LIFE-CYCLE COST ANALYSIS AND PERFORMANCE COMPARISON OF ASPHALT OVERLAYS ON PCC PAVEMENTS IN WET-FREEZE REGIONS OF CANADA

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ABSTRACT

Long term pavement performance studies and continuous evaluations can help inform better rehabilitation strategies, thus suggesting more innovative rehabilitation designs. This research sought to answer questions on which overlay type would perform better overtime in wet-freeze regions, and what are the major factors influencing their performances. This paper addressed the performance of asphalt concrete over PCC pavements on four LTPP data sites in the selected wet-freeze climate locations of the US and Canada. It has been found that the performance of PCC pavements is subjected to different rehabilitation strategies in the GPS-7 section of the LTPP program. Initially, both convolutional and the modified asphalt overlay strategies were applied for the asphalt concrete pavements rehabilitations for both GPS-7B and C. Then, the performance comparisons are conducted. Firstly, the data obtained were analysed to evaluate the reduction in distresses and roughness index (IRI) achieved after these rehabilitation strategies were applied. Meanwhile, trend analyses were carried out to note the improvements overtime. It was found that the surface distresses such as longitudinal and transverse cracks took longer periods to occur on the modified overlays, and those defects have lower severity compared with the conventional asphalt overlays. What's more, both types of overlay treatments resulted in similar levels of IRI after few successive years of service. However, the rate of roughness changing seemed better if the modified asphalt overlay was conducted on the milled surfaced and with thickness asphalt overlays. Finally, the scenarios generated for LCCA proved that modified asphalt overlays are more suggested than conventional asphalt overlay considering the overall pavement maintenance cost.
Keywords: *Modified, Conventional, Asphalt, PCC pavements, Pavement distress, Performance, LCCA*

1. Introduction

In recent years, focus of pavement engineers has increasingly been on developing strategies to design more sustainable pavements, with improved and prolonged service life (TechBrief, 2016). It is well established that existing pavements made from concrete (rigid pavements) are being affected by increasing traffic levels and drastic change in climatic conditions. This in fact, is leading to increased distress levels and loss of smoothness of these pavements (TRL, 2008). Hence, the need for a continuous advancement in innovations to improve its service life.

Asphalt overlays have been found to be one way of reviving pavements. Overtime, asphalt overlays have varied according to materials used. Further, in recent times, modifications of these asphalts overlays have been made to accommodate for the failures and limitations of conventional forms of overlays. The use of modifiers such as sulphur, rubber tires, polymer products neat rubbers etc., in asphalt, have resulted in enhanced tensile strength; decreased pavement distresses such as cracking and rutting (Yildirim, 2007) and improving pavement service life (Harol, 2001). However, the question still remains as to what extent modified asphalt reduces this distresses and performance ratio compared to conventional forms.

It is therefore important to understand how different forms of asphalt overlay perform over Portland Concrete Cement (PCC) pavements. This understanding will better help in informing better choices of rehabilitation strategies, especially under different climate conditions such as the Wet-freeze. Hence, a need for evaluation of various rehabilitation practices/strategies under varying conditions. In this work, an assessment of the performance of modified and conventional asphalt overlays over PCC pavements is studied, using data obtained from LTPP Infopave.

2. Preservation, Maintenance and Rehabilitation of PCC Pavements

PCC pavements are generally rigid pavements made from concrete which conventionally consists of four types. The major distinguishing characteristic amongst them being their crack control features (TAC, 2013). Improving safety conditions and service life over these pavements are usually priority considerations in developing maintenance plans. These plans would typically involve preservation, maintenance, rehabilitation or outright reconstruction. The preservation or rehabilitation strategy would largely depend on the condition of the existing surface, the availability of funds, the comparison between the costs and the benefits, the availability of materials and so on (TAC, 2013). Pavement preservation involves practises that improve the condition and service life of infrastructure such as preventive maintenance and minor rehabilitation without adding structural capacity to them (FHWA, 2013).

There are various strategies that are employed in achieving these objectives of safety and service life improvements for concrete pavements. Preservation strategies include but are not limited to; crack and joint sealing, diamond grinding, shot blasting, partial or full depth repair with concrete and Hot Mix Asphalt (HMA) Overlay. Rehabilitation methods are; bonded or unbonded concrete overlay, cracking and seating with resurfacing, rubberizing and resurfacing as well as HMA overlay (TAC, 2013). HMA overlay is noted to add between 10 to 15 years to the service life of PCC pavements, but its performance is largely dependent on the thickness of the overlay (TAC, 2013).

2.1 AC overlays and PCC Pavements

AC over PCC has increasingly become a popular method of maintenance of rigid pavements which has resulted in greater experience in design and construction (FHWA, 2013). When using AC overlays on PCC, it becomes necessary to consider the pavement thickness, climate, traffic levels, AC mix design and very importantly the integrity of the existing concrete pavement (FHWA, 2013). The interaction between these factors would need to be measured to obtain a good evaluation.

The addition of modifiers as earlier discussed to conventional asphalt have arguably yielded better results although have resulted in higher initial costs (Yildirim, 2007; Harol, 2001; Kaloush et al. 2009). Justification for additional costs is therefore necessary to reflect better investment decisions, as there are always budget constraints associated with these forms of investments (Hall et. al, 2003). Research by the Arizona DOT suggests that these higher costs accrued to modified asphalt reduce over the service life of the pavement as it results in less distresses and damage (Karamihas and Senn, 2010).

A major failure associated with these forms (conventional or modified asphalt concrete) over concrete pavements is reflective cracking (FHWA, 2013). This has further lead to the development of strategies such as saw and sealing AC overlays on concrete pavements to mitigate this type of failures. For example, it might be necessary for perform rubblization on concrete pavements especially if in poor condition when placing structural asphalt overlay using a tack coat, to give better performance (Hoerner et al. 2001; TRB 2006). The presence of interlayer has also been found to help reduce the occurrence of reflective cracking (Chowdhury et. al, 2009)

The LTPP data base serves as a valuable source of information where data on long term performance of various design and construction pavement strategies can be continuously evaluated (FHWA, 2013). This allows room for in-depth comparison of performance in diverse conditions such as climate, traffic and so and has provided a base for evaluation of the performance of PCC pavements. In more specific details, the evaluations by researchers over the years on the performance of AC overlays on PCC pavements in specific locations are thus discussed.

Studies by Hall et.al., (2005) and Carvalho et al. (2011) using the LTPP data identified primary factors affecting performance according to information provided in the data base to be pre-overlay preparation, overlay thickness, use of rubblization on existing pavements and saw and sealing. Pre-overlay preparation was generally found to improve pavement smoothness over time. However, study by (Karamihas and Senn, 2010) in Arizona, found that roughness increased more rapidly for sections with minimal preparation compared to those that received intensive preparations. There was also no relationship found between the development of cracks and pre-overlay preparation

A relationship was found between thickness of overlays and rutting in study by (Karamihas and Senn, 2010) who considered 4 inch and 8 inch AC overlays. It was observed that thicker layers resulted in decreased occurrence of rutting overtime. Further, in studies by Carvalho et al. (2011) there was no statistical difference found between overlay thickness and the development of cracks. However, earlier study by Cho et. al, (1998) saw a relationship between fatigue cracking and pavement thickness with thicker pavements performing better in this regard.

Furthermore, study by Karamihas and Senn, (2010) discovered that roughness on AC overlays increased slower over time on locations that received intensive pre-overlay preparation compared with site that received minimal or none. Also, Perera and Kohn (2006) concluded that a statistical relationship exists between pavement roughness and overlay thickness, saying that areas with greater thickness performed better.

In summarising their literature review FHWA (2013) found that various PCC pavement repair techniques worked in improving pavement performance relatively. However, AC overlay performance were better reflected over longer periods of time. In agreement with Hall et.al (2005), they concluded that immediate repairs would result in better pavement performance than when delayed.

2.2 LTPP Program and InfoPave

The Long-Term Pavement Performance (LTPP) program is administered by the Federal Highway Administration under the US department of Transportation and has been in existence for about 30 years. It is a large research program that involves the study of pavement performance overtime and involves two fundamental classes of study with other smaller studies. These fundamental studies are the General Pavement Studies (GPS) and Specific Pavement Studies (SPS) which together have about 2,500 test sites on in-service highways throughout North America (FHWA, 2016). All LTPP data is obtained from the data base called the LTPP Infopave.

The performance of PCC is subjected to different rehabilitation strategies one of which involves Asphalt Concrete (AC) overlay over PCC pavements studied under the GPS-7 experiment in the LTPP program. Under the GPS-7, seven AC overlay techniques are applied to different test sections. The rehabilitation treatment factors studied in this work are the AC overlay with Conventional Asphalt Cement (7B) and AC overlay with Modified Asphalt Cement (7C) both with CPR or No Pre-treatment

It is the objective of this research study to examine the relative effectiveness of the use of two AC overlay rehabilitation strategies which are conventional and modified asphalt over rigid pavements in wet-freeze climatic conditions and the influence of possible factors such as AC thickness and pre-overlay preparation on their relative effectiveness.

