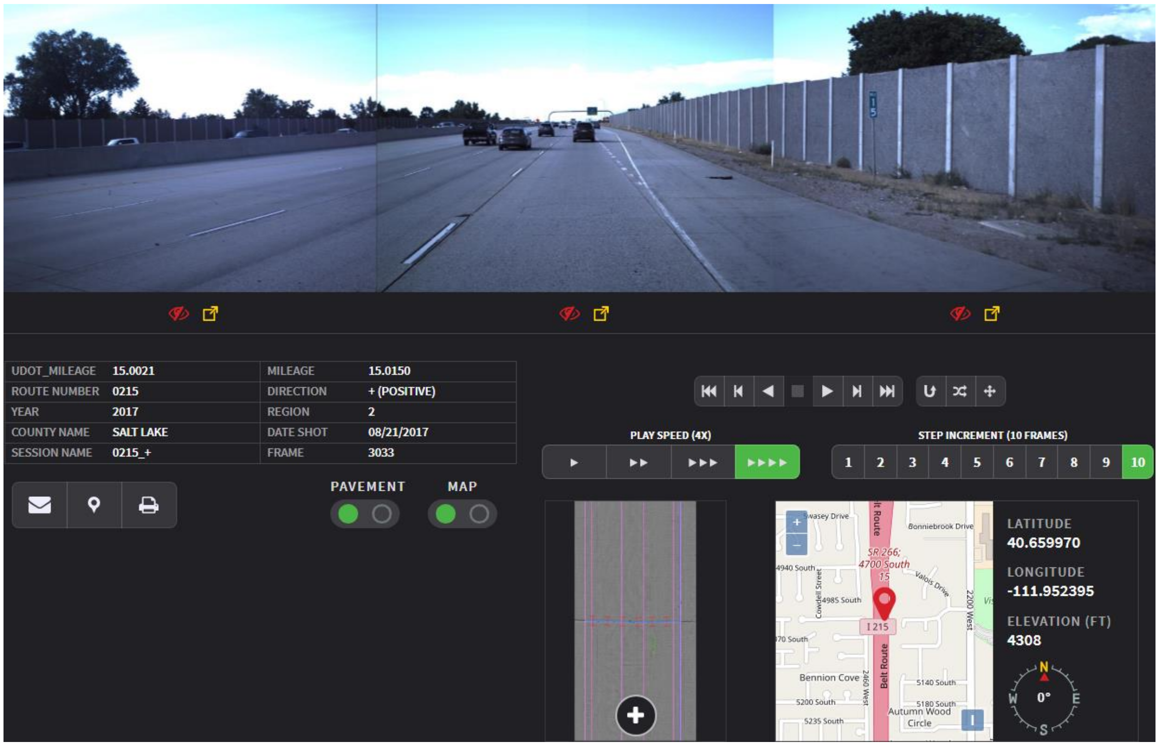

Figure 3-1 Screenshot of Roadview Explorer software.

The spacing interval between each inspected section is 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 is always matching the TLT section starting mileage point unless the image data is incorrect.

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

The deduct value is then calculated based on the recorded cracking dimension. Deduct values come from UDOT according to distress extent, severity level, and the 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 is one millimeter; the recorded length unit of the crack is recorded in millimeters and converted into feet when calculating the deduct value. The measured surface is the right outside lane and represents the entire pavement section. This is done because most of trucks travel in this lane. Finally, only one direction of the section is measured.

3.2 Data Points

The first data point was estimated as the approximate construction end date 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 was analyzed based on a time scale while load-related data was analyzed based on traffic. Specifically, the available traffic counts (average annual daily traffic, or AADT) was multiplied by the percent of trucks. This value was then multiplied by 3 to represent the average number of axles. The data was interpolated and prorated based on the time scale.

4.0 DATA EVALUATION

4.1 Overview

According to the evaluation method, the final examination score of 5 years' ENV and WP index for each TLT section are presented in the following sub sections; the IRI analysis was then added after the evaluation. Detail description with a short conclusion for each surface section is provided.

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

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

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

The total inspected sample section for SR-36 is 3168 feet long, which is six sections. There was no serious distress found in September 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; both WP and ENV index show no 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 (f^{t2})	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

IRI	2010	2011	2012	2013	2014	2015	2017
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 is located in North Salt Lake. It runs north and south between I-15 and Limes Canyon. SR-89 is connecting I-15 at Beck St; it is a three-lane arterial road in both directions. The average 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 surfaces on this section; it had an ENV drop from 92 to 67 in one year, mostly due to transverse cracks. The severity level transverse cracks that were measured in those four sections reached 64.29% of the MAE. According to the pre-treatment evaluation, transverse and block cracks were the majority of distresses on the surface before SR-89 received the treatment. The extent of transverse cracking was 20% and for block cracking it was 39%. It is possible that these pre-treatment distresses may have reflected to the surface.

WP distress did not show up as fast as the environmental distress; most of the wheel-path distresses were wheel-path longitudinal cracking. No obvious fatigue cracking was observed. This information is shown in Table 4-2.

Table 4-2 SR-89 Condition Data

	Cracking type	Severity	Extent (2017)	Index		
				2014	2015	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

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	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. 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 is bleeding. The 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 considered distress for the WP or ENV evaluation, both indexes remained constant from 2014 to 2017. This is shown in Table 4-3.

Table 4-3 SR-186.1 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>6.6%</td><td colspan="2" rowspan="7">93.37</td><td colspan="2" rowspan="7">97.40</td><td colspan="2" rowspan="7">95.65</td></tr>
<tr><td>M</td><td>1.25%</td></tr>
<tr><td>H</td><td>0.0%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td>L</td><td>0.0%</td></tr>
<tr><td>M</td><td>0.84%</td></tr>
<tr><td>H</td><td>0.0%</td></tr>
<tr><td>Block (ft)</td><td>L</td><td>0.0%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft^2)</td><td>L</td><td>3.43%</td><td colspan="2" rowspan="3">100</td><td colspan="2" rowspan="3">99.89</td><td colspan="2" rowspan="3">98.28</td></tr>
<tr><td>M</td><td>0.0%</td></tr>
<tr><td>H</td><td>0.0%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">1,643,004</td><td colspan="2">3,410,859</td><td colspan="2">5,416,855</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>153</td><td>191</td><td>167</td><td>-</td><td>169</td><td>182</td><td>164</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>47</td><td>75</td><td>33</td><td>-</td><td>39</td><td>43</td><td>42</td></tr>
</table>

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 the new surface treatment. This may have affected the slight increase in the ENV index evaluation result.

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

Two sections were inspected on SR-186.2. The majority of distresses on SR-186.2 were LNWP and transverse cracks. The reason for the LNWP cracking on SR-186.2 seems to be the quality of the construction joint. The LNWP crack was uniform and straight and it is following the pathway on the right lane going through the wheel path at some points. The final result of ENV and WP is similar to the evaluation score of the pre-treatment evaluation. This indicates that the distresses have reflected through the treatment. Table 4-4 shows the data for this section.

Table 4-4 SR-186.2 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>16.04%</td><td colspan="2" rowspan="7">99.53</td><td colspan="2" rowspan="7">95.72</td><td colspan="2" rowspan="7">85.55</td></tr>
<tr><td>M</td><td>1.25%</td></tr>
<tr><td>H</td><td>5.77%</td></tr>
<tr><td rowspan="3">LNWP (ft.)</td><td>L</td><td>0.46%</td></tr>
<tr><td>M</td><td>3.05%</td></tr>
<tr><td>H</td><td>2.34%</td></tr>
<tr><td>Block (ft.)</td><td>L</td><td>0.0%</td></tr>
<tr><td rowspan="4">WP</td><td rowspan="3">WP (ft^2)</td><td>L</td><td>6.15%</td><td colspan="2" rowspan="3">98.38</td><td colspan="2" rowspan="3">99.64</td><td colspan="2" rowspan="3">96.41</td></tr>
<tr><td>M</td><td>2.09%</td></tr>
<tr><td>H</td><td>0.0%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">2,177,045</td><td colspan="2">4,625,633</td><td colspan="2">7,376,736</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>165</td><td>161</td><td>181</td><td>-</td><td>143</td><td>157</td><td>162</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>50</td><td>41</td><td>49</td><td>-</td><td>59</td><td>64</td><td>57</td></tr>
</table>

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

The SR-269 section was constructed in August of 2012. The section from MP 0.0 to MP 0.5 and MP 1.4 to MP 1.8 is located between 300 West to State Street in Salt Lake City on both 500 South and 600 South. It is a four-lane, one-way arterial road on both sections. SR-269 on 600 South is taking the traffic from I-15 to the east direction and sending the traffic on the west direction to I-15 on 500 South. 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 ENV and WP have a significant drop from a good condition to almost failure condition in just two years because of Longitudinal Cracks. The majority of the deterioration was seen on wheel path as longitudinal cracks.

Also, the traffic on SR-269 by 2017 had already reached 20 million load repetitions. This is shown in Table 4-5.

