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# RADAR CHART TOOL FOR EVALUATING THE PERFORMANCE OF PAVEMENT REHABILITATION TREATMENTS

Abdelaty, Ahmed[1,4], Jeong, H. David[2] and Smadi, Omar[3]
[1] Graduate Research Assistant, Dept. of Civil, Construction & Environmental Engineering, Iowa State University, Ames, IA 50011, USA
[2] Associate Professor, Dept. of Civil, Construction & Environmental Engineering, Iowa State University, Ames, IA 50011, USA
[3] Associate Professor, Dept. of Civil, Construction & Environmental Engineering, Iowa State University, Ames, IA 50011, USA
[4] abdelaty@iastate.edu

**Abstract:** The transportation network of the United States has reached a mature state where maintenance and rehabilitation have become more important than new construction activities. Hence, highway agencies are directing their available funds more towards maintenance and rehabilitation rather than expanding the existing network. Agencies are required and sometimes federally mandated to make maintenance and rehabilitation decisions based on sound performance measures. This study uses case studies to evaluate the performance of three major rehabilitation treatments including hot mix asphalt (HMA) resurfacing, HMA resurfacing with cold-in-place recycling, and HMA resurfacing with milling by using one state highway agency's historical pavement condition data and rehabilitation records. First, heterogeneous databases are merged in spatial environment to create one integrated master database. Second, 8 case studies are conducted to evaluate the pavement performance at each distress level by using radar charts. The radar charts effectively visualize the pavement performance at the distress level before and after treatment application. Visualization of the multiple performance indicators is more effective than using one single condition index. The proposed approach for evaluating pavement performance is expected to help agencies and practitioners evaluate and visualize the performance of their assets by using multiple performance indicators.

## 1 Introduction

The US has the largest transportation network in the world with close to 2.7 million miles of paved roads, which is a key success factor for promoting the nations' economy (U.S. GAO 2008). In an effort to maintain the existing transportation network at an acceptable level of service, state highway agencies (SHAs) are more likely to spend funds on maintenance and rehabilitation than on expanding the existing network. Accordingly, the highway trust fund, established in 1956, is used to fund surface transportation programs using user taxes. In 2013, the Federal Highway Administration (FHWA) received about $41 billion for the construction, reconstruction, and improvement of highways and bridges according to the FHWA eligibility criteria (U.S. GAO 2014). However, agencies used 32 percent of these FHWA funds for road resurfacing, rehabilitation, and reconstruction while only 5 percent were used for new construction. This percentage of spending on road rehabilitation and resurfacing emphasizes the importance of these activities and indicates that the US transportation network has reached a mature state where maintenance and rehabilitation are more important than new construction.

Several rehabilitation treatments are available to restore the functional and structural performance of existing pavement. The choice to apply a specific rehabilitation treatment is governed by several factors, such as the pavement’s existing condition, funding availability, and treatment performance. Treatment performance significantly affects the economic value of the pavement and hence is considered an influential factor in the selection process when several treatments are technically feasible (Flannery et al. 2016). As such, a realistic treatment performance evaluation is needed to improve existing transportation asset management practices and promote evidence-based decision-making systems.

Rehabilitation and maintenance treatments are meant to extend the pavement service life by addressing existing pavement distresses, and it is important for pavement managers to know the extended service life or treatment application benefits based on different factors, such as pre-treatment conditions, volume of traffic, and type of treatment. This extended service life results from treatment applications that can be measured using different performance indicators such as pavement distresses, roughness, or friction. For example, pavement roughness indicates the pavement ride quality, which directly affects user ride quality and costs; hence, keeping pavement roughness below a specific threshold value is important to achieving user satisfaction and minimizing user costs. Similarly, other performance indicators are used to measure a treatment’s effectiveness in terms of pavement functionality, safety, and ride quality. A robust performance evaluation process should consider every performance indicator to provide decision makers with a complete picture regarding the treatment performance. State highway agencies (SHAs) have been collecting pavement condition data for years and it is possible to transform agencies’ decision-making processes from engineering judgement to data-driven and evidence-based processes.