3. Methodology

LCCA analysis of both conventional and modified AC overlay alternatives based on different scenarios bas been discussed. Figure 1 describes the basic framework for LCCA analysis in this paper. Firstly, different kinds of LTPP data, both environment and performance data, were obtained from data release. After that, a thorough distress trend analysis was conducted for performance evaluation. Finally, LCCA analysis was discussed and analysed for long term pavement performance evaluation, thereby giving recommendations for pavement management.

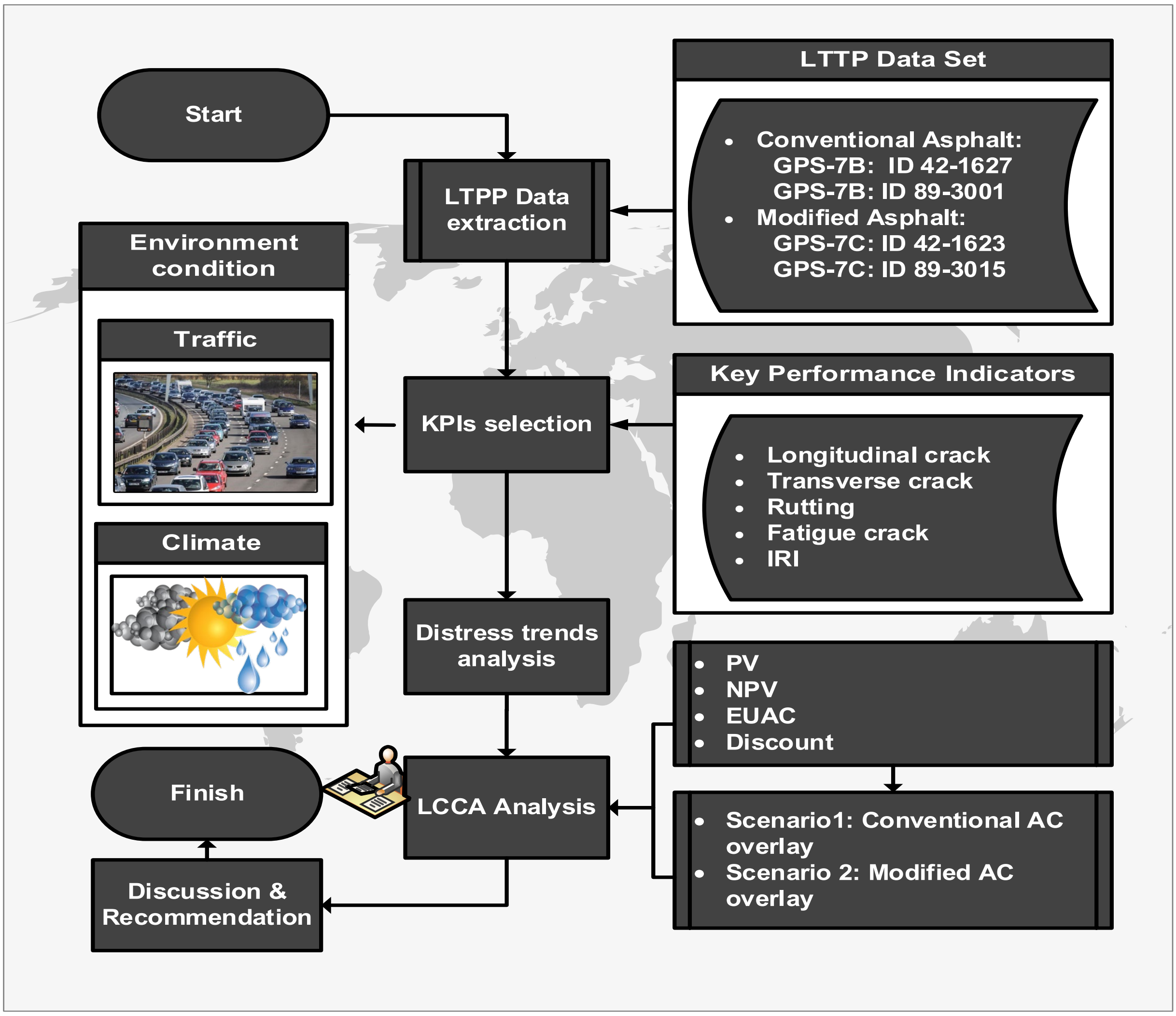


Figure 1: Methodology framework of LCCA

3.1 Performance criteria used

The performance criteria selected for this study are based on relevance to interpretation to performance of overlay and the availability of data for chosen experiment type and sites. This section provides a general overview to definitions, measurement criteria and interpretations of measurements. These test sites have been evaluated based on transverse cracking, longitudinal cracking, fatigue cracking, faulting, overlay rutting and IRI (International Roughness Index)

Transverse cracking

These types of cracks are located perpendicular to the centerline of the pavement and not found at joints of PCC, otherwise will be known as reflective transverse cracks. They are usually measured by length and number and are classified into three severity levels; Low, Moderate and High. Unsealed cracks with mean width less than or equal to 6mm or sealed cracks with unknown diameters in good condition are classified as low severity. Moderate severity cracks include those with mean width greater than 6mm but less than or equal to 19mm or cracks mean width less than or equal to 19mm close to a web of random low severity cracks. High severity cracks are those greater than 19mm or cracks less than or equal to 19mm located close to random moderate or high severity cracks. Data obtained from the LTPP Infopave summarises provides the three severity levels (SHRP-P-338,1993; FHWA, 2005).

Longitudinal cracking

These are cracks which are located parallel to the centerline of the pavement. They are usually measured in two different ways. Along the wheel path and not along the wheel path. Just like transverse cracks, they are measured in meters and classified according to three severity levels; Low, moderate and high, with the definitions of each one similar to that of the transverse cracks earlier discussed (SHRP-P-338, 1993; FHWA 2005). These cracks are presented in the LTPP Infopave according to severity levels and have been interpreted as such.

Rutting

"A rut is a longitudinal surface depression in the wheel path. It may have associated transverse displacement" (SHRP, 1993). It is usually measured as mean rut depth in millimetres and is calculated from dipstick surveys for right and left wheel paths.

Fatigue cracking

These are a series of interconnected cracks which are just developing and are characteristically found along wheel paths. At latter phases they form chicken wire/alligator patterns. They are usually measured in square meter (area) and are generally classified according to three severity levels; low, moderate and high. Low severity is characterised by no or few interconnected cracks with no spalling or sealing, where pumping is not evident. Moderate severity is characterised by cracks that are interconnected forming a pattern in a given area and maybe spalled or sealed without pumping being evident. Areas of interconnected cracks in complete patterns which are moderately or severely spalled and may be sealed are classified as high severity. Pumping maybe evident and area subject to pieces moving under traffic (SHRP-P-338, 1993; FHWA 2005). This type of distress in the LTPP Infopave have also been characterised according to severity levels.

IRI

International roughness index (IRI) is calculated by evaluating the longitudinal profile (Perera and Elkins, 2015). A change in roughness overtime which is as a result of a change in longitudinal profile over time serves as a good indication for pavement performance. Road profiler is used to profile test sections with profile data generated at intervals of 25mm. For the LTPP Infopave, roughness data has been characterised as mean IRI. This is the average IRI of the left and right wheel path and is measured in meter per kilometer (m/km).

LCCA analysis

Recently, the economic analysis of long time pavement performance prediction approach has been widely used, for which Life-Cycle Cost Analysis (LCCA)（Wang, et al.2016, Wu, et al.2017）has been extensively studied by agencies for decision making of pavement management. Typically, an LCCA analysis system consists of elements such as establishing the design alternatives, determining analysis period, determining the discount rate according to the economic development of the country or the state, estimating the specific cost and finally the analysis of results.

Considering LCCA, two important indicators, as shown in Eq. (2) and Eq. (3), play key roles in this approach. First is Net Present Worth (NPW), which converts the cost of pavement maintenance for different years into the present year using the discount value thereby doing the comparison. The other important indicator is the Equivalent Uniform Annual Cost (EUAC), which is calculated based on the value of NPV and distributes the cost into the pavement life cycle.

$$\mathrm{PW} = \mathrm{C} \times \left(\frac{1}{1+i_{discount}}\right)^{n} \tag{1}$$

Where PW represents the Present Worth ($), C represents Future cost ($), $i_{discount}$ represents Discount rate and *n* represents years between future operation and the present.

$$\mathrm{NPW} = \mathrm{IC} + \sum_{j=1}^{k}\left(M\&R_j \times \left[\frac{1}{1+i_{discount}}\right]^{n_j}\right) \tag{2}$$

Where NPW represents the total net present worth of all the cost throughout pavement service life, IC represents the initial construction cost of the pavement, *k* represents the total number of the future maintenance and rehabilitation activities, $M\&R_j$ represents the specific cost of j^{th} future maintenance and rehabilitation activities.

$$\mathrm{EUAC} = \mathrm{NPW} \times \left[\frac{i_{discount} \times (1+i_{discount})^{AP}}{(1+i_{discount})^{AP}-1}\right] \tag{3}$$

Where EUAC represents the Equivalent Uniform Annual Cost of the maintenance/ rehabilitation activities, NPW represents the net present worth of the operations (Xu, et al., 2011).

