Comparative Study Between the Pavement Condition Indices

E. M. Ibrahim[1]

[1] Civil Engineering Department, Delta Higher Institute of Engineering and Technology, Mansoura 35516, Egypt

Emails: engemanmagdy@yahoo.com

Abstract

Highways perform a seminal role in the economic development for any country. The road network is a crucial infrastructure that needs to be developed and kept in a function able condition; so that, its benefits can be achieved. For ages, pavements were kept but not administered. The expertise of the pavement engineer determined the choice of Maintenance and Repair (M&R) methods regardless of the expense and quality of the life cycle as opposed to other pavement segments in the map of the roads` network. Nowadays, in the light of economic environment, since the pavement infrastructure has worn out, a more organized and disciplined way to specify M&R needs and priorities seems a must. To keep the pavements well, the factors affecting pavement performance need to be identified. Examples of such factors are climate, drainage, material properties, construction quality and traffic loads. Due to exposure to traffic and environmental factors distresses show up with time throughout the service life of the pavement. Thus, pavement performance is negatively affected and if not treated at the right time, the service life will be shorter along with inferior ride quality. In order to evaluate pavement condition and thus its performance, a reliable pavement condition index is needed. This index is based upon pavement condition surveys which can be conducted either manual (visual inspection) or automated (by a van). If the quality of the pavement is assessed and the distresses are identified, there are currently several indices available for evaluating pavement performance. This paper presents a comparative study between the pavement condition indices to determine the most suitable method for implementation in roads.

Keywords: Pavement survey; Pavement evaluation; Flexible pavement distresses; Pavement condition index.

1. Introduction

Pavement Performance model is a major component of pavement management system (PMS). Different models can be used for predicting pavement deterioration such as deterministic, probabilistic and artificial intelligent models. Probabilistic models include Markov process model or survival curve. They are able to predict performance by limited data and predict performance even if some years are missing flintsch [1]. A prediction model should evaluate the distresses and its behavior with maintenance. Figure 1 shows the condition versus the age and the cost of repair in every stage. The figure reveals that the performance rates of pavements always conduct aging pavement section break down faster and they cost more much to fix. Practically it is not advisable to include only the roads requiring reconstruction in the maintenance plan of the road network. This is not only an expensive plan, but good and fair pavements will also get worse to very poor levels. Hence, the process of only fixing the bad roadways when they become at very poor condition is not a cost-effective strategy. Unlikely institutions are adopting frequent early treatments in the life of pavements to keep the

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condition of roads acceptable. Thus, the maintenance techniques are presented to keep the life cycle cost of the roads at acceptable levels Hafez, [2].

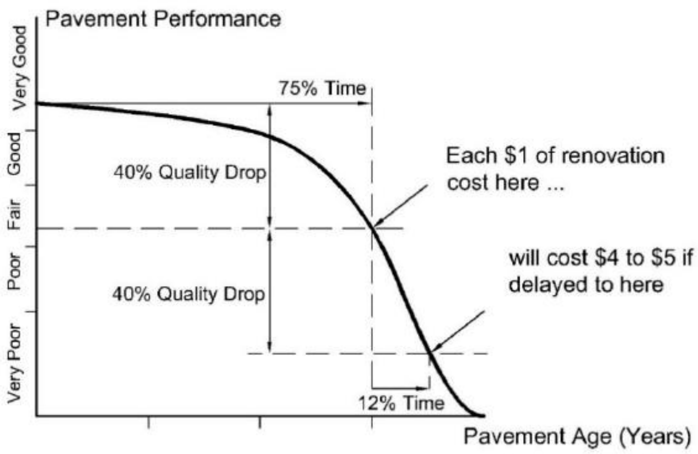

Figure 1: Pavement Performance and Maintenance Cost with Time, Shahin and Kohn, [3]

In essence, the objective of the pavement condition survey can be crystalized as recognizing the pavement distresses of each road sector and / or measuring the surface roughness and friction. Distress data refers to that kind of information that combines the types, extent and severities of distresses on the pavement surface. Usually, this kind of information is crystalized in the shape of pavement pictures and videos that are in turn investigated by experienced engineers who recognize current distresses. The condition survey is a critical part of pavement management, since specific distresses are very much related to certain causes of pavement deterioration. Flexible pavements are surveyed either manually by visual inspection or automatically by an equipped Van or by both methods. Table 1 provides a comparison of both methods of pavement survey. Hence, the selection of whether manual or automatic is based on an agency's requisites and its accessible sources.