The main objective of this research is to evaluate the performance of the most-used treatments in Iowa by considering different parameters such as type of treatment, treatment thickness, traffic, and pavement type. The study visualizes the performance of pavements by using radar charts. The radar charts provide agencies and practitioners with deep insights on how pavements perform in terms of various performance indicators.

## 2 Literature Review

Many studies have evaluated the performance of pavement maintenance and rehabilitation treatments. The researchers found that treatment types, performance indicators, and statistical methods were the key differences between past studies. Studies used data used data collected by SHAs. Treatment types vary between preservation, maintenance, and rehabilitation for composite, flexible, and rigid pavements. The type of treatments evaluated were subject to the number of data collected and interest in specific treatments by agencies and researchers. The performance indicators used in the evaluation were generally the International Roughness Index (IRI), pavement condition rating (PCR), structural number (SN), fatigue cracking, and rutting depth.

For example, Labi et al. (2007) and Ji et al. (2012) evaluated the performance of microsurfacing in Indiana by using condition data collected from closely monitored sections. Condition data for these sections were collected annually using visual surveys and non-destructive tests. In Indiana, Irfan et al. (2009) used data collected by the Indiana Department of Transportation (DOT) to evaluate the performance of hot mix asphalt (HMA) overlays. In Kansas, Liu et al. (2010) used data from Kansas DOT pavement management information system (PMIS) to evaluate the performance of thin surface treatments in Kansas. The database used in the studies conducted by Labi et al. (2007) and Irfan et al. (2009) contained data about pavement referencing, pavement condition, traffic volume, freeze-index, and preservation contracts data, and the Kansas DOT’s PMIS contained traffic, pavement condition, and pavement referencing data.

There are several performance indicators used to evaluate the performance of maintenance and rehabilitation treatments such as IRI, PCR, rut depth, and fatigue cracking (Hall et al. 2002, Irfan et al. 2009, Labi et al. 2007, Wang et al. 2011, and Lu and Tolliver 2012). Shirazi et al. (2010) developed a weighted average index that combined several distresses. Chen et al. (2003) used the distress score concept developed by the Texas DOT to evaluate treatment effectiveness in Texas. The distress score quantifies the visible surface deterioration of pavements and was computed as a function of utility values for rutting; patching; and block, alligator, longitudinal, and transverse cracking. Hall et al. (2002) used road roughness level or ride quality, measured in IRI, to evaluate performance since it was found to be an influential factor that affects overlay treatments. Irfan et al. (2009) linked the used IRI for treatment performance evaluation because of its use for pavement preservation decisions and because it was found to be collected on a regular basis. On the other hand, some studies selected IRI as a performance indicator because the treatments under evaluation were expected to address minor distresses and improve ride quality (Labi et al. 2007 and Lu and Tolliver 2012).

Labi and Sinha (2004) used the present serviceability index to evaluate the performance of seal coats in Indiana. The study acknowledged that PSI may not be the most ideal performance indicator since the PSI is directly associated with ride quality. However, the study used the PSI instead of the PCR because of the lack of PCR data. While many studies used common performance indicators to evaluate the performance of treatments, Liu et al. (2010) used the time between two consecutive treatments or time between treatment application and reconstruction to estimate the service life of thin surface treatments. The methodology adopted by Liu et al. (2010) reflects the SHAs policy and experience on the estimation of treatment performance. However, it should be noted that this methodology does not consider the delay in consecutive treatment applications due to funding gaps. Finally, a study by Broughton and Lee (2012) used visual inspection of distresses to evaluate the effectiveness of a treatment. Visual inspection is a subjective method that cannot be relied on to evaluate the effectiveness of a treatment. However, visual inspection is the only available method that can be used to evaluate pavement performance when no data are available.