Table 4-5 SR-269 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	11.95%	96.69	93.39	78.83
		M	3.33%			
		H	1.28%			
	LNWP (ft)	L	17.59%			
		M	6.46%			
		H	0.0%			
	Block (ft)	L	0.31%			
WP	WP (ft^2)	L	29.36%	94.67	95.79	79.32
		M	3.94%			
		H	8.06%			
	Cumulative Load Reps			6,289,214	12,070,284	20,283,460

IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	116	128	-	-	107	110	127
	Stand. Dev	19	35	-	-	29	27	65

<u>4.2.6 I-80.1 Fire Station to Silver creek, MP 145.5-147.5</u>

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. It 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 I-80 TLT section 1, an OGSC treatment was placed on June 2012. A total of four sample sections were evaluated. The most recognizable distress on I-80.1 is wheel path longitudinal cracks. This TLT's treatment 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 reason for this is either the high-traffic volume or the pre-treatment distress reflect; perhaps both. This interstate highway is one of the busiest in Utah with 40,000 AADT in 2016, including 39% trucks. This is shown in Table 4-6.

Table 4-6 I-80.1 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 colspan="2" rowspan="7">100</td><td colspan="2" rowspan="7">95.51</td><td colspan="2" rowspan="7">92.33</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>3%</td></tr>
<tr><td>M</td><td>6%</td></tr>
<tr><td>H</td><td>1%</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>68%</td><td colspan="2" rowspan="3">100</td><td colspan="2" rowspan="3">91.97</td><td colspan="2" rowspan="3">66.05</td></tr>
<tr><td>M</td><td>0%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td colspan="3">Cumulative Load Reps</td><td colspan="2">9,046,952</td><td colspan="2">16,989,213</td><td colspan="2">27,802,986</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>59</td><td>74</td><td>53</td><td>-</td><td>49</td><td>57</td><td>65</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>13</td><td>27</td><td>12</td><td>-</td><td>10</td><td>14</td><td>19</td></tr>
</table>

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 from MP 143.0 to MP 145.2 is located between High Ute Ranch and the Fire Station on I-80. It is a three lane highway in both directions. The AADT for I-80 at this section is 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 has a better surface condition than I-80.1. It has fewer cracks and a darker surface color. From the pre-treatment evaluation result, I-80.2 had about 49% extent of the LNWP cracks, and only 6% extent of the WP cracks; the post-treatment result shows that I-80.2 has less LNWP extent than WP cracks, wheel path results in 24% of MAE, and LNWP only 9%. This is shown in Table 4-7.

Table 4-7 I-80.2 Condition Data

	Cracking type	Severity	Extent (2017)	Index 2014	Index 2015	Index 2017
ENV	Transverse (#)	L	16%	99.29	92.06	84.47
		M	6%			
		H	1%			
	LNWP (ft)	L	4%			
		M	5%			
		H	0%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	13%	99.94	99.25	91.88
		M	2%			
		H	1%			
	Cumulative load reps			4,932,948	13,959,839	26,314,134

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	59	63	62	-	48	49	60
	Stand. Dev	12	13	16	-	10	11	12

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

The SR-171 section was constructed in July of 2013, which is the most recent construction surface out of the 14 TLTs sections of this study. This section is from MP 8.0 to MP 9.4; it 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 good, both ENV and WP have a value higher than 90. No significant distress issues were experienced on this route. Most of the cracks appeared on the intersection or near a drainage well. It is noted that the ENV index increased from 2014 to 2015; this is attributed to changes in camera systems used in the recording vehicle. Table 4-8 presents this data.

Table 4-8 SR-171 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>6%</td><td colspan="2" rowspan="7">94.95</td><td colspan="2" rowspan="7">99.06</td><td colspan="2" rowspan="7">92.54</td></tr>
<tr><td>M</td><td>4%</td></tr>
<tr><td>H</td><td>0%</td></tr>
<tr><td rowspan="3">LNWP (ft)</td><td>L</td><td>5%</td></tr>
<tr><td>M</td><td>0.33%</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>10%</td><td colspan="2" rowspan="3">100</td><td colspan="2" rowspan="3">99.45</td><td colspan="2" rowspan="3">94.79</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">2,065,786</td><td colspan="2">6,147,590</td><td colspan="2">11,527,695</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>95</td><td>84</td><td>98</td><td>-</td><td>90</td><td>100</td><td>112</td></tr>
<tr><td colspan="2">Stand. Dev</td><td>44</td><td>35</td><td>48</td><td>-</td><td>51</td><td>49</td><td>51</td></tr>
</table>

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

The SR-48 (marked as SR-209 after 2015) DGA section was resurfaced in May of 2012. This TLT section is from MP 1.2 to MP 4. It 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 has six inspected sections; the WP index dropped sharply after 2015. In 2017, the WP dropped to 74.65 which is just below the wheel-path index threshold value. Most of the distress on SR-48 was wheel-path cracks. Those cracks were caused by loading and asphalt fatigue. A large area of the alligator cracks is seen on both left and right wheel-path areas. Other minor longitudinal cracks occur along with 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 (f^{t2})</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

The SR-154 section was resurfaced in July of 2012. This section is from MP 0.0 to MP 0.5, 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 ENV and WP are still slightly above their threshold value, which mean the section has not failed yet.

The main distress on this section was longitudinal cracking along the road; more than half of the LWP cracks were on the wheel-path area. This data is shown in 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

<u>4.3.3 SR-210 Alta Bypass, MP 12.5-13.6</u>

The SR-210 TLT section was resurfaced on August of 2012. This treated section is from MP 12.5 to MP 13.6, which is the 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 is the special case for this surface performance evaluation study mostly due to the unique location of this route at an elevation 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 main reason for SR-210 getting a low value on ENV index, a negative value. The cracks on SR-210 were deep and wide, 87% of those LNWP were High-Severity level, and 93% of the transverse cracks were High-Severity level transverse cracks. SR-210 has the lowest traffic loading but was the first section with the ENV value below the threshold. It is evident that the reason SR-210 has such a low value on WP is partially because of the environmental distress. This is presented in 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

		2010	2011	2012	2013	2014	2015	2017
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 in July of 2013. This section is from MP 60.8 to MP 62.9, which is from 1000 North to the Davis County line. It is a single-lane arterial road in both directions. The AADT for SR-154 at this section was 13,130 in 2012, and 12,000 in 2016.

SR-68 is performing well on both the ENV and WP indexes; four sections were evaluated, according to the data, there are not any serious cracks on it, except at MP 62.7

to 62.8. This section has a construction joint crack that goes right to left along the TLT section. This crack is believed to be caused by poor shoulder construction quality and cannot be counted simply as Wheel-Path cracking. It is included as the percentage of the extent 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

IRI		2010	2011	2012	2013	2014	2015	2017
	Year	2010	2011	2012	2013	2014	2015	2017
IRI	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. One has failed. Table 4-14 provides a summary of the evaluation of 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 was resurfaced on July of 2012. This section was treated with Stone Matrix Asphalt from MP 131.7 to MP 136.1. It is a three-lane highway in both directions. The AADT at this section was 45,960 in 2012, and 58,000 in 2016.

I-80 TLT section number 3 is the first SMA Thin-Lift Treatment surface on I-80; a total of 8 sample sections were evaluated. Both ENV and WP indexes show good performance for 2015 and 2017, especially looking at the WP index having a value of 99 after 25 million load repetitions. The major cracks on I-80.3 were the low-severity level

LNWP cracks. Their extent reached 14% of the MAE which made the ENV drop to 90. This is summarized in 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

<u>4.4.2 I-215 End PCCP to 3300 South, MP 0.8-1.8</u>

The I-215 section was resurfaced on June of 2012. This section was treated at MP 0.8 to MP 1.8, which is from the Belt Route/I-80 intersection to 3300 South. It is a two-lane highway ramp from MP 0.8-1.2, and a three-lane highway from MP 1.2-1.8, 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 evaluated. Just like I-80.3, this SMA treated surface showed good performance on both ENV and WP index, even after having the highest traffic volume of all sections. According to the evaluated sample sections, only 1% of the MAE on the wheel-path crack was discovered on the treatment surface in 2017. This is shown in table 4-16.

Table 4-16 I-215 Condition Data

	Cracking type	Severity	Extent (2017)	Index		
				2014	2015	2017
ENV	Transverse (#)	L	5%	100	96.20	91.95
		M	1%			
		H	0%			
	LNWP (ft)	L	8%			
		M	2%			
		H	0%			
	Block (ft)	L	0%			
WP	WP (ft^2)	L	9%	100	94.81	95.55
		M	1%			
		H	0%			
	Cumulative Load Reps			12,596,690	26,001,407	40,451,170

		2010	2011	2012	2013	2014	2015	2017
IRI	Year	2010	2011	2012	2013	2014	2015	2017
	AVE	83	87	77	-	73	75	80
	Stand. Dev	32	32	19	-	17	23	26

4.4.3 Summary of SMA Sections

Two SMA sections were evaluated; both of them are performing 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 this 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 from zero. A higher IRI value represents the road having a rougher surface. In this study, all of the TLT sections have 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 are similar. Thus, a quantitative value of road condition index number does not correlate well to the scale of IRI since the measurement methods for both are completely different; only some minor correlation between IRI and condition index was found to exist.

