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General Guidelines to Highway Agencies to Enhance their Local Pavement Rating Systems: A Case Study of Nevada's Pavement Rating System

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Abstract: Evaluation of pavement condition is the principle source for the effective management of the pavements within any network or state. Many highway agencies within United State are using different pavement rating systems to evaluate their pavement condition. The data collection system, measurement units, calculation techniques have been modified and updated by several states with technological development with time. Recently, several highway agencies are willing to update their old pavement rating systems or gradually switch to more accurate rating systems but facing difficulties. This paper focuses on the potential enhancement on the Pavement Rating Index (PRI) used by Nevada Department of Transportation (NDOT) and thus eventually transitioning to the Pavement Condition Index (PCI) developed by U.S. Army Construction Engineering Research Laboratory. Pavement condition data that were utilized to calculate PRI over the last 15 years were converted into PCI compatible format using a suitable conversion technique. Estimated PCI values were plotted against its corresponding PRI showed moderate correlation with R^2 value of 0.57. The current PRI system was then enhanced to eliminate the observed deficiencies in the current system. The statistical relationship between the enhanced PRI against PCI showed improved correlation with R^2 value of 0.78. The study concluded that a successful switch from PRI system to PCI system can be achieved in Nevada while maintaining the use of the historical pavement condition data. This paper provides general recommendations for other agencies that are transitioning from local pavement rating system to PCI system.

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***Key words**: Fatigue; Longitudinal cracking; Pavement condition index; Pavement management, Pavement rating index, Rutting; Transverse cracking.*

Introduction

Pavement Management System (PMS) is a set of tools that assists to make decision in finding cost effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition within the available funding. PMS supports the pavement management process by providing an inventory and condition of existing pavement assets. The PMS condition data is typically used to form a unified pavement condition index which can strongly aid in evaluating various pavement rehabilitation, maintenance, and preservation strategies and estimate the impact of those strategies on the future condition of the pavement network for various budget levels [1].

The pavement condition is evaluated based on the severity and extent of the observed distresses on the road surface. Different states use different pavement rating systems to evaluate the condition of pavement. Some of the common indices include Pavement Condition Index (PCI), Present Serviceability Rating (PSR), and Pavement Serviceability Index (PSI) [2]. As the overall condition of the pavement is reflected by these indices, PMS uses these indices to recommend the repair and maintenance treatments. Many of the current pavement rating indices that are utilized by several U.S. highway agencies use zero-to-hundred scale (0 denotes a poor condition and 100 being excellent condition). Meanwhile, Nevada uses Pavement Rating Index (PRI) system which range from 0 to 700+ (0 being excellent condition and 700+ indicate a poor condition) to evaluate flexible pavement conditions. Generally, most pavement rating indices have certain deduct points based on available distresses which are subtracted from a grand value (e.g. 100). On the other hand, PRI system of Nevada assigns certain points for each distress category and sums them up to find the overall condition of pavement without subtracting the point summation from a grand value.

Several deficiencies were observed in the current PRI system while evaluating the existing flexible pavement conditions in Nevada. The most common deficiencies faced were absence of severity level for fatigue cracking, block cracking type B & C, and patching. Furthermore there was no definition for extent level for flushing, raveling and rutting. Hence, the current pavement rating system may affect the assigned maintenance strategies for pavement sections which may increase maintenance cost associated with

Table 1. NDOT Maintenance Strategies for Flexible Pavements.

Repair Category	PRI Points
Preventive Maintenance (N)	< 50
Corrective Maintenance (M)	50 to 399
Overlay (O)	400 to 699
Major Rehabilitation (R)	> 699

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inaccurate pavement condition assessment. Table 1 shows the maintenance strategies for flexible pavements adopted by NDOT based on PRI points.

With the current shortage in the available pavement reservation funds for highway agencies, the use of an accurate pavement rating index will help in assigning the right maintenance treatment. Consequently, most state Department of Transportation (DOT) and transportation agencies are seeking a well-established pavement condition indicator such as PCI. Using such index may provide the window of opportunity to effectively allocate the available funds. Therefore the objectives of this research study are as follows:

- To present several proposed enhancements in the current NDOT PRI system for pavement condition rating to be compatible with PCI system.
- To provide other highways agencies a general framework for transitioning from their local pavement rating systems to PCI system.

Literature Review

Since the introduction of PMS in the United States in 1979, different state DOTs started to use different types of pavement rating indices to evaluate their pavement conditions in order to effectively maintain their road network within the desired level of serviceability and the available funding. With the progression of time and technology, there have been continuous modifications in PMS process. One of the major components of PMS is the pavement condition rating. So far, there is no unified pavement rating system that all the states are utilizing. A review of the literature on pavement condition rating systems reveals that a bewildering array of rating systems has been used. More than two dozen of different rating systems exit. Nowadays, PCI as defined by the American Society for Testing and Materials (ASTM) Standard D6433 [3] has been widely accepted as an established pavement condition indicator [4]. The PCI measures the general condition of the pavement surface based on observable distress types, severities and quantities. Use of PCI provides a common basis for assessing the overall condition of pavements and facilitates the formulation of effective strategies for maintenance and rehabilitation [5].

Different states are using various pavement rating systems. For example, the Idaho DOT is using cracking index, roughness index and rutting index to rate their pavement condition. The scale of pavement rating index is from 0 (very poor/failed) to 5 (excellent). The roughness index is a function of International Roughness Index (IRI) and cracking index is a function of severity and extent of six different types of cracking whereas the rutting index introduced in the year 2010 incorporates rutting. The index used to rate pavement sections is the lowest of roughness index and cracking index. Condition data are collected through visual inspection by raters. The considered distresses include transverse cracking, longitudinal cracking, alligator cracking, block cracking, edge cracking, pothole and patching. Roughness and rutting are measured separately. Though this rating index has a well-defined extent and severity level for surface distresses, yet the assigned points for each distress are not well defined. It does not seem to have any numerical equations to quantify cracking index. The cracking index is assigned based on the visual inspection of concerned sections which seems to be more subjective. In addition, the scale ranges from 0 to 5 which is considered to be a small range to propose the required maintenance for pavement [6].