The choice of a pavement condition indicator to evaluate a treatment’s performance is critical. However, few studies acknowledged that the service life of a treatment would vary depending on which performance indicator is used. For instance, microsurfacing may have a service life of 2 to 10 years in terms of IRI, over 10 years in terms of rutting, and 4 to 15 years in terms of PCR. Service lives are estimated based on the time elapsed by the pavement to revert to the pre-treatment condition or a specific condition trigger (Labi et al. 2007). Thus, there is need to adopt a multi-dimensional approach to measure treatments performance. This approach would provide deeper insights regarding the performance of several treatments. Also, it provides decision makers with necessary information to support data-driven asset management processes.

## 3 Data Collection

The study primarily used two sources of data including a) pavement treatment contracts data from the Iowa DOT Office of Contracts and b) raw pavement condition assessment data from the Iowa DOT. The pavement treatment contracts database is in an Excel-based spreadsheet that contains a list of all projects let by the Iowa DOT and Iowa cities or counties. Each record in the database contains information about the project such as project number, accounting number, project type, project length, and location referencing data. The spreadsheet includes a wide range of treatment types from simple maintenance treatments such as crack sealing to heavy rehabilitation treatments such overlays. The location referencing data provides the location information of the project by using geographic coordinate system (GCS). The GCS uses longitude and latitude data to locate a point along the project, which is the midpoint of the project. The raw pavement assessment condition data is in a Geographic Information System (GIS) based database that contains distress data collected approximately every 32 to 52 feet (10 to 16 meters). The Iowa DOT collects pavement condition data every other year for the same section. In this study, three major rehabilitation treatments including HMA resurfacing, HMA resurfacing with milling and HMA resurfacing with cold in place recycling (CIPR) are evaluated because they are the most commonly used treatments by the Iowa DOT.

# 4 Spatial Integration

Figure 1 illustrates the research framework used to evaluate the performance of treatments. The first step is to spatially integrate the two databases together to form a master database that included pavement condition data before and after treatment application, type of treatment, and pavement and traffic information. The geographic coordinates of the treatment projects were used to precisely locate the projects on the pavement condition assessment data. Then, by using the GIS geoprocessing tools, a buffer with a diameter equal to the project length was created. The clip geoprocessing tool is then used after creating a buffer that represents the boundaries of the treatment project. The clip tool simply cuts out the raw pavement condition data using the project buffer that was created from the previous step. The clipped raw pavement condition data was then imported to an excel file. Finally, the performance of pavement treatments is visualized in a radar map for evaluation purposes.