As expected, all of the TLTs had lower IRI after they received the treatment. IRI is expected to increase as the road gets damaged from the environment and traffic. More distresses on the road are expected to cause a higher IRI. Larger standard deviation is also expected due to the increased variability of road surface condition. From the yearly IRI average value, a clear drop is observed between 2012 and 2013; the standard deviation also decreases after the treated surface. The lower standard deviation stands for more consistent IRI result of the entire treated road section. TLTs offered a newer surface with less variability, and thus a lower IRI number and standard deviation are expected after the treatment. The road is continually supporting loads. The damage increases and the surface gets more distressed every year. IRI and its standard deviation are supposed to increase with time.

5.0 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 is analyzed based on the time since construction, given that the weather and temperature are time-dependent factors. WP index is 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 construction was perfect, and thus the ENV and WP index were both 100 at the original point.

5.2 Life Expectancy Estimates

The life expectancy of TLTs is estimated by the cross point of 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 TLTs due to the ENV or WP evaluation.

5.3 Environmental Factors

Figure 5-1 is a summary of all 14 TLT's surface ENV index data points. As was discussed in the previous chapter, many factors contribute to environmental distresses. Given that all sections except for one are located approximately in 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.

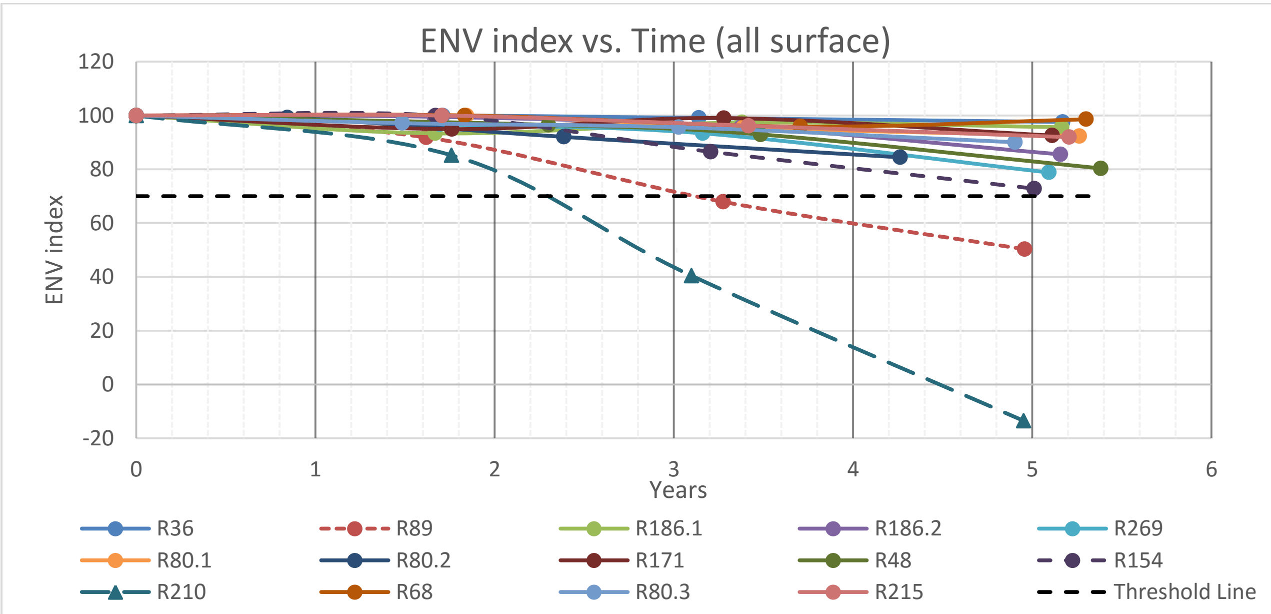

Figure 5-1 ENV Index Summary Plot

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 TLT surfaces have an estimated life that ranges from six to eleven years. Half of the TLT sections have more LNWP cracks in comparison to other distresses. This is a common problem due to the low density at the pavement surface joint. The other half of the TLT sections have significant transverse cracks caused by low-temperature environmental conditions. Most of the TLT surface treatments follow 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 type. 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-a-half years, but SR-210 did not follow this pattern.

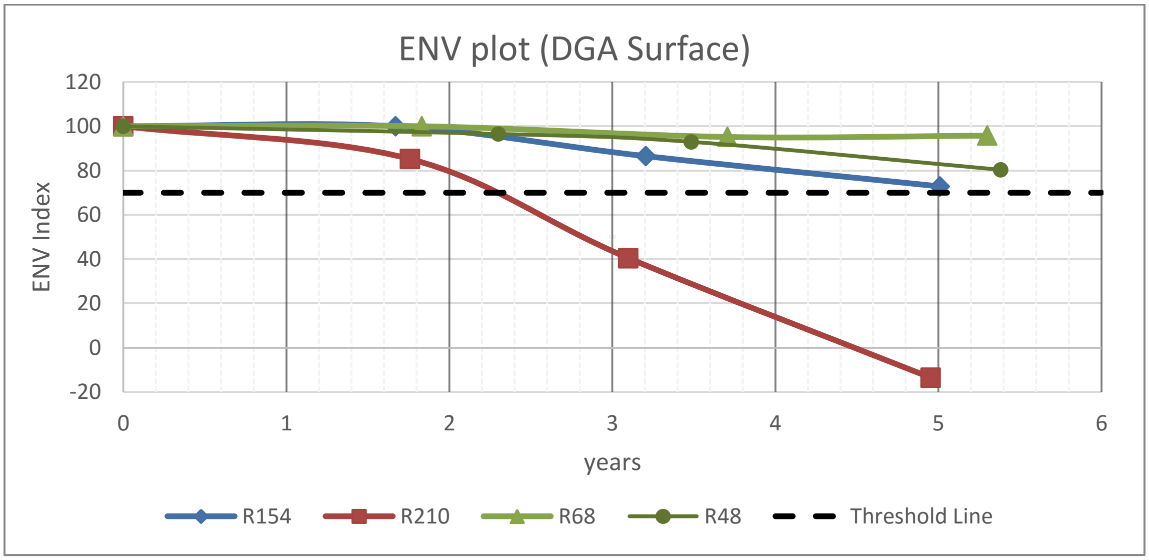

Figure 5-2. DGA TLTs ENV plot

As was discussed in Section 4.3.3, SR-210 is the route going to Alta and Snowbird mountain resort, and it is subjected to harsh winter conditions. The average elevation of SR-210 is 8000 feet from sea level, which is 3800 feet higher than Salt Lake City. As shown in Table 5-1, this high elevation makes the average temperature of the SR-210 section about 10 degrees lower than the greater Salt Lake area (NOAA data) and the snowfall of the Alta area is ten times more than the Great Salt Lake area. This environment is believed to be a critical issue for the SR-210 TLT section as this environment 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 DGAs studied have a better score than SR-210, by following the data point decreasing trend, the lifetime of each section is estimated and the result is shown in 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 ENV performance. Excluding that section, the average lifetime of DGA thin-lift treatment increases to 9.2 years.

5.3.2 OGSC ENV study

The OGSC surface treatment made the biggest sample group in this study. The ENV index of all OGSCs is shown in Figure 5-3. Seven sections had reasonable decreasing trends, and only SR-89 stands out from the group. The estimated life ranges for OGSC surface treatment due to ENV condition were between 6 and 11 years, and the average is 7.2 years (SR-89 being the exception since it failed at 3.3 years).

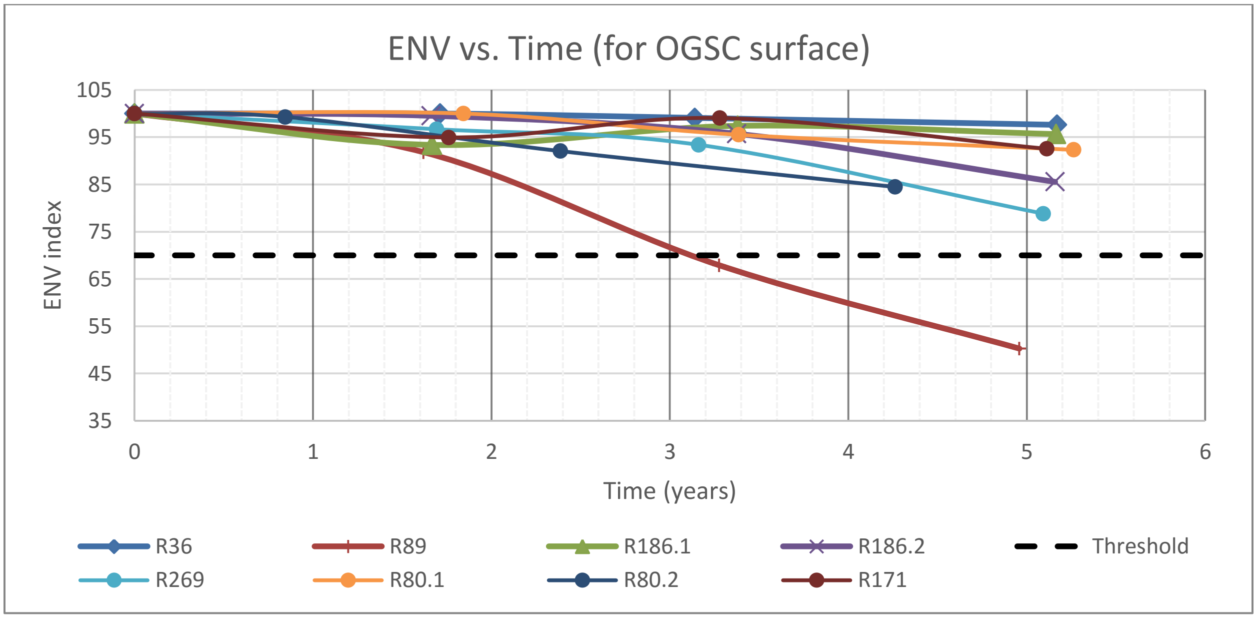

Figure 5-3. OGSC TLTs ENV Index Plot

After five years, the ENV index of the majority OGSC surface treatment ranges 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 "self-healing" of the asphalt pavement has been reported. Self-healing is still a challenging issue for pavement engineering. This complicated mechanism is not well understood and was not considered for this study, so "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 OGSC thin-lift treatment is about 7.2 years.