Table 1. Comparison of Flexible Pavement Survey Types, Okine and Adarkwa [4]

	Visual Inspection	Automatic
Time	Longer time of the data collection	Reduces time of the data collections
Safety	Risk for personal are collected data	More safer
Objectivity	primarily subjective as it relies on experience of individuals	Objective scales
Expenditure	Less expensive	Very expensive instrument cost
Amount of Data	Agencies can only collect less data at a time	Huge amount of information gathered & stored according to the capacity of equipment
Data treatment	vulnerable to transcription errors	Not vulnerable to transcription mistakes
Employers	Source of employment for rating staff	proper in agencies aiming to downsize number of employees
Coverage	Inspectors can cover entire width of road section relatively easier	May cover footprint of data collection vehicle. Multiple runs sometimes needed to cover entire road width

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2. Flexible Pavement Distresses

Flexible pavements may suffer from several structural and functional distresses that lead to progressive deterioration of ride condition, structural strength, and motorist/pedestrian safety. That is the highly common technique for manifesting the degree of pavement deterioration or rate of the pavement performance based on types, severities, quantities of pavement distresses. Each class of pavement distresses (structural and functional) contains several types of distresses and / or failure Hass et al., [5]. Primarily many of the distresses are due to malfunctions in construction, substances and maintenance that have nothing to do with the design Huang, [6]. At some point of time, this type of pavement may suffer from different distress types such as rutting and cracking. Environmental conditions could lead to an increase in the moisture content of the pavement granular base/subbase layers and subgrade soils, resulting in a decrease in the compressive strength and shear moduli. As a result of these weakened conditions, the repeated vehicle loading can lead to rutting, fatigue cracking, and migration of fine particles (pumping) Yoder and Witczak, [7].

Sayers , [8] categorized the distresses as: Fractures which caused by overloading such as cracking, fatigue, moisture damage, slippage and temperature changes, distortion which appear in the form of deformation, corrugation, shoving and rutting and disintegration which is caused by loss of bond between binder and aggregate such as raveling or stripping. Alligator or fatigue cracking can be seen as a series of interconnected cracks due to the fatigue breaks of an asphalt surface under repeated traffic pressures. That is the cracking begins at the bottom of the asphalt surface or stabilized base, where the tensile stress or strain is the highest in the wheel path. While the rutting is defined as the surface depression during a wheel way. It originates from the permanent deterioration within any pavement layer and at the top of subgrade layer, one caused by consolidation or lateral movement of the fabric because of traffic loads. In addition, the rutting can be resulted from the plastic movement of the asphalt mixture Wang and Huang,[9].

Evaluation of Egyptian road network's pavement surface conditions illustrated that rutting and fatigue cracking are the foremost vital distresses explored because of high levels of severity and density, leading to their high consequences on the pavement quality. Dynamic pavements have to be designed to produce a durable, skid resistance surface under harsh conditions. As a result of these distresses, the pavements deteriorate along their service life. This deterioration is caused by environmental effects, traffic loads, drainage, material properties and structural / construction properties or a combination of both. The environmental factors include rainfall, radiation, freeze, thaw temperature and moisture. While the traffic loads contain the repetition, axle load, tire pressure, axle spacing and speed. Structure and construction properties include layer thickness, material properties, subgrade properties, drainage, material / construction variability, equipment specification and quality of construction. Figure 2 shows the main factors affecting flexible pavement performance.