4. Results and Discussion

This sections presents results and discusses performance trends. The availability of data for specific performance criteria and general characteristic information were deemed a major limitation for this study.

4.1 General pavement characteristics

As can be shown in Table 2, the pavement structure for each site with the highlighted layer being the one under consideration for this study. Table 3 further shows CPR activities carried out on each of the sites pre-overlay. Intensive preparation is considered on site 18-3015 with fracture treatment for its PCC base and milling of surface to receive overlay. Minimal preparation was considered for site 42-1627 with full depth transverse joint repair, site 89-3001 and 42-1623, although 89-3001 had sawing and sealing after overlay. AC shoulder restoration was performed for all sites excluding 18-3015. There were also two previous AC layers on sites 42-1627 and 89-3015 with overall thickness of 82.5mm and 172.5mm respectively.

Table 1: General pavement characteristics at all location

Layers	Pavement layer thickness (mm)			
	GPS 7B		GPS 7C	
	42-1627	89-3001	42-1623	89-3015
Subgrade (untreated)	NA	NA	NA	NA
Unbound (granular) base	600	385	150	332.5
Bound (treated) base		150	160	
Portland cement concrete layer	242.5	225	232.5	205
Asphalt concrete layer	82.5	80	25	0
Portland cement concrete layer	257.5			
Asphalt concrete layer	20		62.5	92.5
Asphalt concrete layer	62.5		37.5	80
Asphalt concrete layer	37.5			62.5

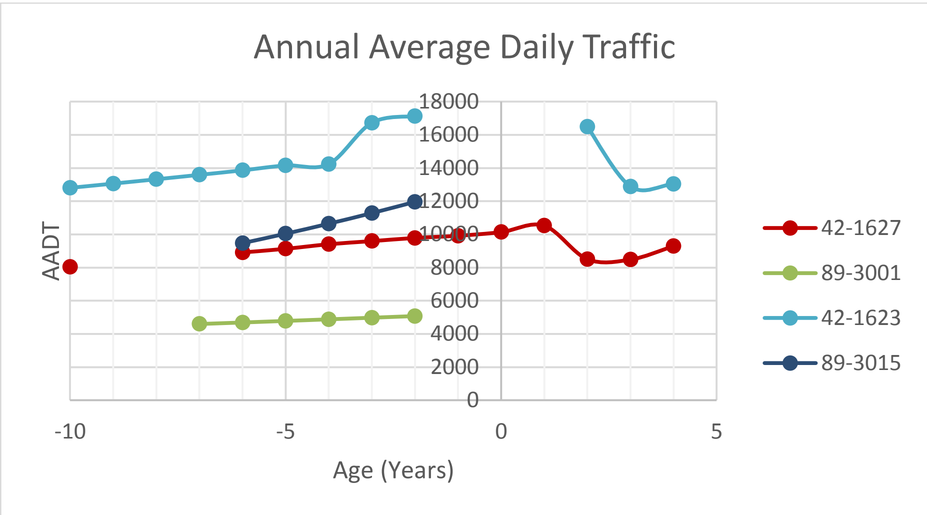
*Note: NA indicates the data is not available

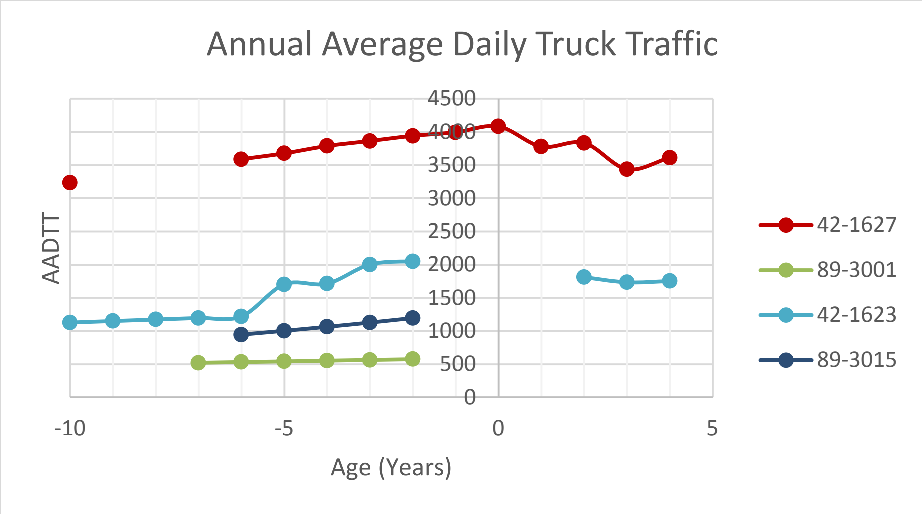
Table 2: CPR Activities

CPR activities			
42-1627	**89-3001**	**42-1623**	**89-3015**
AC shoulder restoration	AC shoulder restoration	AC shoulder restoration	Fracture treatment of PCC base
Full depth transverse joint repair patch			51- Milling off of AC

4.2 Traffic Information

Traffic information is presented in Figure 2 for all locations. Age 0 in the figure depicts the year of rehabilitation with the AC overlay. Negative age (e.g -1) signifies the number of years before rehabilitation. Experiment sections in Quebec (sites 42-1627 and 42-1623) did not provide traffic information from 2009 and the other sites did not have traffic data after 2014. Which has limited interpretation of post treatment data using these conditions.





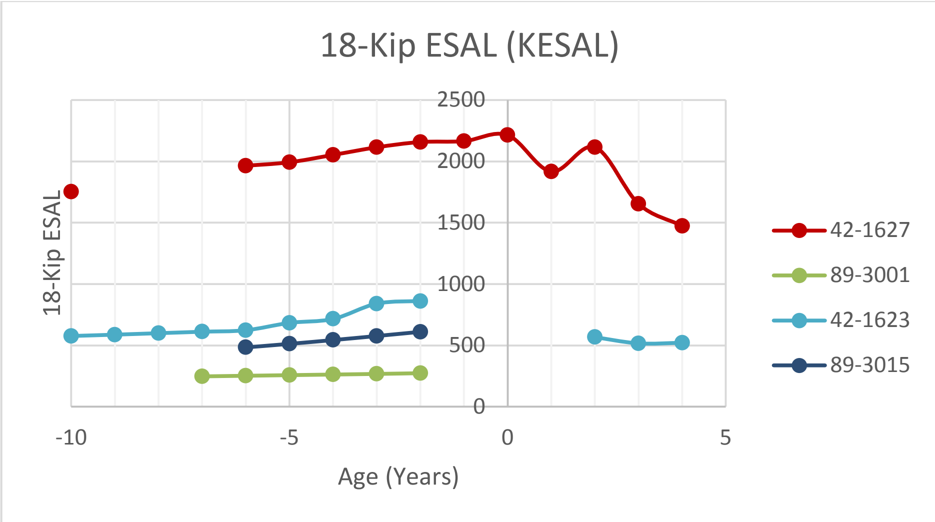
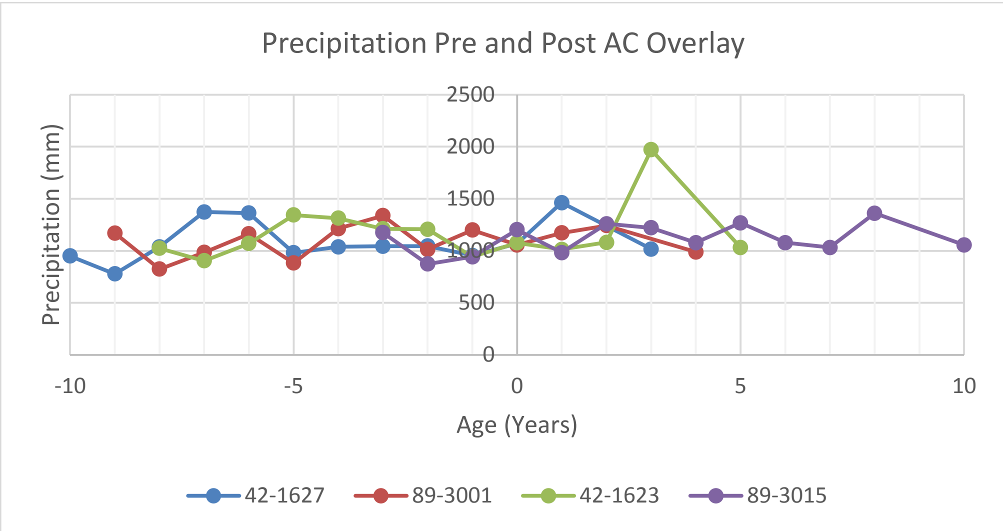