State Route 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. This gives the average remaining life of about three years. This result matches 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

SMA treatments consist of only two sections, I-215 and I-80 section 3. As shown in Figure 5-4, both SMA sections have 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 10 years and for I-80.3 as 11 years. On average, the life is estimated as 10 years for SMA surface treatment.

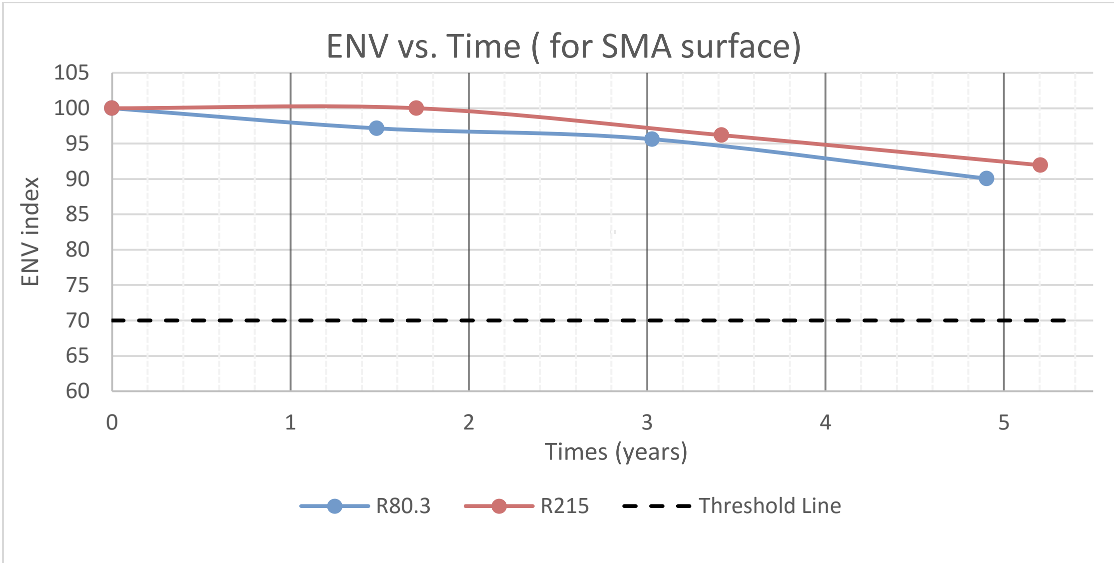

Figure 5-4. SMA TLTs ENV Plot

While only based on two surface sections, the SMA shows good performance. SMAs have better conditions than the other treatments. 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 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 as 10 years. Both SMA thin-lift treatment sections are still in "new" or "good" condition, which gives the extreme high prediction of the lifetime result.

5.4 Loading and WP index

According to the date and the traffic, 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. This is shown in Figure 5-5

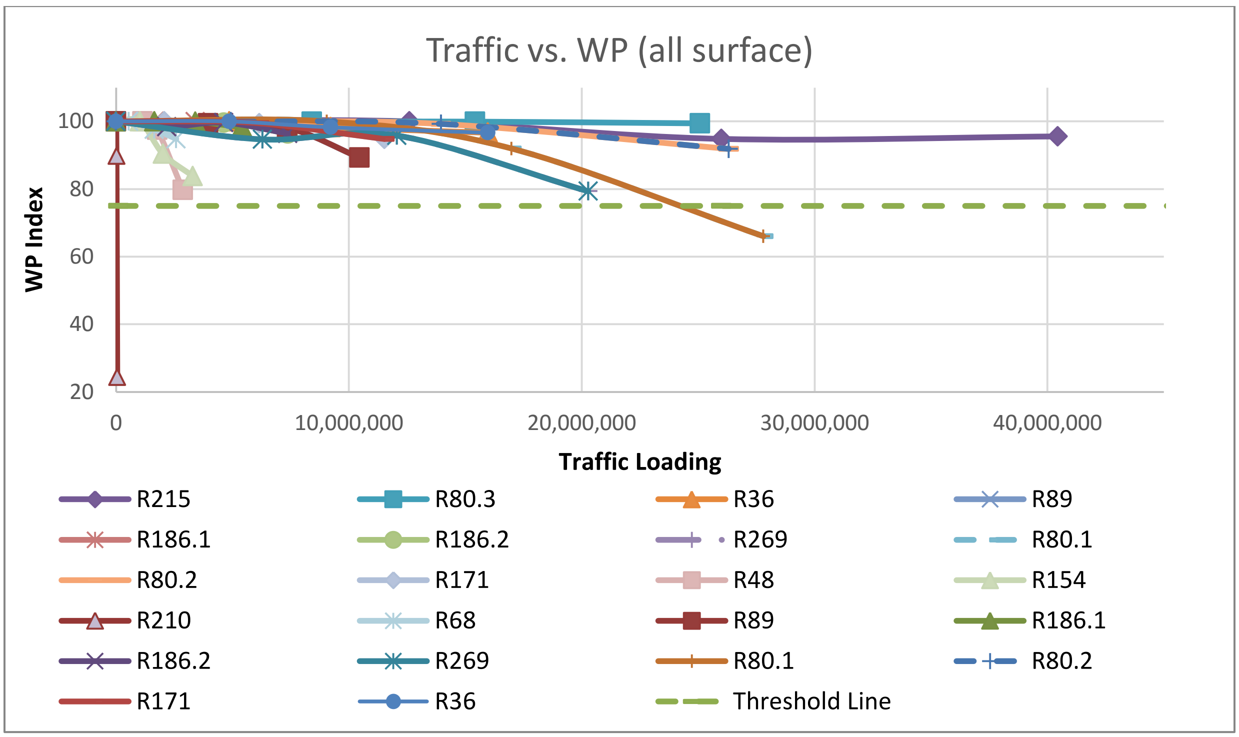

Figure 5-5. WP Index Summary Plot

<u>5.4.1 OGSC WP Analysis</u>

The Open-Graded Surface Course treatments consist of eight surface sections. The majority of OGSC surface treatments follow the general trend of decreasing performance at an increasing rate. Other studies have determined the life expectancy of an OGSC pavement under the designed condition to be between 8 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.