North Carolina DOT uses Pavement Condition Rating (PCR) to evaluate their pavement condition. The scale of PCR ranges from 0 (poor/failed) to 100 (excellent). Condition data are collected through visual inspection by raters. The distresses include alligator and transverse cracking, rutting, raveling, bleeding, patching, oxidation and roughness. Deduct values are assigned for each distress and subtracted from 100 to obtain the PCR of the pavement section to be evaluated. The extent, severity level and type of distress are used to estimate the PCR. This rating system has well defined severity level. However, for distresses such as transverse cracking, raveling, and rutting, it lacks the well-defined extent level [7].

Pavement Surface Evaluation and Rating (PASER) is another pavement rating system developed by Transportation Information Center, University of Wisconsin-Madison. The PASER rating system uses visual inspection to evaluate the condition of pavement. The rating scale ranges from 0 (poor/failed) to 10 (excellent). The rating of pavement is done through visual inspection of the distresses present in identified pavement section. There is no any well-defined severity and extent level for the distress. It also lacks the numerical equations to assign deduct points to quantify the distress. As it is done through visual evaluation, it seems to be more subjective [8]. Table 2 summarizes the pavement rating system used by various highway agencies within United States.

From the aforementioned literature, it can be concluded that there is a need for a unified pavement condition rating system that clearly defines distress types, severity and extent levels, as well as a well-defined computational equations. As PCI rating system has most of these components, it has gained popularity for structural evaluation of pavement. As PCI is a well-established pavement condition indicator and widely accepted by many pavement engineers, many of the state DOTs and highway agencies may find enhancement towards the PCI system from their current pavement rating system advantageous.

In 2001, the city of San Jose performed a study on upgrading from their existing Overall Condition Number (OCN) to Pavement Condition Index (PCI) to accurately evaluate their pavement conditions. The study concluded that the conversion of condition data from OCN system to PCI system was complex because the two systems use different index scales to measure pavement distresses. OCN had a scale from 0 (new - excellent) to 40 (failed) whereas PCI has range from 100 (new - excellent) to 0 (failed). The correlation (R^2) between PCI and OCN was found to be less than 0.2. The reason behind the weak correlation was the difference in data collection procedure and the point calculation method between two systems [15]. Nevada DOT is also in the process to enhance their PRI system to be compatible with the PCI ASTM system.

Pavement Rating Index of Nevada Department of Transportation

Since 1980, NDOT has been using PMS. This was followed by several refinements and updates according to the technological advancement and the updated industry standards. Among the PMS

Table 2. Summary of Current Pavement Rating Systems [3, 6-14].

Agency	Pavement Rating System	Distress type										Distress Point (Deduct) Equation
		Alligator Cracking		Longitudinal Cracking		Rutting		Block Cracking		Raveling		
		Extent	Severity	Extent	Severity	Extent	Severity	Extent	Severity	Extent	Severity	
Nevada DOT	Pavement Rating Index	✓	✗	✓	✓	✗	✓	✓	✗	✗	✓	✓
Ohio DOT	Pavement Condition Rating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
Idaho DOT	Cracking Index, Rutting Index	✓	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗
Washington State DOT	Pavement Condition Rating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
North Carolina DOT	Pavement Condition Rating	✓	✓	✗	✗	✓	✓	✗	✗	✓	✓	✓
University of Wisconsin-Madison	Pavement Surface Evaluation and Rating	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
US Army Corps (PCI)	Pavement Condition Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Oregon DOT	Good-Fair-Poor Condition Rating	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓
Texas DOT	Condition Score	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓
Minnesota DOT	Pavement Quality Index	✓	✗	✓	✓	✗	✓	✓	✗	✓	✗	✓
Georgia DOT	Pavement Condition Evaluation System	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓

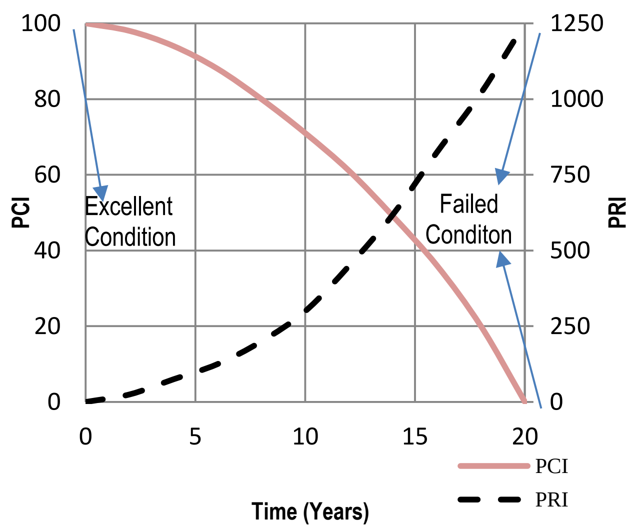

Fig. 1. Plot of PCI and PRI with Time.

components, NDOT has developed the Pavement Rating Index (PRI) to rank and evaluate the pavement conditions. This index evaluates the condition of the road network in terms of roughness, rutting, friction, various types of cracking (fatigue, longitudinal, transverse, and block), flushing, patching and raveling. PRI values ranges from "0" (excellent) to "700+" (failed condition). Numerical equations are used to assign evaluation points to each distress category based on the extent and/or severity as well as traffic level. The summation of the total evaluation points is the PRI. It is noticed that the PRI points are in opposite direction compared to the PCI system to evaluate pavement condition (Fig. 1). Table 3 describes the procedure to assign PRI points for various distresses. A rating area of 100 ft long and 10 ft wide for each mile is used to collect the condition data. The data collection is completed manually every two years. Profilometer van is used to collect roughness data. The details on various flexible pavement distresses that PRI system includes as follows [13]:

Cracking

Two types of fatigue cracking are defined by the PRI system: type A which represent a hairline cracking while type B represent interconnected cracks that form an area representing a typical alligator cracked surface. The extent is measured in linear feet for type A and in square feet for type B. Average crack width is measured to define severity level of both types. In the case of longitudinal and transverse cracking, the level of extent is measured in linear feet while severity is measured as the average width of the

Table 3. PRI Formulation for Various Distresses [16].