Figure 2: Factors Affecting Flexible Pavement Performance

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3. Pavement Condition Indices

In fact, precise expectation of the pavement network condition and performance seems a must for the well-qualified administration of the transportation infrastructure system. The pavement condition is related to several factors; including the structural integrity, structural capacity, roughness, and skid resistance. These factors are assessed by observing and measuring the pavement distress. Hence, the precision of the pavement performance expectation model is affected by the exploitation of pavement performance norms: namely, the pavement condition index (PCI), international roughness index (IRI), present serviceability index (PSI), pavement condition rating (PCR), structural condition index (SCI), riding comfort index (RCI), pavement quality index (PQI), remaining service life index (RSLI), pavement distress index (PDI), critical condition index (CCI), rutting index (RI), crack index (CI), pavement performance index (PPI), surface distresses index (SDI), distresses manifestation index (DMI), urban distresses index (UDI), pavement structural condition (PSC), overall pavement condition (OPC) and modified pavement condition rating (MPCR). Some of these indices only depend on one type of distress such as the Rutting Index (RI) or combination of distresses such as the Pavement Condition Index (PCI) and Pavement Condition Rating (PCR). Moreover, some of these indices are indicators of the pavement structural condition such as those depending on the Falling Weight Deflectometer (FWD) data while others are indicative of the ride quality such as the International Roughness Index (IRI). Of these pavement indices, the PCI was found to be the most widely used index for pavement condition evaluation Wang and Huang, [9].

Once the pavement condition is evaluated and the distresses are determined, pavement performance can then be assessed. Egypt pays great importance to the National Road Project, which aims at improving and upgrading existing roads and constructing thousands of kilometers of new roads to facilitate and ease the movement of people and goods. It is also a way to open new horizons for investment, improve infrastructure, link the governorates and build new communities thus improving the quality of life and increasing the national income of the country. The majority of past studies focused on the use of different indices to evaluate pavement condition with the PCI being the most commonly used index. Thus, the main objective of this paper is to compare the flexible pavement indices.

A. PCI

The PCI developed by the U.S. Army Corps of Engineers was a very comprehensive condition index Shahin and Kohn, [10]. PCI is a numerical index between 0 (worst condition) to 100 (best condition), which is used to indicate the condition of a specific section of road pavement. The PCI is determined by manual or automated inspection process for 19 pavement distress types (cracks, rutting and weathering). It considers the extent and severity of each distress. For more clarity, it offers a measure of the current state of the pavement according to the distress apparent in the pavement layer, which also indicates the structural integrity and the working conditions of the surface (roughness and safety). The calculation of the PCI depends on charts for each distress and correlation of deduct value ASTM, [11]as shown in Figure 3. Continuous monitoring of the PCI was used to establish the rate of pavement deterioration, which permitted early identification of major rehabilitation needs, as shown in Table 2. The Egyptian Code of Practice (ECP) for urban and rural roads [12] included the PCI used to evaluate the pavement.