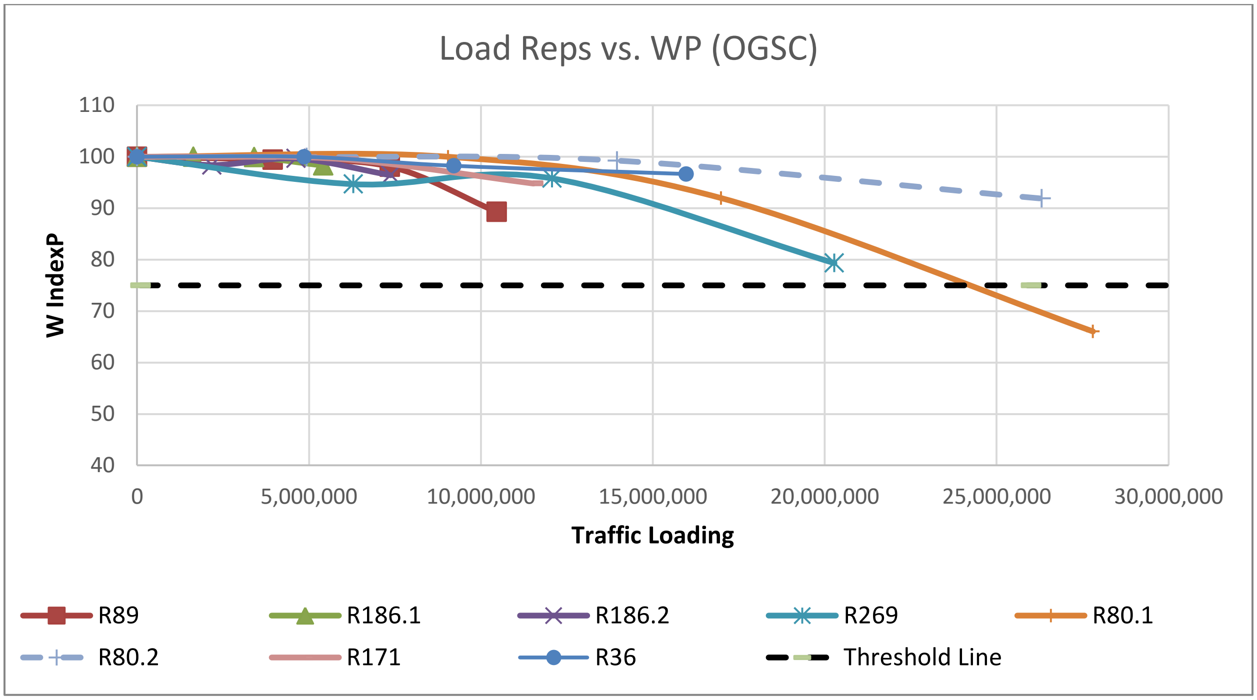

Figure 5-6. OGSC WP Index Plot

The estimated lifetime for 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 estimation of the life expectancy of the OGSC surface from the WP evaluation analysis is about 8.5 years on average. This value is lower than the ENV 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		

5.4.2 DGA WP Analysis

The Dense Graded Asphalt surface treatment Wheel Path result shows that SR-154, SR-68 and SR-48 are still above the threshold value, and that SR-210 has failed. The value for the first three sections starts decreasing after 3 million load repetitions. SR-210 has the most special situation in the 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 Figure 5-7.

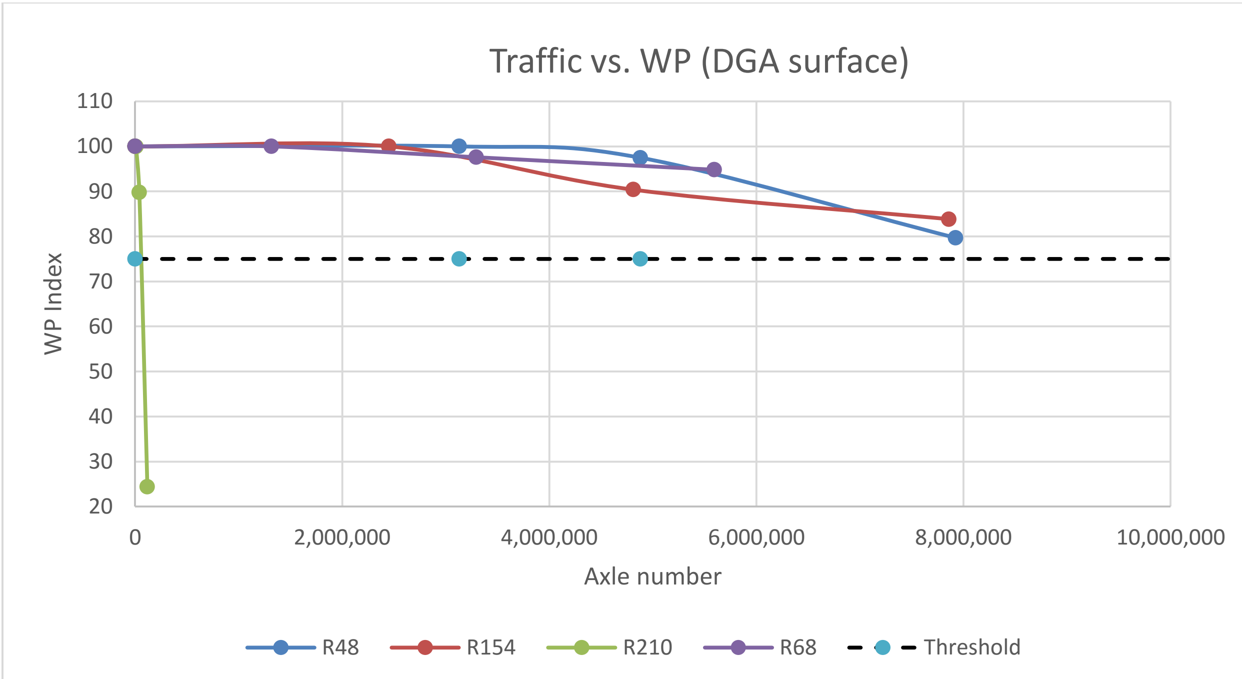

Figure 5-7. DGA WP Index Plot

The average failure point of DGA is about 8 million load repetition, which is about 8.5 years depending on the specific traffic (without SR-210). Table 5-6 shows the life predictions for 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		

5.4.3 SMA WP analysis

The Stone Matrix Asphalt has the best performance among the three types of surface treatments studied. The plot shows the good quality of SMA on the Wheel-Path 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 the excellent performance results.

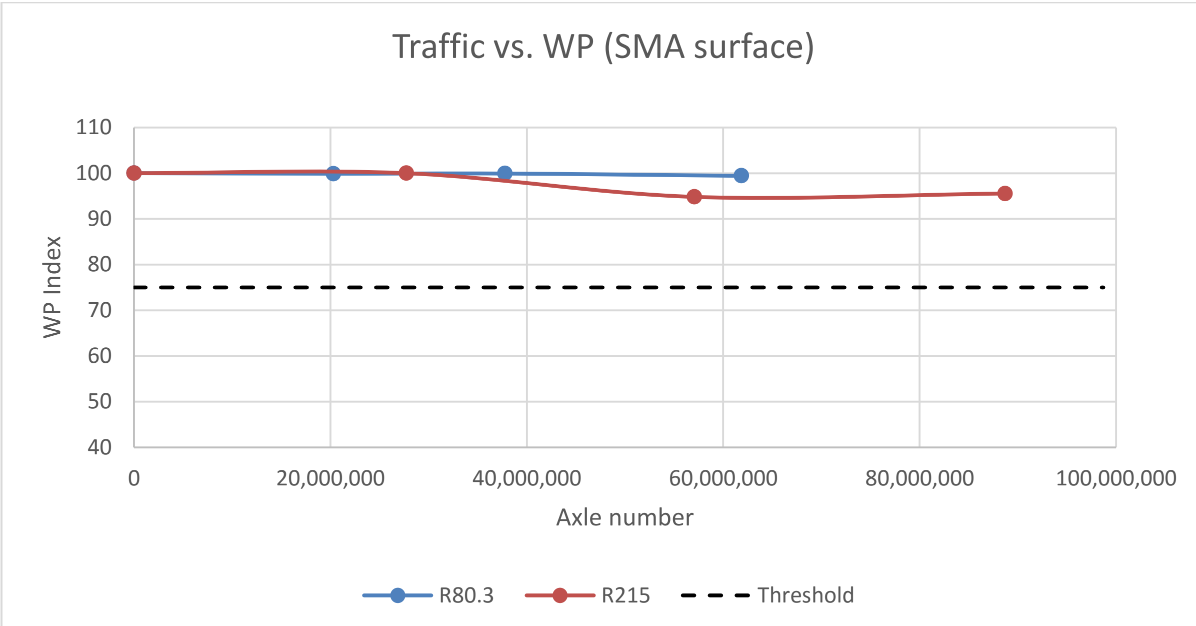

Figure 5-8. SMA WP Index Plot

The SMA surface shows no WP index drop within the five years of this study. Both of the treated surfaces have the final WP index higher than 95, and no obvious decreasing trend or WP distress under such a high traffic volume. SR-215 has the highest traffic loading in all of 14 TLT sections (40 million load repetitions), but the wheel path shows no serious damage. SR-80.3 has the second highest traffic load repetitions and has a WP index of 99, the best performance evaluation on the Wheel-Path index. This results in a 13.5 years lifetime as shown in Table 5-7.

It is speculated that the reason that SMA treatments have such good performance evaluation results is because of the higher binder content. In many ways SMA is similar to 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 could be the main distress of 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		

5.5 IRI evaluation with the WP and ENV

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

5.5.1 IRI evaluation with the WP and ENV

Figure 5-9 shows the relation between IRI and the sum of WP + ENV. The IRI value is expected to increase when the amount of distress increases and the total distress should be the total number of ENV and WP. However, as can be seen, there is not a clear trend. Different TLT sections have different behavior. No obvious trend or rule can be found from this plot.