Distress		Interstate (IR) only		Non IR, NHS, and STP w/ADT > 805		All Other Routes (Low Volume Roads)	
	Roughness	IRI	PMS Points	IRI	PMS Points	IRI	PMS Points
IRI	Smooth	0 - 40	0	0 – 80	0	0 - 90	0
		41 - 70	100	81 – 100	100	91 - 130	100
	Medium	71 - 90	200	101 – 115	200	131 - 150	200
		91 - 105	300	116 – 130	300	151 - 170	300
	Rough	106 - 115	400	131 – 160	400	171 - 200	400
		> 115	500	> 160	500	> 200	500
Friction		Friction Number	PMS Points	Friction Number	PMS Points	Friction Number	PMS Points
		2 to 20	400	2 to 20	400	2 to 20	400
		21 to 30	250	21 to 30	250	21 to 30	250
		31 to 36	100	31 to 36	100	31 to 36	100
		above 36	0	above 36	0	above 36	0
Rutting		Average Rut Depth	PMS Points	Average Rut Depth	PMS Points	Average Rut Depth	PMS Points
		0 to 0.25"	0	0 to 0.25"	0	0 to 0.45"	0
		0.26 to 1.00"	(675.7 x RD) - 168.9	0.26 to 1.00"	(675.7 x RD) - 168.9	0.46 to 1.19"	(675.7 x RD) - 304.1
		1.01 to 1.5"	(392.2 x RD) + 111.8	1.01 to 1.5"	(392.2 x RD) + 111.8	1.20 to 1.7"	(392.2 x RD) + 33.3
		above 1.5"	700	above 1.5"	700	above 1.7"	700
Fatigue A & B or Block B & C Cracking		Fatigue A = 1.5 x Extent		Fatigue A = 1.5 x Extent		Fatigue A = 1.0 x Extent	
		Fatigue B = 2.00 x Extent		Fatigue B = 2.00 x Extent		Fatigue B = 1.50 x Extent	
		Block B = 1.00 x Extent		Block B = 1.00 x Extent		Block B = 0.50 x Extent	
		Block C = 1.00 x Extent		Block C = 1.00 x Extent		Block C = 0.50 x Extent	
Non Wheelpath Linear or Block A or Transverse Cracking		PMS Points = Extent x (LC Severity Factor) where LC Severity Factor is Determined from:					
		Crack Width	LC Severity Factor	Crack Width	LC Severity Factor	Crack Width	LC Severity Factor
		< 1/4"	0.2	< 1/4"	0.2	< 1/4"	0.2
		1/4" to 7/8"	0.8 x (Crack Width) + .80	1/4" to 7/8"	0.8 x (Crack Width) + .80	1/4" to 7/8"	0.4 x (Crack Width) + .90
		> 7/8"	1.5	> 7/8"	1.5	> 7/8"	1.25
Patching		0.5 x Extent		0.5 x Extent		0.25 x Extent	
Flushing		Picture No.	PMS Points	Picture No.	PMS Points	Picture No.	PMS Points
		17 (low)	0	17 (Low)	0	17 (Low)	0
		18 (Moderate)	100	18 (Moderate)	100	18 (Moderate)	100
		19 (Severe)	250	19 (Severe)	250	19 (Severe)	250
Raveling		Picture No.	PMS Points	Picture No.	PMS Points	`Picture No.	PMS Points
		20 (Low)	100	20 (Low)	100	20 (Low)	100
		21 (Moderate)	250	21 (Moderate)	250	21 (Moderate)	250
		22 (Severe)	500	22 (Severe)	500	22 (Severe)	500

cracking over the rating area. Block cracking is defined in three different types: Type A has rectangular blocks of size larger than 5 feet on each side while type B and C block cracking is a network of interconnected cracks that form a series of irregular shaped polygons. Block cracking with size of polygon from 1 ft × 1 ft to 5 ft × 5 ft is classified as type B cracking whereas size less than 1 ft × 1 ft is defined as type C. Severity for all types of block cracking is defined as the average crack width while the extent for type A is measured as the total linear feet of the crack throughout the rating area whereas the extent of types B and C is measured as the total square feet of the cracking throughout the rating area.

Rutting and Patching

Rutting is considered only if it is half inch or deeper. Only in this case the rater will record rutting. There is no extent rating for rutting. In the case of patching, extent is measured as the total square feet of the patching throughout the rating area while there is no severity level for patching.

Flushing and Raveling

Severity level of flushing and raveling is defined as low, moderate or severe as they correspond to standard photographs developed by NDOT, which best depicts the amount of flushing or raveling present. No extent is recorded for both distresses.