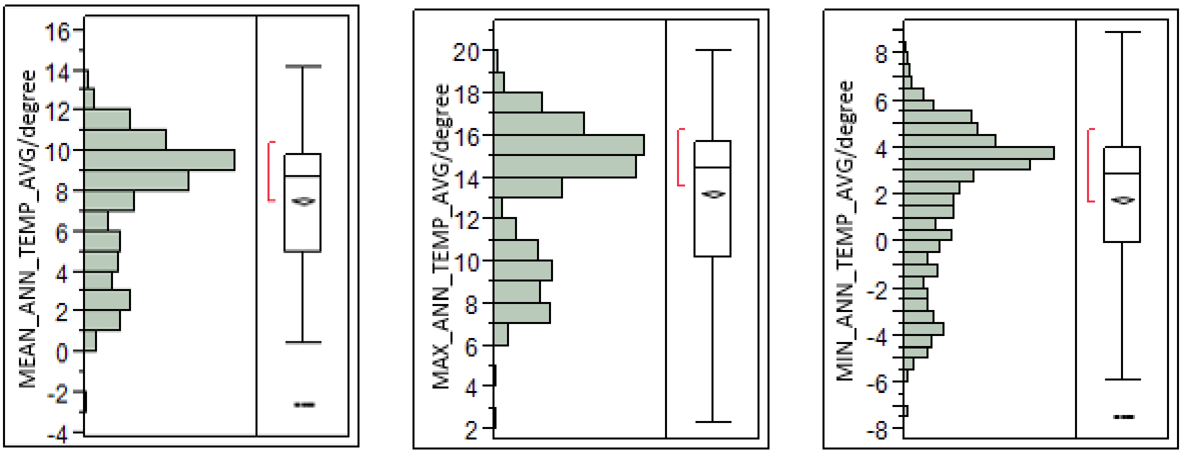
Figure 2: Traffic data

Annual daily traffic and truck traffic are highest at site 42-1627, but the 18-Kip ESAL is highest on 42-1623, probably because it is an Urban principal arterial road.

4.3 Climate information

Climate conditions at all locations can be viewed in Figure 3. Precipitation levels across sites are similar and was at its peak in 2011 at 1,971.4mm after all the sites had been overlaid with the AC considered in this study. Here in Figure 2, the median value of MEAN_ANN_TEMP_AVG MAX_ANN_TEMP_AVG ,MIN_ANN_TEMP_AVG are 8.7℃, 14.4℃and 2.9℃respectively, which represent the air temperature according the data collection system of LTPP. When it comes to pavement surface, the high temperature would be much higher than the recorded air temperatures, whereas the low temperature can be much lower than that corresponding recorded air temperature, which makes the pavement vulnerable to climate change. According to a report by Transportation Research Laboratory (2008) in the United Kingdom, the most impact of climate on pavements are due to extreme and average temperatures, soil moisture and precipitation. Asphalt surfaces and concrete pavement structure are prone to damage by high temperatures.





Histogram and box plot of temperature data

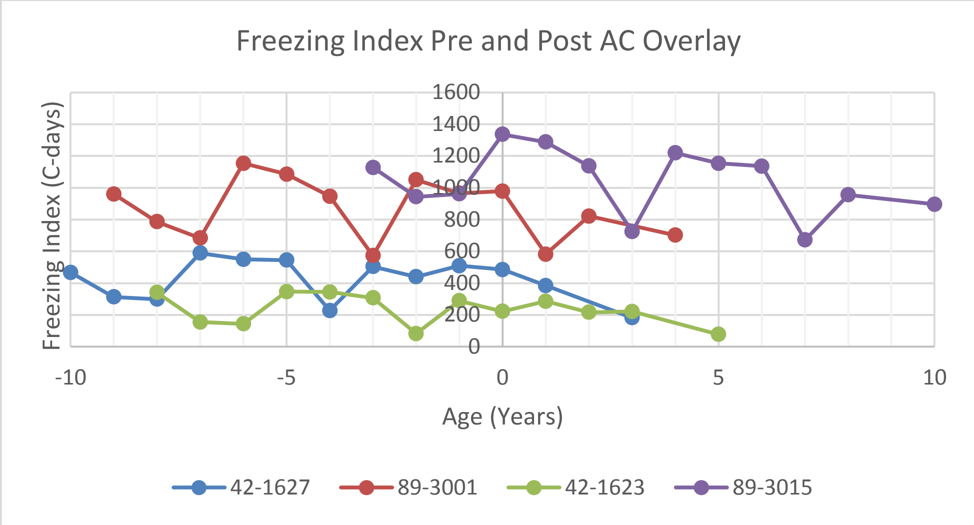


Figure 3: Precipitation, Temperature and Freeze index at all sites

4.4 Performance findings

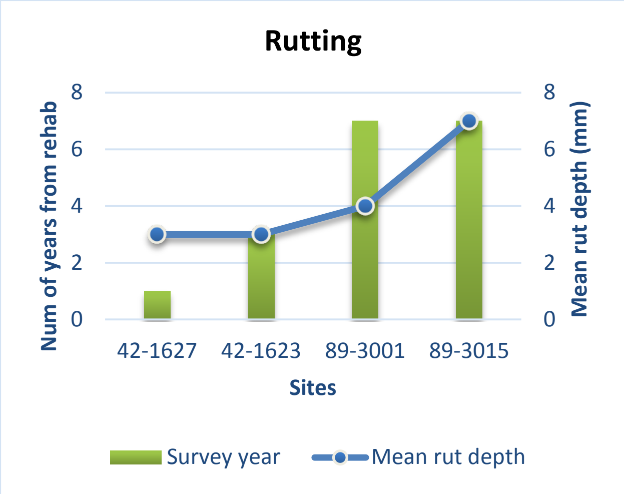
The pre-rehabilitation data for the IRI and identified distresses for the experiment sites were determined using the last recorded measurement of these parameters prior to AC overlay. However most of these distresses did not occur prior to the overlay. The last recorded measurement prior to the overlay was mainly used for evaluating the IRI. The years under consideration are from 2000 to 2016 for available data.

4.4.1 Analysis of trends in distresses

All analysis has been made with reference to the date of rehabilitation and survey date after rehabilitation. For all the distress data, there was only one survey date post rehabilitation except for site 89-3015 which had numerous survey dates after.

Rutting

Data obtained for the mean rut depth is plotted for all sites, in Figure 4 and for site 89-3015, in Figure 5. Only site 89-3015 had distress data prior to overlay date (August, 2003).



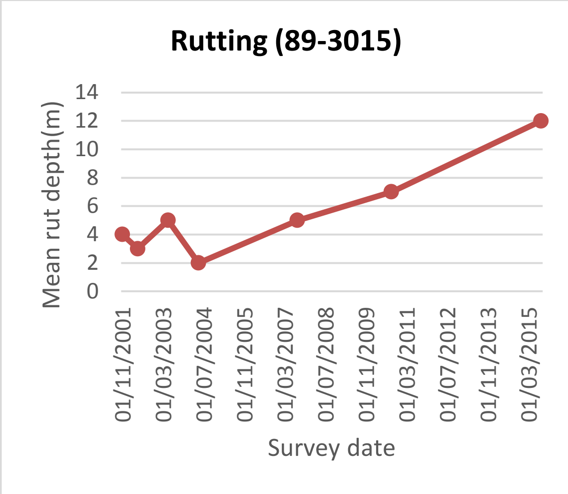


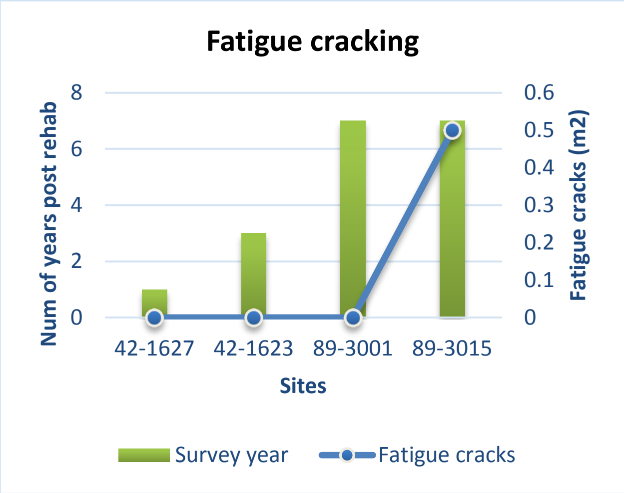
Figure 4 : Comparison of Rutting for all sites