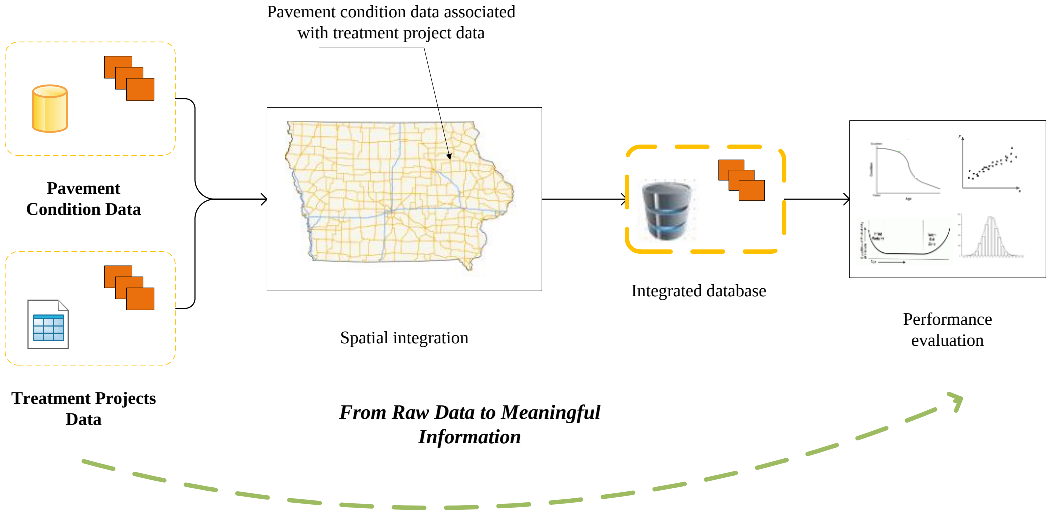

Figure 1. Spatial analysis and performance evaluation framework

# 5 Performance Indicators

All rehabilitation treatments evaluated in the study have an asphalt concrete surface. Therefore, distresses that are common for asphalt concrete surfaces are considered as potential performance indicators. Since the service life of a pavement treatment can change based on the performance indicator used, an accurate and reliable treatment performance evaluation should consider using multiple key performance indicators for the evaluation process. The Iowa DOT collects distress and condition data for pavement with asphalt concrete surfaces including rut depth for left and right wheel paths, alligator cracking, transverse cracking, longitudinal cracking, longitudinal cracking on wheelpath, and IRI for left and right wheel paths. For each cracking type, the Iowa DOT collects three levels of severity including low, moderate and high.

In order to evaluate the performance of a pavement treatment, indexes that range from 0 to 100 are used in which 0 represents poor condition and 100 represents excellent condition. The Iowa DOT uses these indexes to calculate an overall pavement condition index (Bektas et al. 2015). The first step requires aggregating crack severities using the coefficients of 1.0, 1.5, and 2.0 for low, medium, and high severities respectively. The next step is to calculate individual distress indexes including transverse cracking index (TC), longitudinal cracking index (LC), longitudinal cracking index on wheelpath (LCWP), alligator cracking index (AC), ride quality index (RI), and rutting index (RUT). As for ride quality and rutting data, the Iowa DOT averages the international roughness index (IRI) and rutting depths on the left and right wheelpath. Then, the average measure is used to calculate the RI and RUT. However, in this the study, RI and RUT are calculated for each wheelpath which generates RI on the left wheelpath (LRI), RI on the right wheelpath

(RRI), RUT on the left wheelpath (LRUT), and RUT on the right wheelpath (RRUT). The calculation of indexes for left and right wheelpaths is necessary to track the performance variance between the left and right wheelpaths.

In order to calculate the individual distress indexes, failure threshold values are used to deduct points from the maximum 100 points. These threshold values are 500 count/km, 500 m/km, 500 m/km, and 360 m2/km for aggregated transverse cracking, longitudinal cracking, longitudinal cracking on wheelpath and alligator cracking respectively (Bektas et al. 2015). The IRI measurements are used to calculate the RI index. Lower IRI values indicate better ride quality. As such, IRI values that are less than 0.5 m/km corresponds to perfect RI (100). On the other hand, IRI values higher than 4.0 m/km corresponds to poor RI (0). Similarly, RUT is calculated by using rutting values which represent depression in wheelpath. A threshold value of 12 mm corresponds to poor RUT (0). Accordingly, rutting measurements less than 12 mm are applied as deductions proportionally (Bektas et al. 2015).

## 6 Performance Evaluation

Three pavement treatments selected for this study involve resurfacing the pavement surface by adding a layer of new pavement to the existing pavement. However, in HMA resurfacing with milling, part of the existing pavement surface is removed and then a new overlay is placed on the milled surface. Also, in HMA resurfacing with CIPR, part of the existing pavement is recycled and used with new material to resurface the pavement surface.

For each treatment, case studies were conducted to evaluate the performance of the pavement before and after treatment application. Radar maps are used to effectively visualize the pavement performance with respect to eight performance indicators. The pink colored circle inside each radar chart, Figures 2 to 4, presents poor condition threshold values (25). The solid line shows the pre-treatment conditions and the dashed/dotted lines represent the post treatment conditions at different years.

### 1.1 HMA Resurfacing

Three projects (A-1, A-2, and A-3) were selected as case studies as shown in Figure 2. The pavement thicknesses before treatment are 267, 368, and 331 mm and the overlay thicknesses are 76, 89, and 76 mm for A-1, A-2 and A-3 respectively.