Pavement Condition Index (PCI) System

The PCI was originally developed by the U.S. Army Construction Engineering Research Laboratory for airfields and was later extended to roads, streets, and parking lots [17]. The PCI for roads and streets has a scale ranging from 0 to 100, where 100 corresponds to pavement without any distresses, whereas 0 corresponds to failed or extremely poor pavement condition. The PCI is calculated using the type, severity and quantity of the distresses on the pavement being evaluated. There are 19 different types of distresses identified in the PCI system for flexible and rigid pavements. For each distress occurrence, a deduct value is assigned based on type, quantity and severity of distress and is deducted from a base value of 100 to obtain the PCI. Deduct values are proportionate to both severity and extent of distresses. The deduct values are obtained from a set of curves that were developed by a group of experienced pavement engineers. During the development of PCI , it was found that the deduct values for the various distress, type-severity combinations on a pavement section are not simply additive, and a set of corrective curves was developed to correct the multiple distress, type-severity occurrences on the same pavement section. The PCI for a pavement section is then the resulting total deduct values for multiple occurrences subtracted from 100 [5]. PCI provides an indication of the structural integrity and surface operational condition (localized roughness and safety). ASTM D6433 manual procedure is used as a guideline to be considered while observing the various distresses of the pavement. Pavement sample unit of area 2,500±1,000 ft^2 is used for data collection. Table 4 summarizes the PCI system to define severity and extent levels. The following is a brief description of the severity and extent levels of pavement distresses according to the PCI ASTM standards [3]:

Cracking

Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic. Three levels to define fatigue cracking severity: low, medium and high, while the extent is measured in square feet or square meter. While in case of longitudinal and transverse cracking the severity level is defined by low, medium and high whereas extent level is measured in linear feet or meter. Block cracking has the blocks which may range in size from approximately 1 × 1 ft to 10 × 10 ft. Three levels to define block cracking severity: low, medium and high, while the extent is measured in square feet or square meter.

Rutting and Patching

Both rutting and patching have three levels to define severity: low, medium and high whereas the extent for both rutting and patching is measured in square feet (or square meter) of surface area.

Bleeding and Raveling

The severity levels for both bleeding and raveling are low, medium and high whereas the extent is measured in square feet or square meter.

Conversion of Different Pavement Distresses Units From PRI Format to PCI Format

It was noticed that NDOT distress measuring units were different than the PCI format (i.e. level of severity and extent). Therefore, in order to the facilitate an efficient approach to utilize the historical PMS data collected in last 15 years, NDOT distresses were converted into the PCI format in order to calculate the

Table 4. Severity and Extent Levels for Different Distresses for PCI System.

Distress Type	Severity Level			Extent
	Low	Medium	High	
Fatigue Cracking	Longitudinal Fine Crack not Spalled	Light Alligator Crack with Light Spalling	Alligator Cracking Showing Distinct Pieces with Spalling	ft^2
Longitudinal / Transverse Crack	Nonfilled Crack < 0.375" or Filled Crack of any Width (Filler in Satisfactory Condition)	0.375" ≤ non Filled Crack ≤ 3" or Filled Crack of any Width Surrounded by Light Random Cracking	non Filled Crack > 3" or Any Crack Surrounded by Medium/ High Severity Random Cracking or a Crack where Approximately 4" of Pavement Around is Severely Broken	ft
Block Cracking	Non Filled Cracks ≤ 0.5" or Filled Crack with any Width	0.5" < Non Filled Crack ≤ 2"	Non Filled Crack > 2"	ft^2
Rutting	0.25" ≤ Rut Depth ≤ 0.5"	0.5" < rut depth ≤ 1.0"	Rut Depth > 1.0"	ft^2
Patching	Good Condition	Moderately Deteriorated	Badly Deteriorated	ft^2
Bleeding	Slight Degree Noticeable During a Few Days of a Year	Sticky Asphalt Noticeable During a Few Weeks of the Year	Sticky Asphalt Noticeable Several Weeks of the Year	ft^2
Raveling	N/A	Loss of Aggregate > 20 Per sq Yard or Clusters of Missing Coarse Aggregate are Present	Surface is Very Rough / Pitted or May be Completely Removed in Places	ft^2