Figure 5: Rutting for site 89-3015

In comparing the time of occurrence of rutting for sites 42-1627 and 42-1623, the latter with modified asphalt seemed to have had a slower rate of occurrence of rutting with a mean rut depth of 2mm in the third year, while the site with conventional asphalt had the same rut depth just within a year of its occurrence. Although overall rutting performance seemed relatively similar for both types of overlay relative to their extent of occurrence over time (in earlier years). This was irrespective of the level of preparation before overlay (view change to rutting depth for site 89-3015 with same rutting depth of 2 mm in the first year after rehabilitation). But over prolonged periods (7 years) comparing site 89-3001 (conventional) and 89-3015 (modified), with rutting depth of 4mm and 7mm respectively, the occurrence of rutting on modified asphalt seemed to have picked up. According to work by Hall et al. (2005) there was no statistical evidence depicting a relationship between the level of preparation pre-overlay and the level of occurrence of rutting. This might explain why rutting still occurred on site 89-3015 that was milled. However, conclusions drawn in work by (FHWA, 2013) which reviewed other studies of AC overlays on PCC pavements in Texas discovered that, greater thickness and other AC interlayers reduced the occurrence of rutting. This might have decreased the extent of occurrence of rutting limiting it to just 12mm in twelve years on site 89-3015.

Fatigue cracking

Fatigue data for all sites with respect to rehabilitation and survey date is shown in Figure 6 and further details for site 89-3015 in Figure 7.



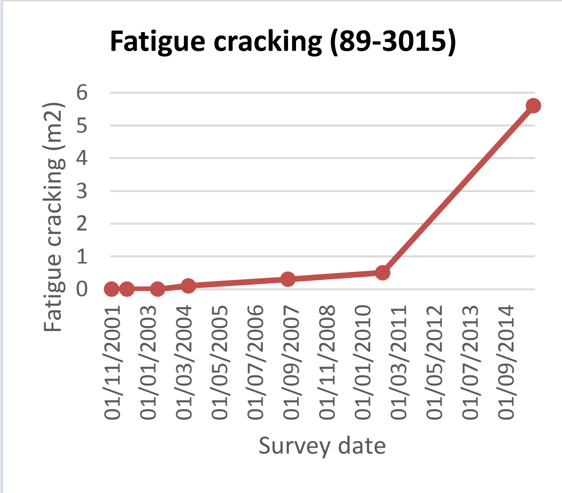
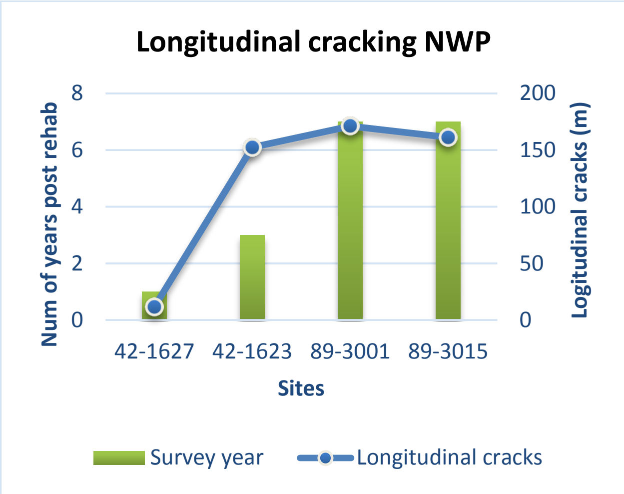


Figure 6: Comparison of Fatigue cracking for all sites **Figure 7: Fatigue cracking for site 89-3015**

From the available data, there seem to be no significant difference in the occurrence of fatigue cracking for both modified and conventional asphalt. Furthermore, there appears to be no dependene on overlay thickness. Within the first one to three years across all sites, there was no evidence of occurrence of fatigue cracking. Accordig to Hall et.al, (2005), there was also no statistical difference in the extent of cracking found between AC overlays that received minimal or intensive pre-overlay preparation. It is also observed that on section 89-3015 experienced a significant increase in fatigue cracking from 2010 (7 years from rehabilitation) This conicides with the increase in annual average temperature increased to 7.1oC in 2010 with the least number of cold days (671 days) with prior years mostly above 1000 cold days. This indicates that fatigue cracking is prone to occur with significant temperature change.

Longitudinal cracking

Non-Wheel Path (NWP) longitudinal cracking data for all the sites are presented in Figure 8 and specific details for site 89-3015 in Figure 9. There was no wheel path longitudinal crack recorded in all the sites. Note that site 89-3001 had a majority of these cracks (152.5m) on the medium severity level and 18.7m of them on the low severity level and site 89-3015 had a large part of these cracks (198.6m) at the low severity level and 3.2m at the medium severity level. Site 42-1627 and 42-1623 had low severity level cracks.



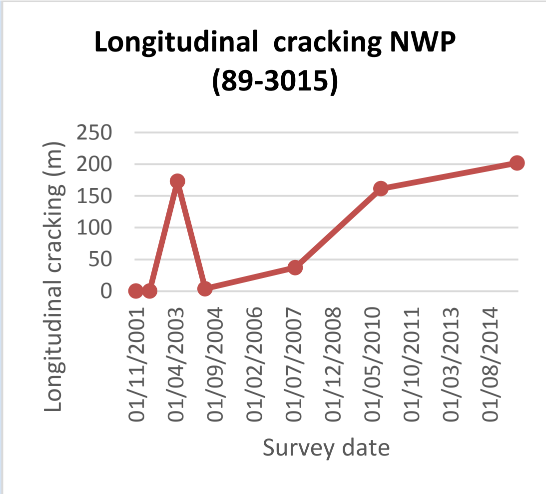
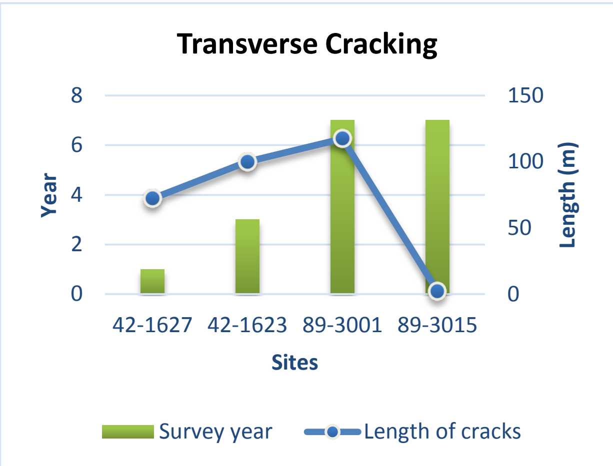


Figure 8: Comparison Longitudinal cracks (all sites) **Figure 9: Longitudinal crack for site 89-3015**

Comparing both sites with modified asphalt, the occurrence of longitudinal cracking was slower for that with a milled surface before overlay (89-3015) with crack length of 37m (low severity) recorded in three years compared with site 42-1623 with crack length of 152.5m (low severity) in the same three years. In a span of seven years, comparing site 89-3015 (modified) having 161.3m (low severity) of NWP longitudinal cracks with 89-3001 (conventional) having 171.2m (with 152.5 medium severity) of NWP longitudinal cracks, 89-3015 seemed to have performed better overtime with lower severity probably because of its milled surface. However, the unmilled surfaced modified site (42-1623) had 152.5m although low severity of NWP longitudinal cracks in just the third year. This might be attributed to the fact that it was not milled before overlay, it has the highest average annual temperature amongst all four sites and the highest loading of 18-kip ESAL being an Urban principal arterial road. Furthermore, between 2007 and 2010, longitudinal cracking onsite 89-3015 increased from 37m to 161.2m. It was observed that a significant jump in average temperature occurred within that period, between 2009 (4.9°C) and 2010 (7.1°C). This might in addition explain the increase in cracking.

Transverse cracking

All sites had low severity cracks, except for site 89-3015 which had total lengths of 5.8m low severity, 7.4m (medium severity) and 3.7m (high severity) cracks in its twelfth year after rehabilitation. Nevertheless, in its earlier years it showed no sign of transverse cracking with just a total length of 2.2m low severity crack showing up in the third year. Generally, transverse cracks are noticed to occur at a slower rate on modified asphalt than on conventional asphalt, with site 18-3015 displaying the lowest number and length of cracks as compared with the rest (Figures 10 and 11) which are relatively depicting the same condition. Sites with conventional asphalt seemed to have transverse cracks occurring earlier in its service life (within 1 year for 42-1627) and site 89-3001 having the highest length (117.4m) and number (34) of transverse cracks in 7 years.