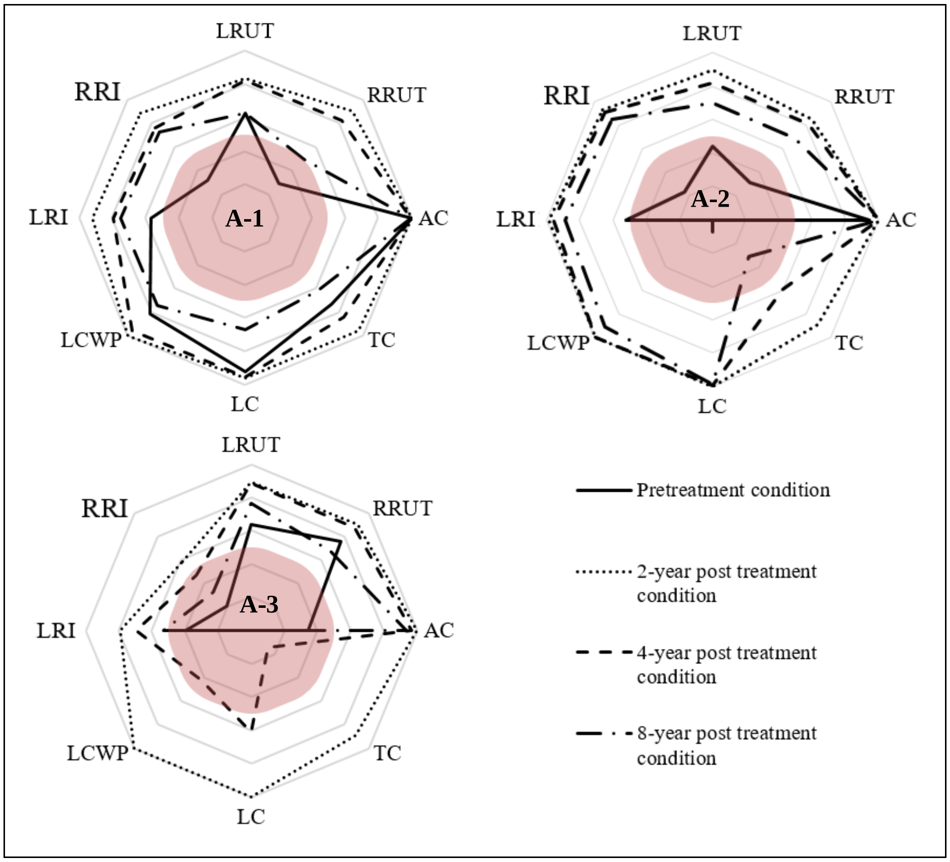

Figure 2: Radar charts for sections with HMA resurfacing

The average daily traffic (ADT) volume is 2,730, 4,560, and 2,400 vehicles and the average number of trucks are 322, 543, and 195 mm for A-1, A-2, and A-3 respectively. The radar charts provide some insightful information about the performance of the HMA resurfacing. For A-1, the pre-treatment RRI and RRUT were significantly lower than LRI and LRUT. It is observed that RRUT after treatment application is lower than LRUT, which can be attributed to the poor pre-treatment condition. For A-2 and A-3, performance in terms of TC is poor when compared to other performance indicators. The performance of the three projects in terms of AC is found to be excellent as the post treatment AC is consistently higher than 90%. On the other hand, it is simple to detect which performance indicators have fallen below the pre-treatment condition. For A-1, LCWP, LC, and TC have fallen below the pre-treatment condition after eight years of treatment application. For A-3, RRUT has also fallen below the pre-treatment condition. The pink colored circle provides a means for agencies and practitioners to quickly detect poor performance indicators. For example, A-3 showed poor performance in terms of RRI, TC and LCWP after four years of treatment application.

### 1.2 HMA Resurfacing with Milling

Three projects (B-1, B-2, and B-3) are selected as case studies as shown in Figure 3. The pavement thickness, overlay thickness and milling thickness for the three projects are the same as 356, 102, and 127 respectively. Also, the projects have the same traffic volume as 21,900 ADT and 4,343 truck volume. Since these projects have the same pavement thickness and traffic volume, they present a good opportunity to study how pre-treatment condition affect the future pavement performance.