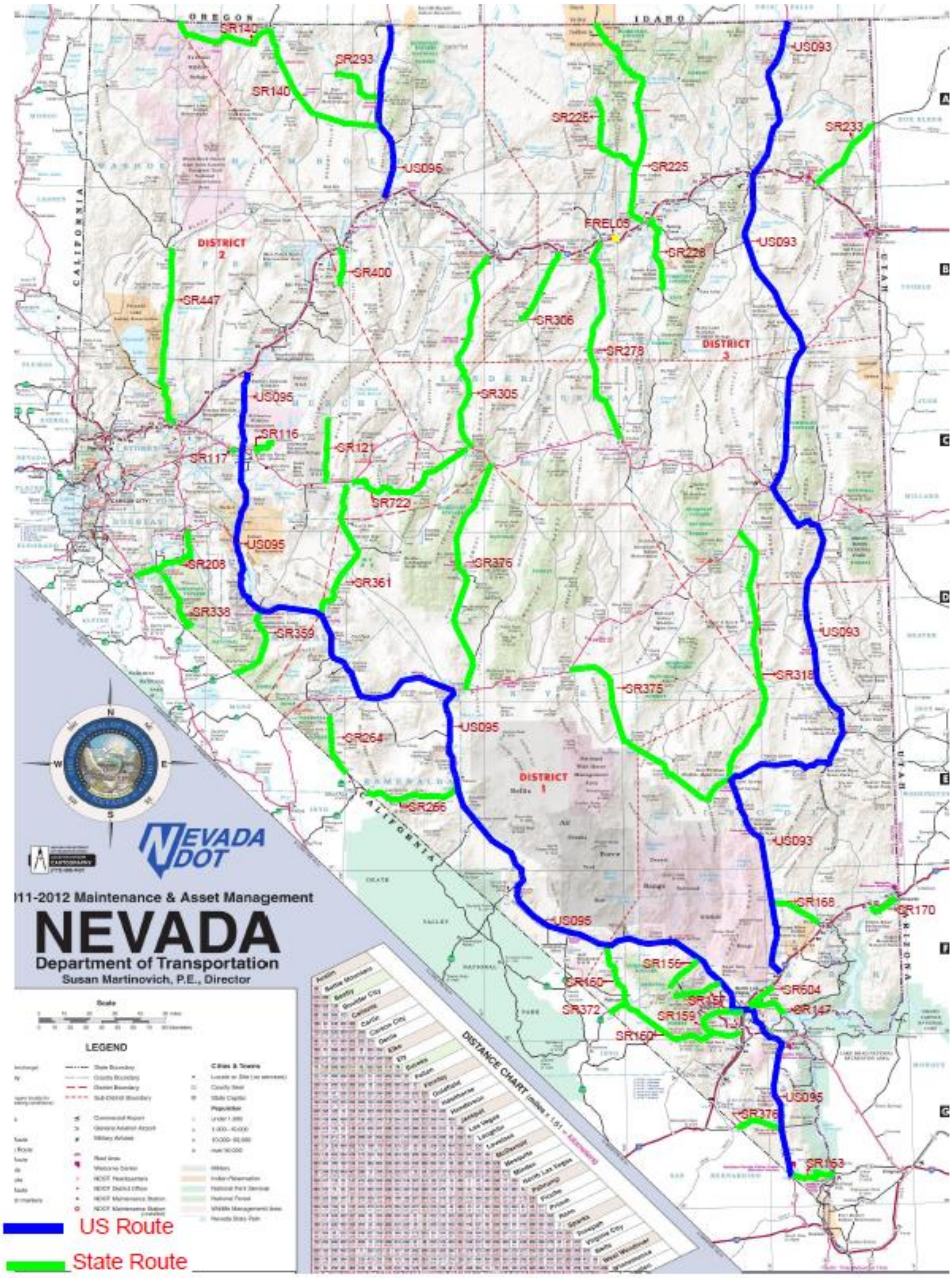

Fig. 2. Distribution of Representative Sections on Different Geographical Locations.

corresponding PCI values according to the ASTM standards. Several challenges were encountered during data conversion from NDOT format to PCI format which are explained in detail below:

Cracking

The challenge that was faced for fatigue cracking, longitudinal, transverse, and block cracking was that PRI system defines the level of severity based on the magnitude of the width of the crack while PCI system defines severity as low, medium and high. Therefore, a proper solution for this challenge was addressed by assigning level of severity for PCI system based on crack width of PRI system.

For example, for fatigue cracking type B, if the crack width is less than 3/8" in PRI system, it is considered to be low severity according to the PCI system. Similarly, if the crack width is between 3/8" and 1", it is considered as medium severity crack in PCI system whereas if the crack width is more than 1", it is treated as crack of high severity.

Similarly, for block cracking if the crack width is less than 1/2" in PRI system, it is considered to be low severity according to the PCI system. And if the crack width is between 1/2" and 2", it is considered as medium severity crack in PCI system whereas if the crack width is more than 2", the crack is treated as of high severity.

Additionally, for fatigue cracking type A, transverse and longitudinal cracking if the crack width is less than 3/8" in PRI system, it is considered to be low severity according to the PCI system. Similarly, if the crack width is between 3/8" and 3", it is considered as medium severity crack in PCI system whereas if the crack width is more than 3", it is treated as crack of high severity.

In case of conversion of extent level, for fatigue cracking type B, longitudinal, transverse, and block cracking type B & C, both PRI and PCI systems define the extent in square feet; hence, no conversion is needed. However for block cracking type A, PRI system defines the extent in linear feet while PCI system defines extent as square feet. Therefore, the conversion into PCI format is performed using following equation:

$$\text{Area of crack} = \text{extent (length) of crack}/510 \times 1000\ \text{ft}^2 \tag{1}$$

According to NDOT distress manual, the maximum extent for block cracking type A is 510 ft. Therefore, unitary method was used to find out the extent (crack area) for PCI system. Fatigue cracking type A defined by PRI system was treated as longitudinal cracking in PCI system. Therefore, all the conversion for fatigue crack type A into PCI format was same as of longitudinal cracking.

Patching

The challenge encountered for patching data conversion is that in PRI system, there is no term to describe the severity level of patching. However, PCI system defines severity as low, medium and high. To complete the conversion process to the PCI unit format, severity level was considered to be only low since other distresses that may present in the patched area are already recorded in the respective distresses during data collection. For the case of extent level conversion, both PRI and PCI system define extent in square feet. Therefore, there was no need for conversion.

Flushing/Bleeding

PRI system defines severity level of bleeding as low, moderate and high which matched the PCI system. Therefore, no conversion for level of severity was introduced. In case of extent level, there was no definition available according to PRI system. However, for PCI system, the extent of bleeding is measured in square feet. Hence, to address this challenge, an assumption was made to assign the extent based on the level of severity. For example, low, medium, and high severity levels were associated to an extent area of 100, 300, or 500 ft^2 respectively. Bleeding generally occurs in the wheelpath and width of wheelpath was assumed to be 3 ft whereas length of a surveyed section is 100 ft which makes maximum bleeding area of 600 ft^2. Therefore, the extent for bleeding was assigned based on the assumption that low severity would occupy less area compared with higher severity.

Raveling

PRI system defines severity of raveling as low, moderate and severe while PCI system defines only two levels of severity as of medium and high level of severity. Therefore, raveling of low and moderate levels defined by PRI system were combined as medium severity for PCI system while the high level of severity did not need a conversion. Additionally, there was no defined extent level for raveling according to PRI system. However, for PCI system, the extent of raveling is measured in square feet. Hence, an assumption has been made to assign the extent based on the level of severity. For example, medium and high severity levels were associated to an extent area of 500, or 750 ft^2 respectively. Raveling can occur in the whole area of surveyed section which makes maximum raveling area of 1000 ft^2. Therefore, it was assumed that of 50% and 75% of total area is covered by moderate and high severity raveling, respectively.