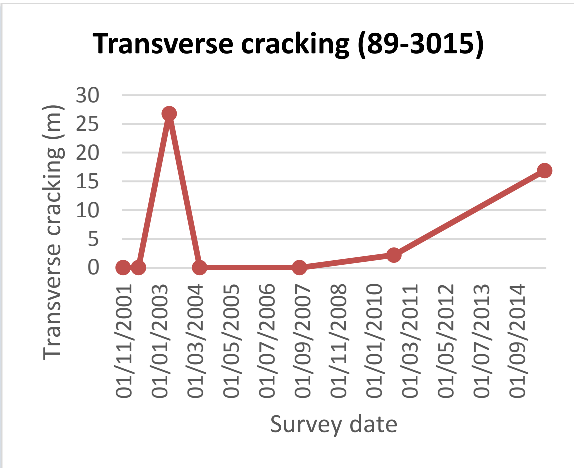


Figure 10: Comparison of Transverse cracks (all sites) **Figure 1: Transverse cracks site 89-3015**

Site 89-3015 with a milled surface before overlay performed significantly well with respect to transverse cracks having a minimal length (16.9m) and number (7) of cracks after twelve years.

4.4.2 International Roughness Index (IRI)

IRI values overtime from 2000 to 2016 for all the sites are shown in Figure 12 for all the sites. It is generally noticed that after AC overlay the IRI values reduced and remained fairly constant over the subsequent years under consideration, meaning that there was an overall improvement in surface smoothness across all the sites.

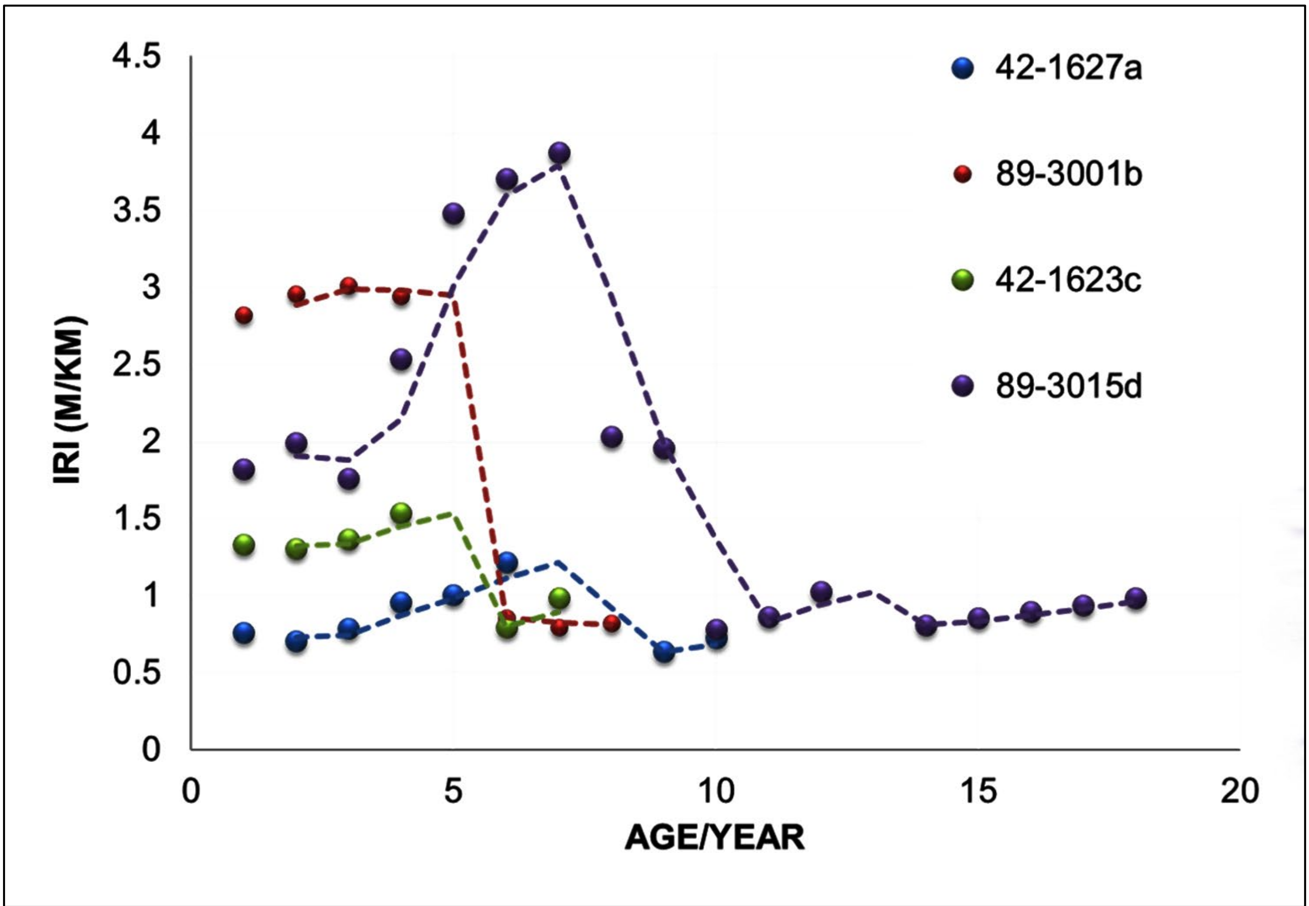


Figure 2: IRI overtime pre and post AC overlay

In further analysing the IRI data, the details of IRI values just before rehabilitation and after rehabilitation for each site is given in Table 4 and Figure 13.

Table 3: Rehabilitation details for IRI

Sites	42-1627	89-3001	42-1623	89-3015
Date prior to rehabilitation	08/09/2005	03/25/2008	03/25/2008	06/23/2003
IRI value	1.213	2.947	1.533	1.024
Rehabilitation date	10/06/2010	01/06/2009	01/04/2008	08/01/2003

First date after rehabilitation	04/11/2012	07/12/2012	07/12/2012	05/21/2004
IRI value	0.636	0.856	0.797	0.809

A correlation of values before and after rehabilitation indicated that there a moderate positive relationship statistically between these values with a p-value of 0.57.

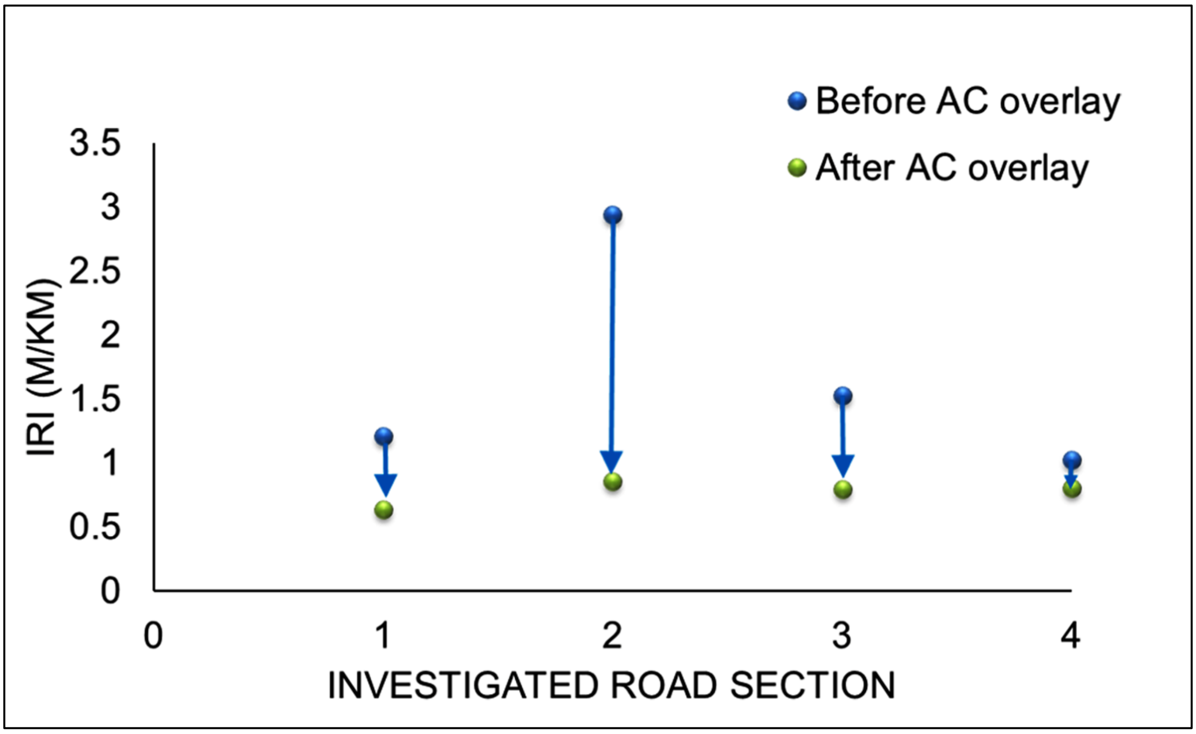


Figure 3: Comparison of Pre and Post IRI values by location

Results further show that the IRI decreased drastically for those sections with very high IRI prior to rehabilitation. Site 89-3001 depicted a reduction rate of change of 0.71m/km from the last time data was recorded (two years) before rehabilitation to the first time (one year afterwards) data was obtained post rehabilitation. Sites 42-1627, 42-1623 and 89-3015 had rates of change of 0.48m/km, 0.48m/km and 0.21m/km respectively for relative data obtained. However, there is indication that the roughest section post rehabilitation (89-3001) deteriorated faster after rehabilitation as indicated in Figure 11 above.