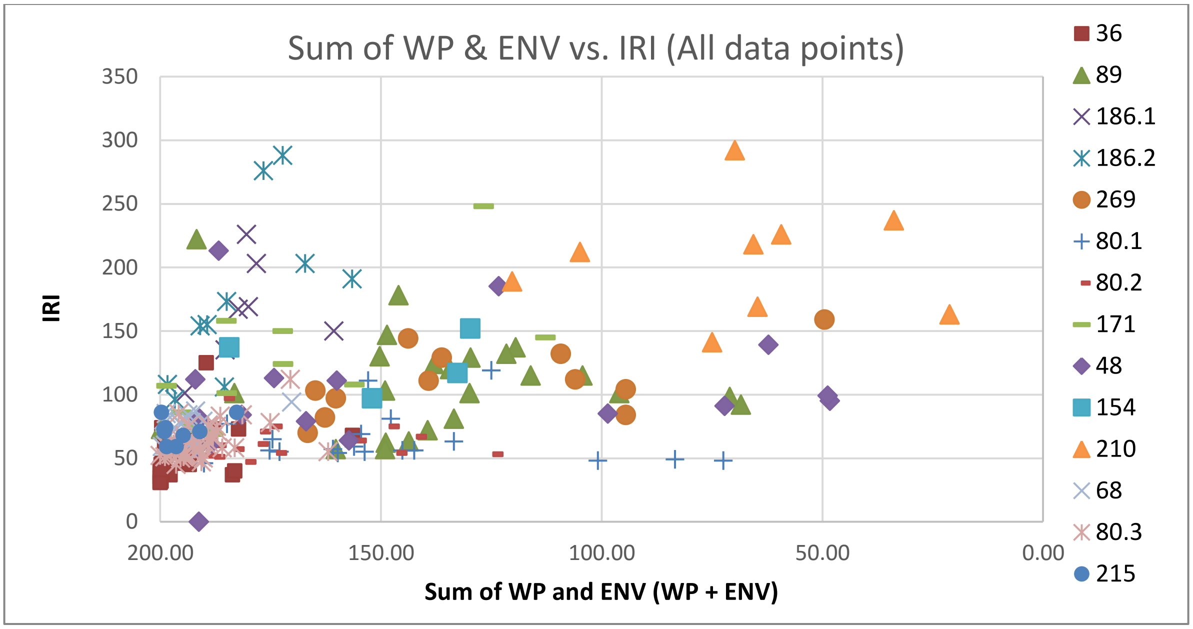

Figure 5-9. IRI Data Summary Plot

The correlation coefficient (R^2) between the IRI and Surface Condition Index was determined for WP, ENV, and ENV+WP. As shown in Figure 5-10, the correlation coefficient is below 0.08. The result of the correlation study 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 cannot give the relationship function for IRI and condition index, so the surface condition indices may not relate to IRI. In other words, unlike what some literature has mentioned, one value cannot be used as a predictor of the other or as an alternative to the other.

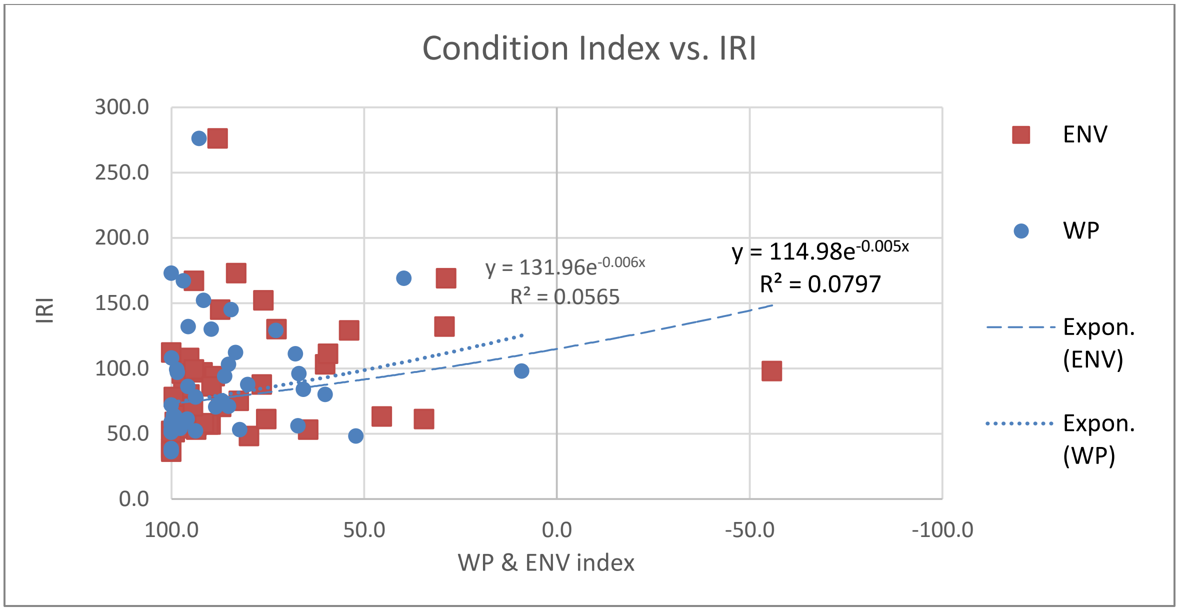

Figure 5-10. TLTs' IRI Data Plot

Even though there is no good relation between 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 WP, ENV, or Sum of WP and ENV; however, the proportion of the data points based on the different performance level could be determined. All TLT sections have the IRI data recorded at every 0.1-mile. By examining all TLT surface sections, 253 performance data points were collected. And the surface condition was divided into 9 different categories, which were integrated by three surface condition levels with 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 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% sections have an IRI between 95 and 170, which is “Failed”; in other words, if the 150 <WP+ENV < 100 there is a 50% probability that the 95 < IRI < 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 in Figure 5-11.

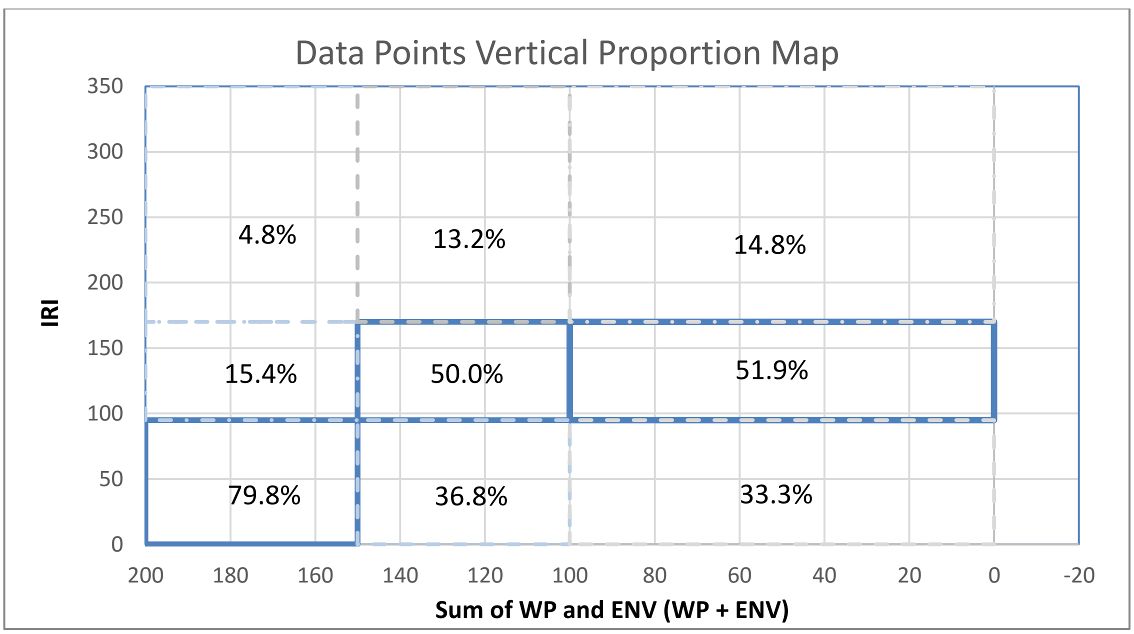

Figure 5-11. IRI Data Points Concentration Plot

<u>5.5.2 Time-Dependent IRI Analysis</u>

As previously discussed, the IRI data depends on the road local profile and the surface condition; 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 Figures 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 of 2.62 in/mile per year with time (2014-2017). SMA treatment only consists of two roads, so no significant conclusions are made.

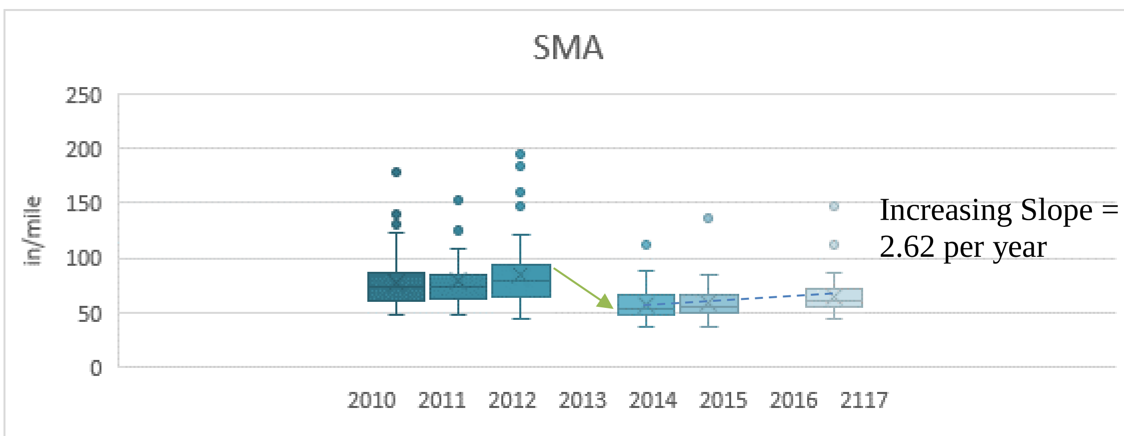

Figure 5-12 SMA IRI Box Plot

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 OGSC sections have lower IRI on both average and data range after they received the TLT in 2012, but less concentrated data points indicate the big variability of the OGSC IRI data. Also, a constantly increasing trend of the OGSC roughness index of 5.17 in/mile per year is found from year 2014 to 2017.