Rutting

PRI system quantifies rutting in terms of rut depth. There are no distinctive rutting severity levels. However, PCI system defines rutting severity as low, medium and high based on the depth of rut. This is a challenge for rutting data conversion in terms of level of severity. As a solution for this challenge, the conversion of severity level from PRI system into PCI format was performed based on the rut depth. For example if the rut depth is less than 0.25", no rutting was considered whereas rutting of low severity was considered if rut depth ranges from 0.25" to 0.5". Similarly, medium severity rutting was considered for rut depth ranging from 0.5" to 1.0 " and high severity rutting if rut depth is greater than 1.0". In case of extent level conversion, there was no definition for extent level based on the PRI system. However, PCI system defines the extent of rutting in square feet. Therefore, to come up with proper solution for this challenge, an assumption was made to assign the extent based on the level of severity. For example, low, medium, and high severity levels were associated to an extent area of 100, 300, or 500 sq ft respectively. As rutting also occur in wheel paths of the pavement, the same assumptions utilized for assigning extent levels for bleeding was used for rutting. Table 5 summarizes the overall conversion process from PRI to PCI units. Numerical examples to illustrate the data conversion for all the distresses are shown in Table 6.

Preliminary Comparison between PRI and PCI Systems

The NDOT PMS data of 37 different representative sections out of 524 from the year 1995 to 2011 were used to calculate the corresponding PCI value. Selection of representative section was performed in a way to cover all the geographical locations and different traffic levels within the state. About 44% of total data points were covered by representative sections. Fig. 3 shows the

Table 5. Conversion of PRI Distress Format to PCI Distress Format

Distress Type	NDOT PRI System			PCI ASTM System				Conversion for NDOT Distress Parameters (Level of Severity and Extent) into PCI Format			
	Type	Severity	Extent	Severity Level			Extent	Severity Level			Extent
								Low	Medium	High	
Fatigue Cracking	A	Crack Width	Crack Length	Low	Medium	High	Crack Length	Crack Width < 0.375"	0.375" ≤ Crack Width ≤ 3"	Crack Width > 3"	Crack Length
	B	Crack Width	Crack Area	Low	Medium	High	Crack Area	Crack Width < 0.375"	0.375" ≤ Crack Width ≤ 1"	Crack Width > 1"	Crack Area
Block Cracking	A	Crack Width	Crack Length	Low	Medium	High	Crack Area				(Extent /510)x 1000
	B	Crack Width	Crack Area	Low	Medium	High	Crack Area	Crack Width < 0.5"	0.5" < Crack Width < 2"	Crack Width > 2"	Crack Area
	C	Crack Width	Crack Area	Low	Medium	High	Crack Area				Crack Area
Longitudinal / Transverse Cracking	N/A	Crack Width	Crack length	Low	Medium	High	Crack Length	Crack Width < 0.375"	0.375" < Rack Width < 3"	Crack Width > 3"	Crack Length
Rutting	N/A	Rut Depth	N/A	Low	Medium	High	Rutting Area	0.25" ≤ Rut Depth ≤ 0.5"	0.5" < Rut Depth ≤ 1.0"	Rut Depth > 1.0"	Rutting Area
Raveling	N/A	Low, Med, High	N/A	N/A	Medium	High	Area	N/A	Low and Moderate Severity	High Severity	Raveling Area
Bleeding	N/A	Low, Med, High	N/A	Low	Medium	High	Area	Low Severity	Medium Severity	High Severity	Bleeding Area
Patching	N/A	N/A	Area	Low	Medium	High	Area		Low Severity		Patching Area

*N/A denotes there is no extent or severity or type for distresses.

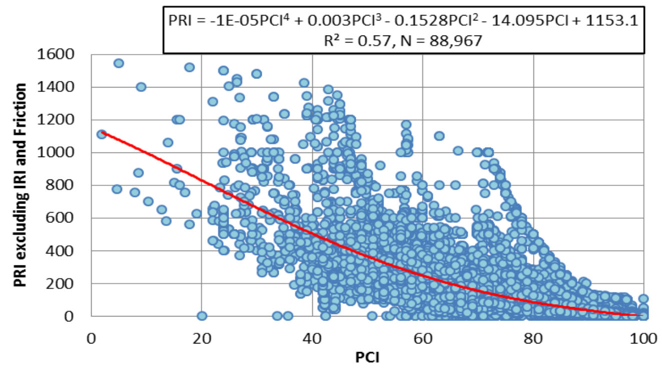

Fig. 3. Comparison of PRI Versus PCI.

Preliminary Comparison between PRI and PCI Systems

The NDOT PMS data of 37 different representative sections out of 524 from the year 1995 to 2011 were used to calculate the corresponding PCI value. Selection of representative section was performed in a way to cover all the geographical locations and different traffic levels within the state. About 44% of total data points were covered by representative sections. Fig. 3 shows the distribution of representative section within the state. The distribution of data points with respect to different traffic level is shown in Table 7. Micro Paver software version 6.5.2 [18] developed by US Army Corps of Engineers was utilized to calculate the PCI value. All distresses units were converted into the PCI required format according to the conversion process mentioned above. Roughness and friction data of PRI system were not used to determine PCI value. Most of the highway agencies use roughness as a separate index to propose the functional maintenance of the pavement [6, 19]. Fig. 3 shows a comparison between PRI versus the corresponding estimated PCI values using over than 88,000 data points. Moderate correlation (R^2 value of 0.57) was found between both indices. However, several data points showed quite dispersion indicating a window for potential enhancements.

Proposed Enhancements in the PRI System

The PRI system lacks a well-defined extent and severity levels for several distresses. For instance, fatigue cracking, block cracking type B & C, as well as patching do not have defined severity levels

Table 6. Examples on Conversion of PRI Distress Format to PCI Distress Format.