Correlation between IRI values after rehabilitation and thickness indicated that there exists a strong statistical positive relationship with a p-value of 0.73. According to results of work by Perera and Kohn (2006) areas with overlay over 50mm can reduce IRI values significantly. Although their work concentrated on asphalt pavements with varying rehabilitation strategies and did not consider PCC pavements. This is true for site 89-3001 where a significant change is noticed in IRI with pavement thickness of 80mm as illustrated in Figure 14. However, no significant change was observed for site 89-3015 with an overlay thickness of 62.7mm. This might be attributed to the low pre IRI value, previous asphalt rehabilitation strategies which did not include modified asphalt and probably other factors not considered in this study.

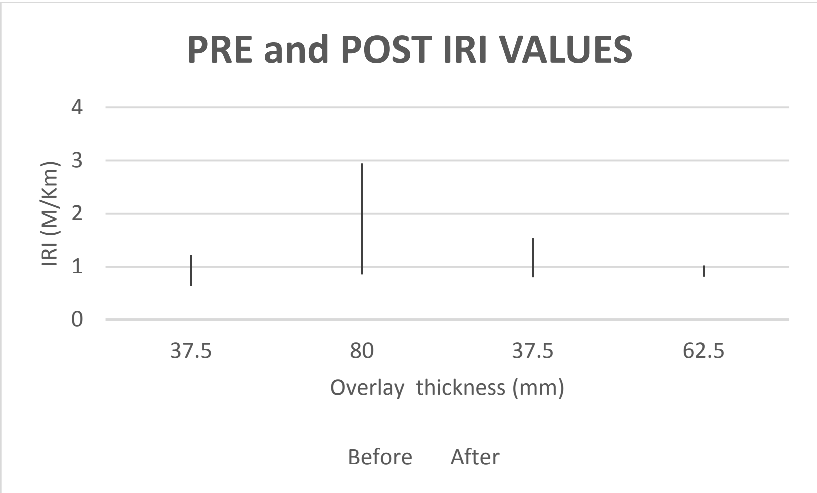


Figure 4: Comparison of IRI values and overlay thickness

To further show the impact of factors on the increase of roughness, the following factors outlined in table 5 have been considered. They include; type of surface preparation (with intensive constituting milling), AC type and time. The rate of change of IRI (development of roughness) value per year observed a slower rate of change for Conventional AC layer with the most thickness (0.017m/km/yr). Modified AC with milling and a considerable level of AC thickness also displayed a lower rate of change (0.020m/km/yr) which is in keeping with results by Karamihas and Senn (2010) who found that roughness increased at a slower rate for sections that received intensive pre-overlay preparation compared to those with minimal preparation. Although Full depth transverse patching was carried out for site 42-1627 which might have caused it to perform better than site 42-1623 , the lower thickness possibly contributed to the higher rate of change in development of roughness overtime.

Table 4: Factors influencing pavement smoothness

Site	Surface preparation	Type of AC	Overlay thickness (mm)	Rate of change of IRI (m/km/yr)
42-1627	Minimal	Conventional	37.5	0.047
89-3001	Minimal	Conventional	80	0.017
42-1623	Minimal	Modified	37.5	0.079
89-3015	Intensive	Modified	62.5	0.020

LCCA Analysis

Several researchers ((Morian et al. 1996; Peshkin et al. 2004; Luhr et al. 2010)) have proved that maintenance treatments on pavement can be of significance importance in extending the pavement service life. To compare difference of the cost effectiveness for the maintenance treatment between conventional asphalt overlay and the modified asphalt overlay, we generated two scenarios (scenario 1 and 2) for a life period of 20 years. Scenario 1 mainly used the conventional asphalt overlay as the rehabilitation operation, whereas scenario 2 adopted the modified asphalt overlay as the rehabilitation alternative. For this comparison experiment, we assumed the initial construction cost for different scenarios to be the same, and the other cost arranged based on the literature review. The major differences between the cost of the two scenarios is the AC overlay cost, which are \$30,000 per lane for conventional asphalt overlay, and 35,000\$ per lane for modified asphalt overlay. The detailed operations activities for different scenarios are illustrated in Table 6 and Table 7. Figure 15 and 16 illustrates the comparison of the PW and the EUAC in different years for two scenarios (we used the discount value of 4%, i.e. $i_{discount} = 0.04$). From table 6 we calculated the overall NPW for scenario 1 to be \$117,700 due to the use of conventional asphalt that needs one more rehabilitation activity in year 10 to maintain the pavement performance to meet required value, whereas according to scenario 2 in table 7, almost $90,533 is needed and it needs only two rehabilitation activities in year 1 and year 20. It can be conclude that even though modified asphalt cost much ($35,000) than conventional asphalt ($30,000), modified asphalt overlay is still suggested for its long time benefits which reduced the maintenances activities throughout pavement life thereby reduced the overall cost of the pavement. Graphically, the description of this conclusion can be found in Figure 15 and Figure 16, where in Figure 15, dashed line represents the discounted cost of modified asphalt overlay in the pavement service life and the other represents the results of conventional asphalt overlay. Though the cost of modified asphalt overlay goes more than conventional asphalt overlay, it needs less rehabilitations activities which makes the total cost less. Similar phenomenon can be found in Figure 15, EUAC for different years of two scenarios.

Table 5: Scenario 1: Pavement maintenance with conventional asphalt overlay

Year	M&R Operations	Cost ($)	Discounted cost (PW)	EUAC
1	Conventional asphalt overlay	30,000	28,846.15385	123,585.6662
3	Cracking sealing	2,000	1,777.992717	43,220.68105
5	Microsurfacing	20,000	16,438.54214	27,185.88029
6	PCC partial depth patch	10,000	7,903.145257	23,189.081
7	Creak sealing	2,000	1,519.835626	20,341.00228
8	PCC partial depth patch	10,000	7,306.90205	18,210.85563
10	Conventional asphalt overlay	30,000	20,266.92506	15,242.77064
12	Cracking sealing	2,000	1,249.194099	13,279.62235
14	Microsurfacing	20,000	11,549.50166	11,890.5853
16	Creak sealing	2,000	1,067.816351	10,860.22671
17	PCC partial depth patch	10,000	5,133.732459	10,439.94526
19	Creak sealing	2,000	949.2848481	9,739.140223

20	Conventional asphalt overlay	30,000	13,691.60839	9,444.603426

Table 6: Scenario 2: pavement maintenance with modified asphalt overlay

Year	M&R Operations	Cost	Discounted cost	EUAC
1	Modified asphalt overlay	35,000	33,653.84615	95,060.44933
5	PCC partial depth patch	10,000	8,219.271068	20,911.01723
6	Cracking sealing	2,000	1,580.629051	17,836.73242
8	PCC partial depth patch	10,000	7,306.90205	14,007.54774
11	Cracking sealing	2,000	1,299.161863	10,899.25916
13	Microsurfacing	20,000	12,011.48172	9,637.840829
15	PCC partial depth patch	10,000	5,552.645027	8,722.229666
18	PCC partial depth patch	10,000	4,936.28121	7,744.821268
20	Modified asphalt overlay	35,000	15,973.54312	7,264.663232