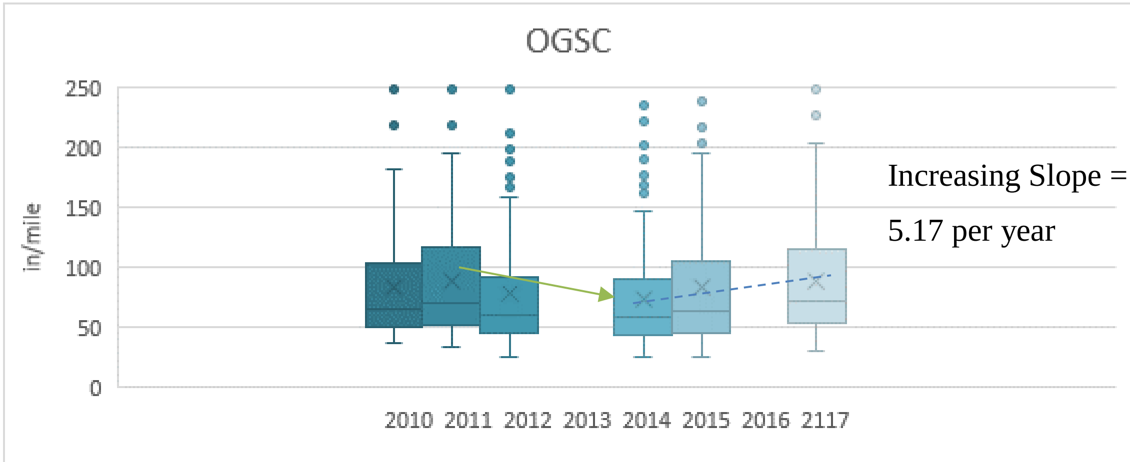

Figure 5-13 OGSC IRI Box Plot

As seen in Figure 5-14, DGA IRI is the highest value out of three TLTs' results, starting above 100 after the treatment. The DGA surface also shows better improvement from the treatment as reflected by an IRI drop 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.

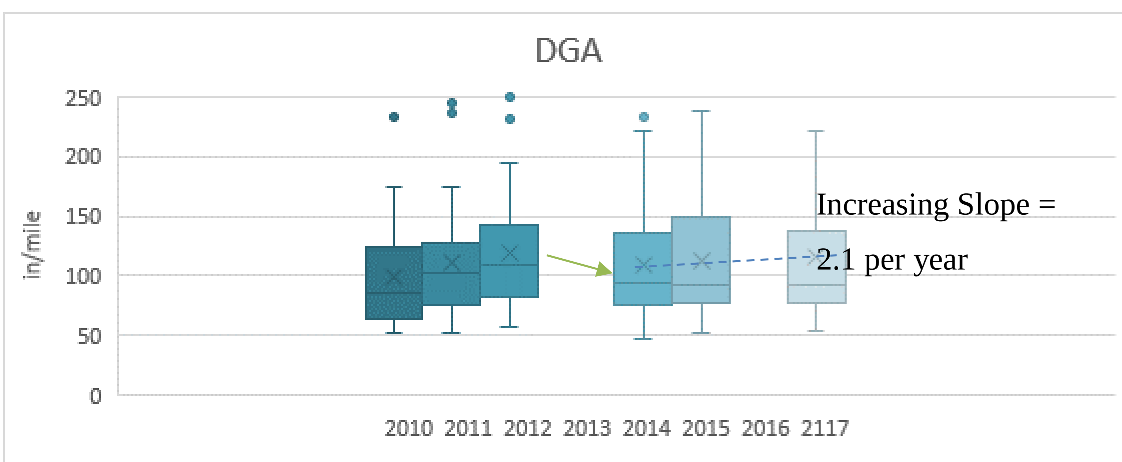

Figure 5-14 DGA IRI Box Plot

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:

- 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;
- IRI does have some general relation with the surface condition index. As long as the condition index stays in the threshold number WP+ENV < 150, IRI will most likely stay below 95;
- DGA has the highest IRI values of all TLT types.

5.6 Summary

Within this performance evaluation study, two TLT sections have failed by WP index, and two TLT sections have failed by ENV index. In total, three sections reached a failure point: I-80.1 and SR-210 failed by the WP evaluation; SR-89 and SR-210 failed by the ENV evaluation. In the first five years, only SR-210 has completely failed from both environmental and load-related distress. It is believed that SR-210 has failed mainly due to environmental distresses; the wheel-path distresses were influenced by the environmental conditions. All of the results are summarized in Table 5-9.

Table 5-9. TLTs Sections' Lifetime Summary

TLTs	State Route	Estimated Time (years)	Already past year	Remain Lifetime (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	

6.0 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 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 10 provinces in Canada. The program has monitored over 2,500 sections of pavements. The database includes information on pavement performance, age, traffic volumes, weather, and materials.

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

6.1 Discussion of Data

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

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

14 years after initial construction. One section was only monitored the same year that it was constructed.

There are some important differences between the LTPP thin lift and local TLT sections. The LTPP thin-lift sections were constructed using the Marshall Mix design method. The TLTs in Utah used the Superpave method. The Superpave method, or 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 ENV and WP indices as it was for the local TLTs. The same design-life criterion that was used to evaluate the local TLTs was used to evaluate the LTPP thin-lift sections. Because all of the thin-lift overlays were DGA mixes, a design life of eight years was considered. 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 was only available for some of the sections. The ENV and WP life columns show the year of a failure for each section. The value of eight plus (8+) was used if failure was not seen during the surveyed period for the given index.

From the table it is noticeable that ten sections failed for ENV distresses before WP and four failed for WP before ENV at 62% & 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, one for WP and one for ENV distresses. These plots are shown in Figures 6-1 and 6-2, respectively. Out of the 16 sections, seven appear to be failing for WP cracking. Figure 6-2, ENV index versus age, shows some interesting behavior in the measurement of the ENV index for the sections. For instance, on section 8B310 the ENV index dips below 70 after one year and picks back up to 76 half a year later. Other sections that experienced this same behavior were 90A310, 8A310, and

49B310. This could possibly be attributed to self-healing of thermal distresses or it's possible the evaluator rated the distress types differently over the survey time period. Self-healing is the closure of cracks due to the liquid behavior of asphalt which increases at higher temperatures (Little and Bhasin 2007). Out of the 16 sections, ten appear to be failing for ENV distresses. This high number may be an indication of the Marshall Mix design method not considering temperature effects in binder selection.

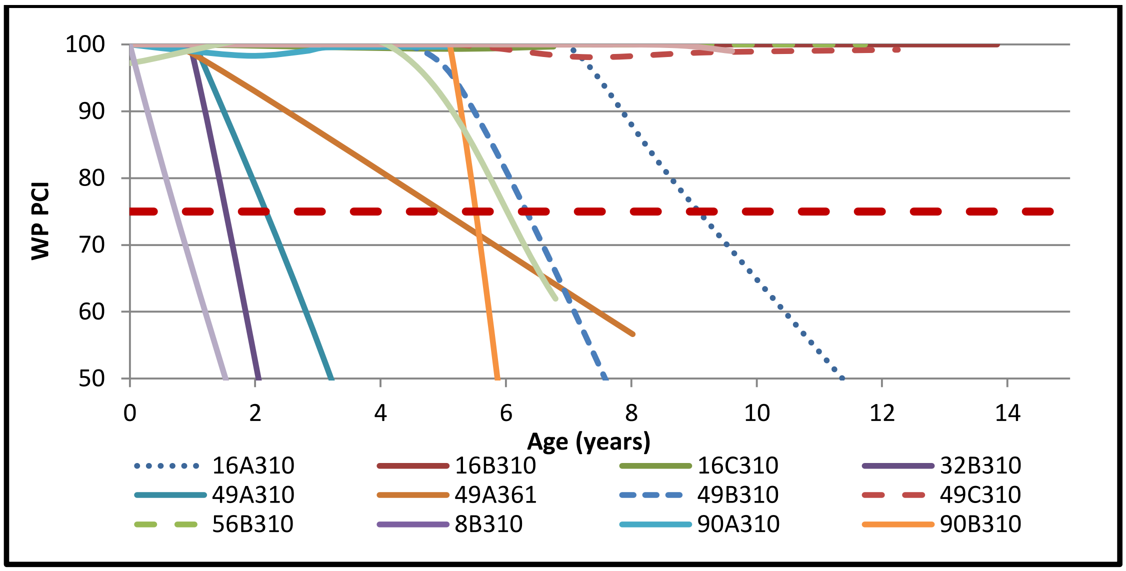

Figure 6-1, Wheel-path pavement condition index with failure line.