Type of Distress	NDOT Format		Corresponding PCI Format	
	Severity	Extent	Severity	Extent
Fatigue Type A	Crack Width = 0.2"	100"	Low	100"
	Crack Width = 0.9"	100"	Medium	100"
	Crack Width = 3.2"	100"	High	100"
Fatigue Type B	Crack Width = 0.2"	100 sq in	Low	100 sq in
	Crack Width = 0.9"	100 sq in	Medium	100 sq in
	Crack Width = 1.2"	102 sq in	High	102 sq in
Block cracking Type A	Crack Width = 0.4"	100"	Low	196 sq in
	Crack Width = 1.5"	200"	Medium	392 sq in
	Crack Width = 2.2"	300"	High	588 sq in
Block cracking Type B&C	Crack Width = 0.4"	100 sq in	Low	100 sq in
	Crack Width = 1.5"	200 sq in	Medium	200 sq in
	Crack Width = 2.2"	300 sq in	High	300 sq in
Longitudinal /Transverse Cracking	Crack Width = 0.2"	100"	Low	100"
	Crack Width = 0.9"	100"	Medium	100"
	Crack Width = 3.2"	100"	High	100"
Rutting	Rut Depth = 0.3"	N/A	Low	100 sq in
	Rut Depth = 0.8"	N/A	Medium	300 sq in
	Rut Depth = 1.2"	N/A	High	500 sq in
Raveling	Low	N/A	Medium	250 sq in
	Moderate	N/A	Medium	500 sq in
	Severe	N/A	High	750 sq in
Bleeding	Low	N/A	Low	100 sq in
	Moderate	N/A	Medium	300 sq in
	Severe	N/A	High	500 sq in
Patching	N/A	100 sq in	Low	100 sq in

*N/A denotes there is no extent or severity or type for distresses

Table 7. Distribution of Data Points on Different Traffic Levels.

Traffic Level	Percentage of Data
ADT > 10,000 or ESAL > 540	24%
1,600 < ADT < 10,000 or 405 < ESAL < 540	26%
400 < ADT < 1,600 or 270 < ESAL < 405	23%
ADT < 400 or ESAL < 270	27%

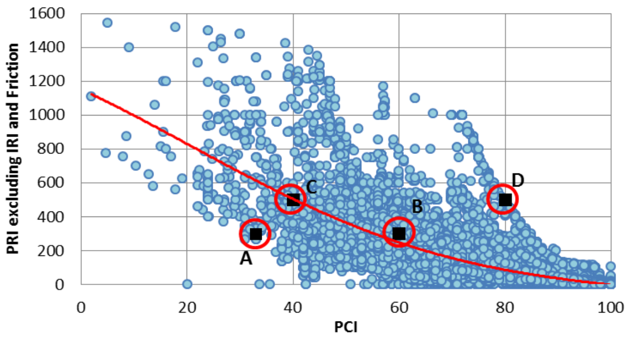

Fig. 4. Deficiency in PRI System for Fatigue and Block Cracking.

whereas flushing/bleeding, raveling and rutting do not consider extent level. Since no severity level was incorporated for fatigue cracking and block cracking type B & C, PRI point will be the same for low and high severity cracking if the amount of extent of cracking is same while the PCI value will be totally different. For example, two pavement segments (A and B) as shows in Fig. 4 had fatigue cracking type B; one with low severity and another with high severity. However, both cracks had same extent level of 150 sq ft. PRI value for both sections was found to be same as of 300. Yet, PCI value for high severity cracking was 33 (segment A) and 60 for low severity cracking (segment B). PRI system did not seem to represent the true condition of the pavement. Hence, same maintenance strategy will be accounted for both segments A & B based on PRI value even though the existing pavement condition is different. On the other hand, PCI system indicates that segment B has fair pavement condition whereas segment A is in poor condition. Therefore, this will trigger different repair strategies for segments A & B. Similarly, pavement segments C & D as shown in Fig. 4 had block cracking type B; one with low severity and another with high severity. Both had a similar extent level of 500 sq ft. PRI value for both sections was found to be same as of 500 since it is not sensitive to severity level. However, PCI value for high severity (segment C) was 40 and 80 for low severity (segment D). Both segments C & D will be assigned with the same repair strategy based on the PRI system. However, if PCI system is implemented, segment C will be categorized under poor condition while segment D as good condition. Therefore, preventive maintenance will be proposed for segment D by PCI system while PRI system proposes for overlay. It was observed that for segment D that the PRI overestimates maintenance strategy (overlay instead of preventive maintenance) which will eventually result in significant increases in the repair cost. Therefore, to overcome such shortcomings, several enhancements were proposed in the current PRI system to make a clear distinction between different severity and/or extent levels.

Several enhancements to the current PRI system were introduced to overcome the observed shortcomings. Enhancements included modifications in severity and extent levels, alteration in the limits to assign PRI points in order to obtain a more compatible system to the PCI procedure. Moreover, it is worthwhile to mention that traffic level is typically not considered in most of the current pavement rating systems including PCI [7, 8, 19]. Hence, the defined three traffic levels in the current PRI system were unified as one level in the proposed enhanced PRI system. Enhanced PRI system was proposed based on the available information on current PRI system where there is no change in data collection system. The followings are the proposed enhancements:

Cracking

Current PRI system only considers the extent level to assign PRI points for fatigue and block cracking type B & C. Therefore, to include the level of severity in calculating PRI, the proposed enhanced system assigns PRI point based on the crack width, extent and type of fatigue and block cracking.

In case of longitudinal, transverse, and block cracking type A, PRI system assigns points using three equations which are based on crack width, extent, and traffic level (Table 3). Enhancement included unifying all traffic levels as one. Additionally, parameters defining the PRI point equations were modified to better correlate to PCI values (Table 6).

Rutting and Patching

For rutting, the PRI point is assigned based on the rut depth. Three assigned severity levels were defined instead of the current four levels in order to match PCI system. In case of patching there are equations to assign PRI points based on the traffic level which have been modified into single equation in enhanced PRI system regardless of traffic level.

Bleeding

The current PRI system does not assign any points for low severity bleeding. The proposed enhanced PRI system assigns 25 PRI points.