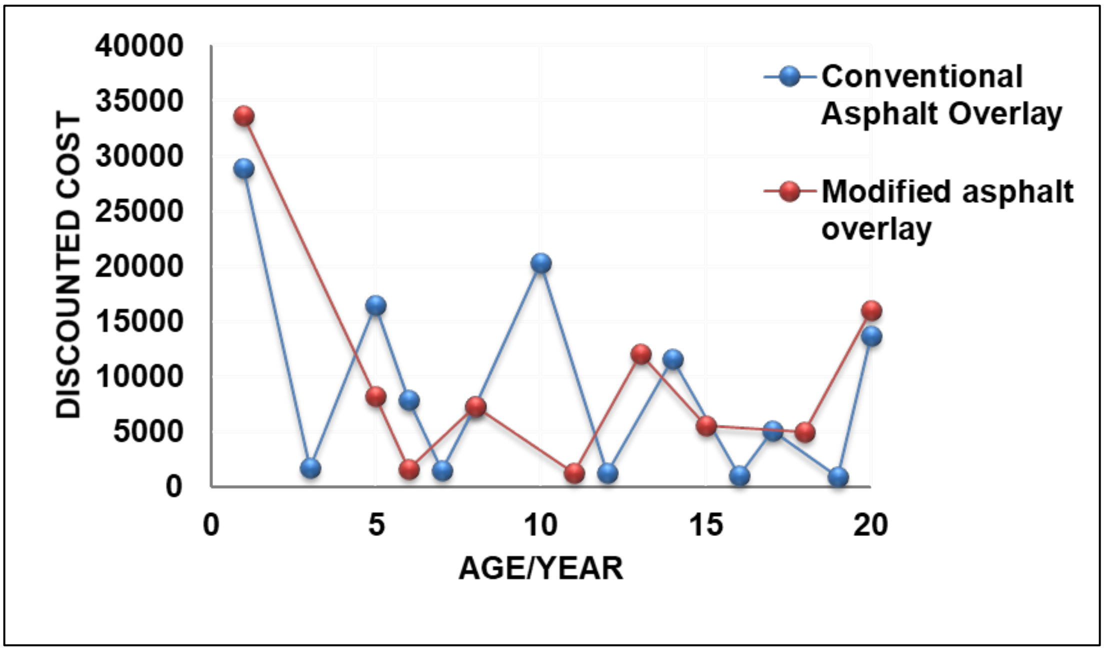


Figure. 15 Discounted present worth of different maintenance operations

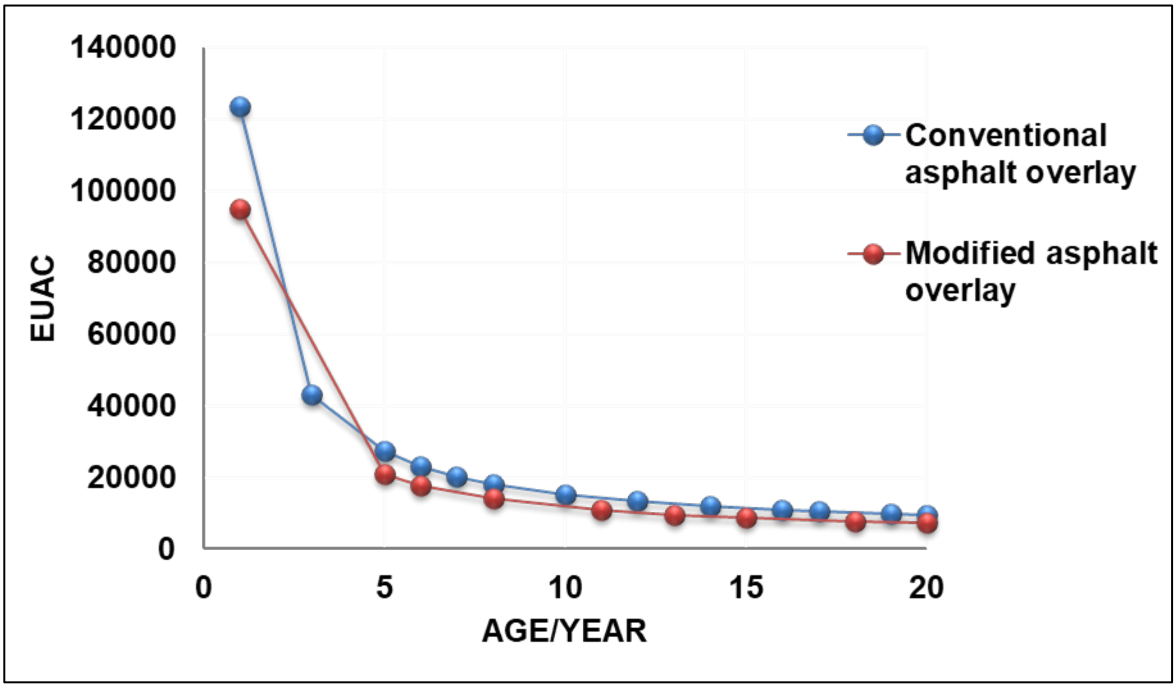


Figure. 16 EUAC of two scenarios

4.5. Further discussions of results

In summarising findings reflecting on the results, analysis showed that;

- There was no significant evidence of occurrence of fatigue cracking in both forms of AC in the first 7 years. There was also, no significant difference in the occurrence of fatigue cracking for conventional and modified asphalt. There might be no relationship between fatigue life of AC overlay on PCC, pre-overlay preparation and overlay thickness as concluded in study by Hall et.al, (2005). Significant temperature difference seems prompt the occurrence of fatigue cracking.
- Furthermore, the occurrence of rutting in the first few years (1 to 3 years) was a little slower in modified asphalt, however in later years (7 years) modified asphalt overlay seemed to have exhibited more rutting as in 89-3015 with 7mm rut depth compared conventional asphalt as in 89-3001 with 4mm rut depth. More rutting experienced in site 89-3015 might be due to previous flexible interlayer.

- AC overlays (both modified and conventional) on PCC did not show any evidence of wheel path longitudinal cracking (at least in the first seven years for conventional AC and twelve years for modified AC). However, modified asphalt performed better overtime with respect to longitudinal cracks, taking longer periods to occur on pavement surfaces with lower severity. Even much better did milled modified surfaces perform compared to its counterpart. It is very likely that factors such as high average temperature and higher traffic loadings (18-kip ESAL) contribute significantly to the occurrence of NWP longitudinal cracks on these types of pavement surfaces as observed for site 42-1623. Significant temperature change might aggravate the occurrence of longitudinal cracking.
- Modified asphalt overlay experienced lower occurrence of transverse cracking overtime compared with conventional asphalt. Milling of surfaces pre-overlay likely significantly contributed to limiting the occurrence and severity of these cracks on modified mixes.
- AC overlays on PCC will generally result in smoother pavements. There exists a moderate relationship between pre and post rehabilitation IRI valves. Performance jump (immediate IRI value change) displayed higher magnitudes for higher Pre IRI values.
- Irrespective of the AC type over PCC pavements, thickness of overlay is a main factor that would influence rate of change of roughness overtime. Thicker overlays seem to produce better rate of change of IRI leading to smoother pavements over more extended periods of time (see site 89-3001). A strong positive relationship statistically exists between overlay thickness and post rehabilitation IRI values.
- Modified asphalt, comparing sites with somewhat intensive preparation before overlay, performed better in terms of roughness. There seem to be a relationship between milling pavement surfaces before overlay and pavement roughness overtime. The rate of deterioration of pavement surfaces is observed to be lower overtime especially for modified asphalt overlay (site 89-3015). This conforms with recommendations from the NCHRP 20-50 project (Hall et.al.,

2005) and FHWA study (Carvallo et.al., 2011) that improvements to pre-overlay preparations would results in better long-term pavement performances. For Conventional pavements to perform better and be comparable to modified, they might need to have much greater thickness.

- Modified asphalt overlay performed better with respect to LCCA analysis than conventional asphalt overlay. Although the initial cost for modified asphalt overlay was higher than that of conventional operations, it can keep the pavement in satisfied condition for a longer time, which reduced the overall operation activities throughout the pavement service life thereby reducing the total cost of pavement maintenance and rehabilitation.

5. Conclusions and recommendations

Analysis undertaken reflect that modified asphalt over PCC have a better long-term performance compared with conventional forms with respect to transverse and longitudinal cracking. This is consistent with previous work (Yildirim, 2007, FHWA, 2013). This however is not necessarily the case with rutting and fatigue cracking performance. Nevertheless, to gain long term performance for these types of mixes, factors such as pre-overlay preparation and pavement thickness have to be considered. More often, these surfaces would require intensive (such as milling) rather than minimal preparations. Also, it is important to consider greater thickness AC when overlaying concrete surfaces. This will enhance pavement smoothness characteristics and long term performance, irrespective of the AC mix type. Although lower thickness modified AC mixes will perform better than similar thickness conventional mixes, it might still be good to plan higher thickness designs. Structural integrity of pavements is also a major consideration and should be accessed before rehabilitation strategies for PCC pavements are finalised. The overall lifecycle cost using modified asphalt overlay is lower than that for conventional asphalt.

Based on the findings of this study, the following are recommended;

1) In both modified of conventional overlays, surface preparation especially milling (in cases of already existing AC overlays on PCC pavements) should constantly be considered when rehabilitating concrete pavements with AC overlay, to gain better performance.

2) When conventional pavements are considered and pavement smoothness is a major objective for rehabilitation, greater thickness design alternatives should be used.

3) Due to limitation of data, factors such as traffic and climate conditions were not statistically taken into consideration during the analysis of this work. Therefore, further studies could look into the effects of this on the performance of AC overlay on PCC pavements

4) Further studies could also consider pavement distresses post rehabilitation over longer periods of time.

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