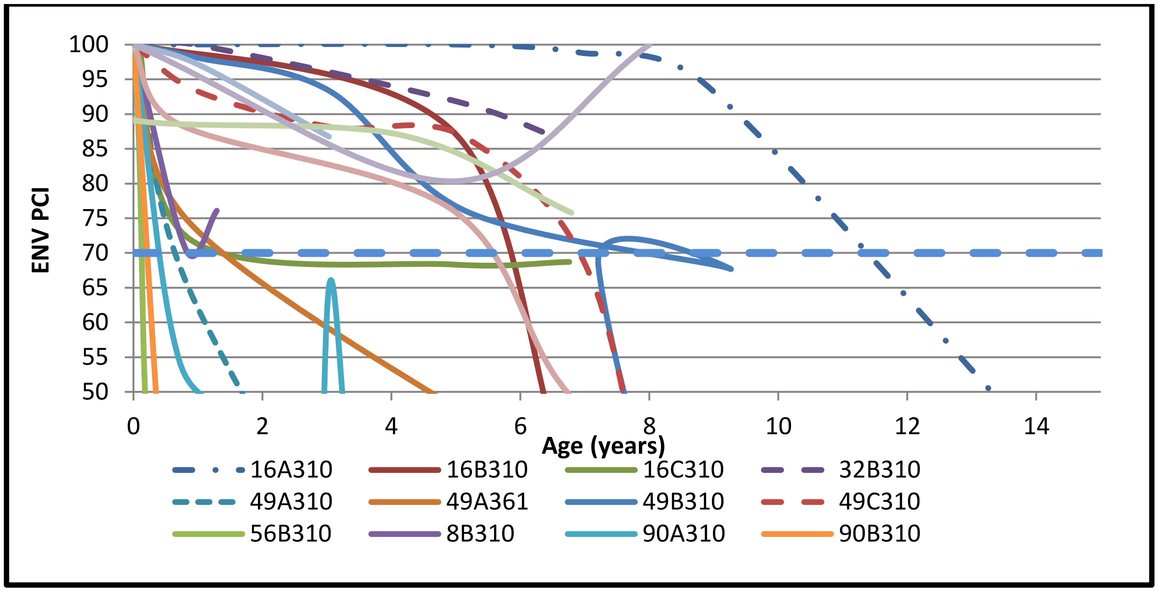

Figure 6-2, Environmental pavement condition index with failure line.

The effect that temperate and climate had on these overlay treatments was substantial. Obviously, colder climates will exacerbate distress formation. In order to show this, the ENV and WP indices for each route were plotted in Figure 6-3 against the annual freezing index for these sections. The freezing index, as defined by the National Snow & Ice Data Center, is the total annual number of degree-days when temperatures are below zero degrees Celsius. Noticeable from Figure 6-3 is the general downward trend in the ENV index scores with increasing freezing index. For the WP index, this trend is not noticeable as the data is more scattered. However, as ENV cracking increases it is expected for WP cracking to increase proportionately. This is primarily from increased water ingress into the pavement and subsequent structural damage to supporting layers.

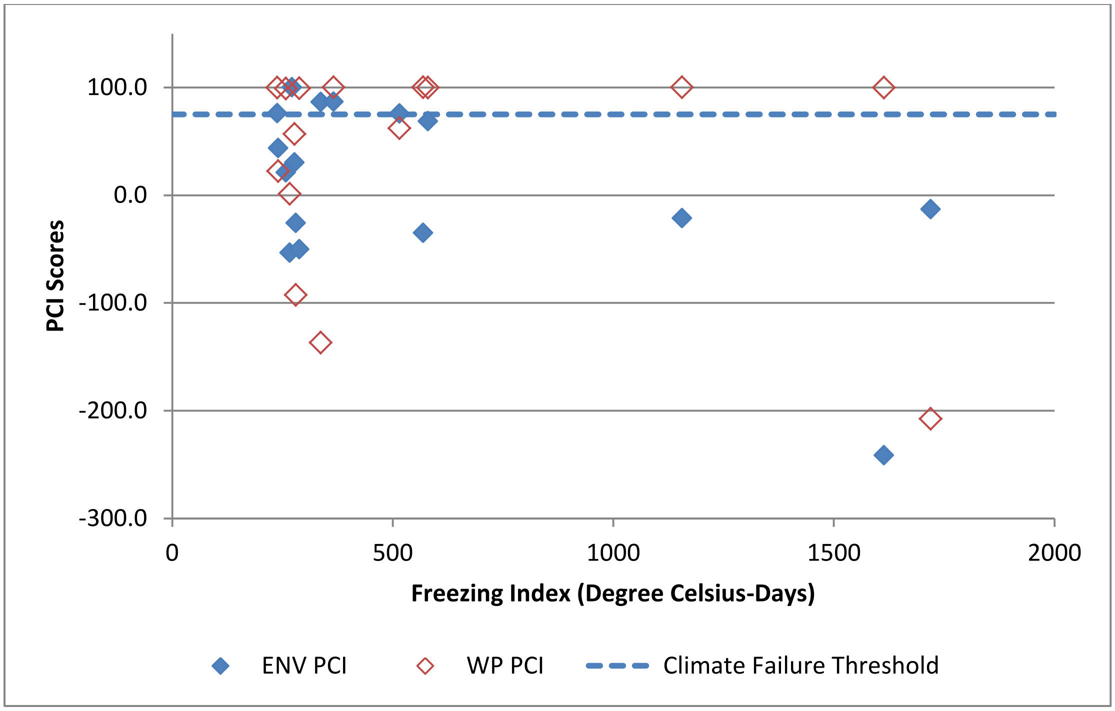

Figure 6-3. LTPP pavement condition indices and freezing index.

6.2 Summary of Comparisons

Similarly to local TLTs, the thin-lift overlays from the LTPP database are seeing a greater number of environmental failures as opposed to structural or wheel-path failures. However, LTPP thin-lift overlays saw a significantly higher number of sections experiencing environmental distress-related failures; 63% opposed to 28% that are likely for the TLTs. This is possibly a result of the Marshall Design method not accounting for climate conditions in the binder selection. Wheel-path failures accounted for 25% of the LTPP thin lifts and may likely account for only 7% of the TLTs monitored in this study.

It is likely that this is due to the adoption of the Superpave Design method that selects asphalt binder based on local climate and shows the benefits of Superpave over the Marshall method.

6.3 Summary

The Long-Term Pavement Performance database was accessed to extract pavement condition data for 16 thin-lift treatment sections from a dry freeze climate and analyzed for performance. These thin-lift treatments were constructed in 1990 using the Marshall Design method and their performance was monitored anywhere from one to fourteen years. These sections were evaluated using the same method that was used for the TLTs. Additionally, the LTPP sections were analyzed for distress performance by freezing index showing decreased environmental performance with increasing freezing index. As was seen in the TLT evaluation, environmental distresses are the main failure mechanism for these sections. Better performance is noticeable in the TLTs evaluated and is likely attributed to the use of the Superpave Design method.

7.0 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) were estimated following procedures developed by Baladi as utilized by UDOT. For all of these sample sections, image data were transferred into numerical data. Two SMAs, four DGAs, and eight OGSCs were evaluated. WP and ENV indexes were calculated, and IRI was analyzed.

First, the average life for OGSC, DGA, and SMA were estimated. The TLTs life prediction is based on WP and 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, DGA, and SMA estimated life as 7.2, 7.4, and 9.9 years, respectively. The life estimation based on the WP index for OGSC, DGA, and SMA are 8.5, 7.0, and 13.5 years, respectively. 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 ability to handle the weather and traffic condition in Utah. Two SMA sections have higher traffic flow than all the other observations, yet the performance results of SMA show that it is the most durable option under intense traffic.

Second, the special location of SR-210 demonstrated 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 leads to the worst weather conditions. Both WP and ENV evaluations showed failure within three years. SR-210 has the lowest traffic flow, but the cold temperature and heavy snowfall caused incredible damage to the treatment surface. The severe environment is a critical problem for this TLT. For high-elevation roads such as SR-210, there should be a better alternative considered to maintain the road surface quality.

Third, 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 high PCI will likely have lower roughness. In summary, the TLTs have a good impact on the road roughness. But based on the limited data, it seems that in comparison to OGSC, SMA results in a lower rate at 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 it also has the highest average roughness.

7.2 Conclusions

Based on the analysis of the results, some key points are made to conclude this TLTs performance analysis. First, the weather is the main cause of distress in Utah since the estimated life based on the ENV is shorter than the result from the WP. The weather condition causes more damage to surfaces than the traffic in Utah. Second, high quality mixes like SMA do result in longer life and lower increase rate in roughness. Third, 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 is comparable to other studies.

7.3 Recommendations & Future Work

After this TLTs evaluation study, the following is 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 back the condition above the threshold. SR-48, SR-154, and SR-269 are very close to the threshold line. Therefore, they need some maintenance 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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