Comparison between Enhanced PRI and PCI Systems

Using the enhanced PRI system, new PRI points were calculated. The plot between new PRI point and PCI value was made to check the improvement in correlation coefficient (R^2 value) of the plot. Several modifications were done to come up with a better correlation coefficient. Final modification on PRI system provided improvement in the correlation coefficient (R^2 value) from 0.57 to 0.78. Fig. 5 shows the plot of enhanced PRI against PCI for representative sections from the year 1995 to 2011. Table 8 summarizes the enhanced NDOT PRI point calculation method. Fig. 6 shows the plot of PCI vs PRI for the segments A, B, C and D after using enhanced PRI system. After enhancement, the deficiency of having same PRI points for two different segments (having same cracking extent but different severity) was eliminated. The new PRI points for segments A (high severity fatigue cracking) & B (low severity fatigue cracking) was 255 and 195 respectively with corresponding PCI value of 33 and 60. Similarly, for segments C (high severity block cracking) & D (low severity block cracking), the new PRI point was 250 and 100 respectively with corresponding PCI value of 40 & 80.

Consider a pavement segment X having distresses as of block cracking type B (low severity and extent of 450 sq in), longitudinal cracking (low severity and extent of 5”) and raveling (low severity). The PRI point of segment X before enhancement was 552 while enhanced PRI point was 192. PCI value of segment X was 80. Based on PRI point before enhancement, the repair strategy for segment X will be overlay while enhanced PRI points will suggest for corrective repair strategy according to Table 1. And PCI value also suggests for corrective repair strategy for segment X. This example shows the influence of enhanced PRI system on repair strategy determination which will eventually help in cost minimization by assigning proper treatment for the segment X (corrective action instead of overlay).

Summary, Conclusions, and Recommendations

The overall objective of this study was to develop an enhanced PRI system to evaluate the condition of flexible pavements in Nevada and consider the possibility of switching into PCI system. Over than

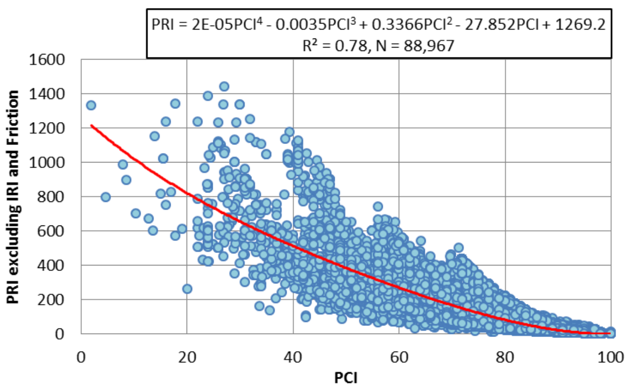

Fig. 5. Comparison of Enhanced PRI and PCI System.

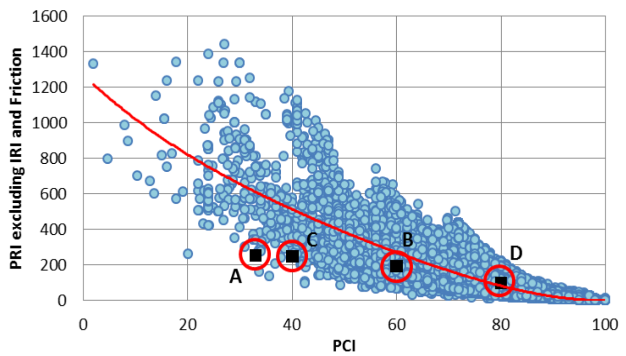

Fig. 6. Improvement in Deficiency in PRI System for Fatigue and Block Cracking after Enhancement.

Table 8. Enhanced NDOT PRI Point Calculation System.

Distress Type	PMS Points			
Rutting	Average Rut Depth	PMS Points		
	0 to 0.24"	0		
	0.25 to 1.5"	(392.2 × RD) + 111.8		
	Above 1.5"	700		
Fatigue A & B or Block B & C Cracking	Crack Width	PMS Points		
		Fatigue A Cracking	Fatigue B Cracking	Block B & C Cracking
	< 1/4"	0.8 × Extent	1.3 × Extent	0.2 × Extent
	1/4" to 7/8"	1.0 × Extent	1.5 × Extent	0.35 × Extent
	> 7/8"	1.2 × Extent	1.7 × Extent	0.5 × Extent
Non Wheelpath Linear or Block A or Transverse Cracking	PMS Points = Extent x (LC Severity Factor) where LC Severity Factor is Determined from:			
	Crack Width	LC Severity Factor		
	< 1/4"	0.2		
	1/4" to 7/8"	0.8 × (Crack Width) + 0.55		
	> 7/8"	1.25		
Patching	0.25 × Extent			
Flushing	Picture No.	PMS Points		
	17 (Low)	25		
	18 (Moderate)	100		
	19 (Severe)	250		
Raveling	Picture No.	PMS Points		
	20 (Low)	100		
	21 (Moderate)	250		
	22 (Severe)	500		

88,000 data points were collected from the historical Nevada's pavement management records for the last 15 years. Data units were converted into PCI compatible format and then compared to the corresponding PRI value. It was observed that PCI system typically represents the existing pavement conditions since it incorporate detailed definitions for severity and extent levels for all pavement distresses. This will lead to more accurate pavement maintenance assignments. Conversely, the absence of severity and/or extent levels of some distresses in the current PRI system may not lead to the same maintenance strategies as recommended by PCI system which will eventually result in increasing the repair costs. Therefore, this study aimed to provide motivation to other local highway agencies to enhance their current pavement rating systems. Based on the observed results, the following conclusions can be made:

- A successful distress unit conversion from the PRI to PCI measurement units was achieved in order to take advantage of utilizing all collected historical data which will eventually serve in calculating PCI values.
- Upon the unit conversion, a moderate correlation was observed between PRI and the corresponding PCI values.
- To improve the statistical relation between PRI and PCI systems, an enhanced PRI system that reflects both severity and extent levels for all pavement distresses was developed.
- The study has the following recommendations:
- It is recommended to modify the current distress data collection system to comply with the PCI ASTM procedure. Severity and extent levels are recommended to be incorporated for all measured pavement distresses.
- PCI system accurately evaluates the existing pavement condition compared to the current PRI system. Hence, it is recommended to eventually switch from PRI to PCI system to precisely assign pavement maintenance treatments.

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