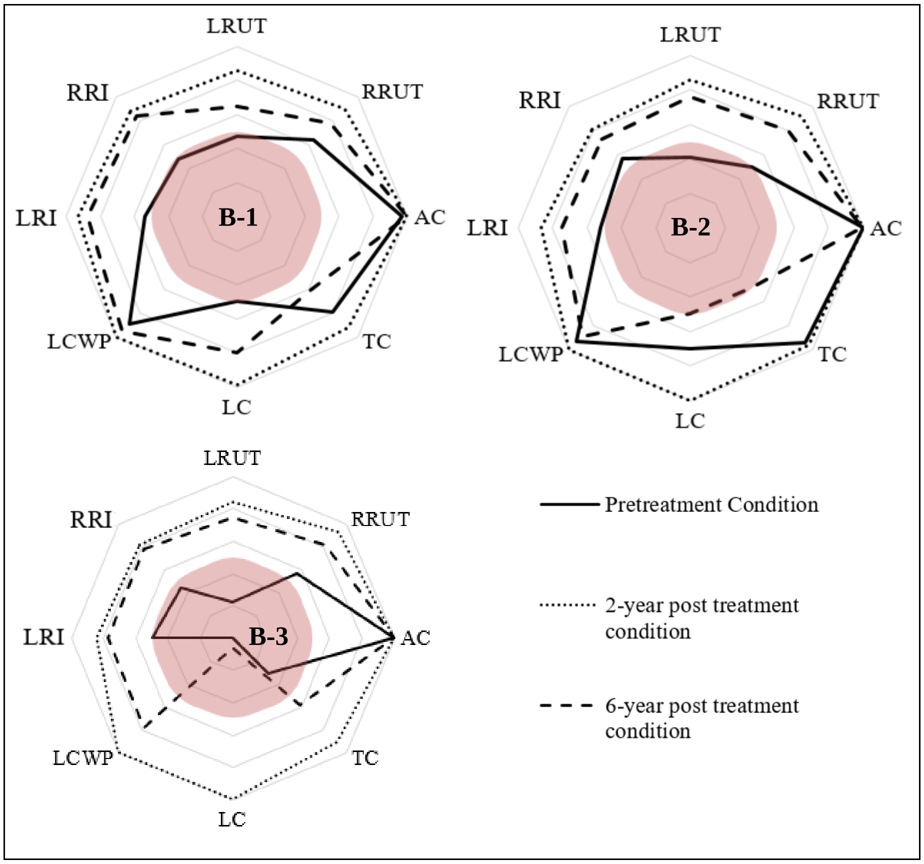

Figure 3: Radar charts for sections with HMA resurfacing with milling

All projects had no alligator cracking and had excellent performance after treatment application. It is also observed that B-3 had the worst pavement condition before treatment application by visually comparing the area of the solid line of the three projects. A visual comparison of the dashed line which represents the condition after six years of treatment application shows that B-3 has the worst pavement condition when compared to B-1 and B-2. The performance of projects B-1 and B-2 in terms of TC is poor as the six-year post-treatment condition is lower than the pre-treatment condition.

A comparison between left and right wheelpaths for RI and RUT can show how pre-treatment condition affects post-treatment condition. The performance of B-1 in terms of RRI and LRI is very similar. The pre-treatment RRI was almost equal to LRI. Also, no significant variance between the post-treatment LRI and RRI. However, for the same project, the pre-treatment RRUT was higher than LRUT by approximately 20-points. Additionally, the 6-year post-treatment RRUT performs a lot better than LRUT. This case indicates that pre-treatment condition can be an influential factor on post-treatment condition. However, the previous observation did not conform to LRUT and RRUT of project B-3.

### 1.3 HMA Resurfacing with CIPR

Two projects (C-1 and C-2) are selected as case studies as shown in Figure 4. The pavement thicknesses before treatment are 413, and 368 mm and the overlay thicknesses are 99, and 86 mm for C-1 and C-2 respectively. The ADT are 1,750, and 3,780 and the average number of trucks are 237 and 576 for C-1 and C-2 respectively.

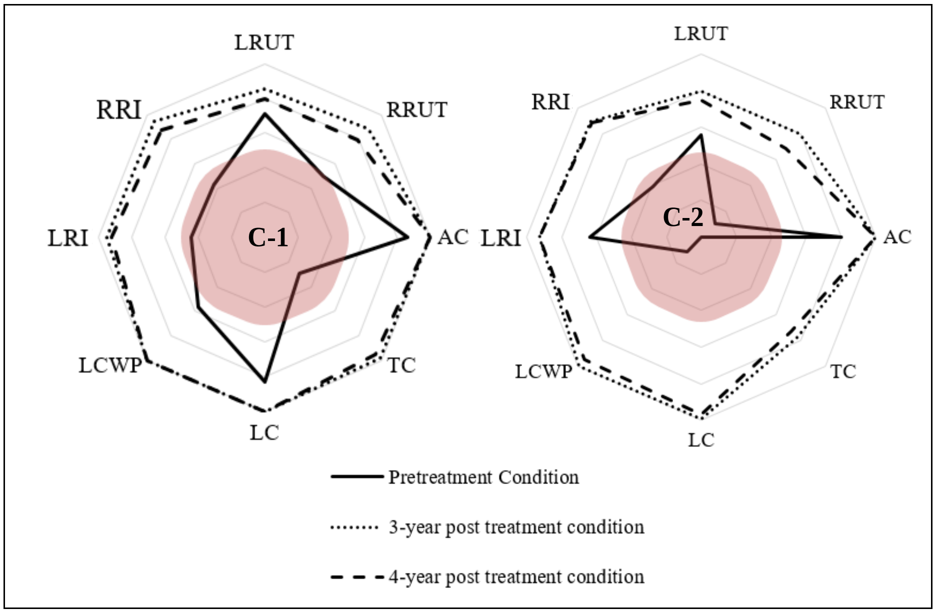

Figure 4: Radar charts for sections with HMA resurfacing with CIPR

The performance of HMA resurfacing with CIPR projects is slightly better than the performance of pavements that received HMA resurfacing or HMA resurfacing with milling. From the radar charts, no performance indicator has fallen below the pre-treatment condition. However, for C-2, the performance of RRUT is slightly lower the LRUT. This can be attributed to the poor pre-treatment conditions. Additionally, the performance of C-2 in terms of TC is deteriorating at a faster rate when compared to other performance indicators. It should be noted than C-2 has higher traffic volume and lower pavement thickness when compared to C-1.

## 7 Summary and Conclusion

This study conducted eight case studies to evaluate the performance of three types of treatments including HMA resurfacing, HMA resurfacing with milling and HMA resurfacing with CIPR. A spatial integration of data between the pavement condition data and pavement treatment projects was made to evaluate pavement surface conditions before and after the application of treatment.

Radar charts were used to visualize the pavement performance over time by using eight key performance indicators. The visualization tool of various performance indicators using radar charts provides agencies and practitioners with deeper insights regarding the performance of each pavement treatment. It also helps observe any irregular performance on the same section. For instance, agencies can easily discover any variance between left and right wheelpaths in terms of ride quality and rutting. Additionally, the radar chart makes it easy to detect when a specific performance indicator falls below a predefined threshold value or pre-treatment value.

The aforementioned advantages are only achieved by visualizing several performance indicators over time. A single overall pavement condition indicator such as PCI or PCR does not provide the complete picture of the pavement performance. This issue is crucial as transportation agencies are standing on the verge of digital revolution. The visualization approach to performance evaluation is an important process for agencies to extract meaningful and important information from a huge pool of data.

As for future research, research will be conducted to integrate other financial, pavement, and geotechnical parameters with the visualization process. This could produce a scorecard that tracks and visualizes the pavement performance and other important pieces of information. Additionally, the proposed approach of using multiple performance indicators to track pavement performance can be extended to address other issues related to pavement deterioration modeling, and maintenance and rehabilitation budgeting.

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