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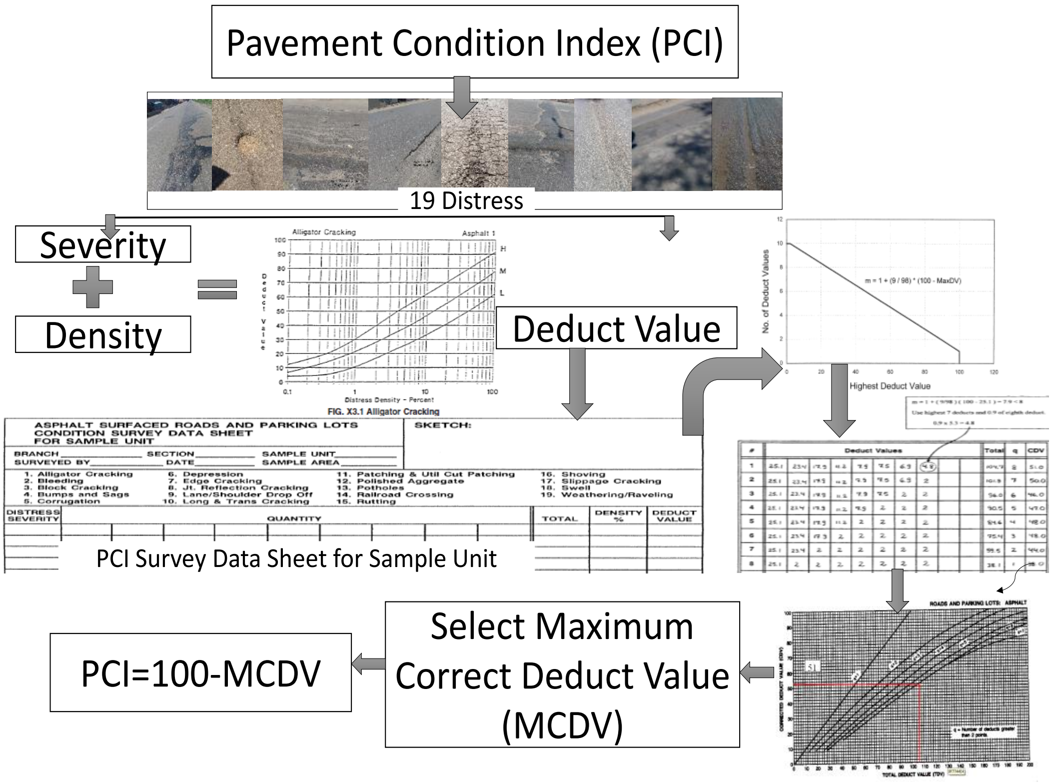

Figure 3: PCI Method

Table 2: Typical Pavement M&R Strategies based upon PCI Values, Shahin and Walther, [13]

PCI	Rating	Strategy
85–100	Good	Routine maintenance
70–85	Satisfactory	Preventive maintenance
55–70	Fair	Minor rehabilitation
40–55	Poor	Minor rehabilitation
25–40	Very poor	Major rehabilitation
10–25	Serious	Reconstruction
0–10	Failed	Reconstruction

B. IRI

Pavement roughness values were measured using IRI, which was a primary indication of the ride quality. The IRI was developed in 1982 as part of an international experiment conducted in Brazil. It constituted the smoothness, safety, and the ease of driving path Prasad et al., [14]. The IRI was measured in units of slope, and it described the suspension motion of a moving vehicle over the distance travelled. Usually, IRI is measured in meters per kilometer or inches per mile Park et al., [15]. The IRI is a measure of the surface profile of the road and is computed from the surface elevation. The IRI ranges from 0 m/km to 20 m/km (greatest roughness). Table 3 shows the guidelines provided by the Federal Highway Administration (FHWA), [16] on the various IRI values measured. IRI is also calculated in accordance with the ASTM Standard E 1926 (ASTM, [17].

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Table **Error! No text of specified style in document.**3: IRI Conditions FHWA, [16]

Condition Categories	PSR Rating*		IRI Rating m/km (in/mi)		Interstate and NHS* Ride quality
	Interstat e	Other	Interstate	Other	
Very good	≥ 4.0	≥ 4.0	< 1.0 (< 60)	<1.0 (<60)	Acceptable 0–2.0 (0–170)
Good	3.5–3.9	3.5–3.9	1.0–1.5 (60–94)	1.0–1.5 (609–4)	
Fair	3.1–3.4	2.6–3.4	1.5–1.9 (95–119)	1.52.0 (95–170)	Less than acceptable > 2.0 (>170)
Mediocre	2.6–3.0	2.1–2.5	1.9–2.0 (120–170)	2.0-3–5 (171–220)	
Poor	≤ 2.5	≤ 2.0	>2.0 (>170)	> 3.5 (>220)	

*PSR = Present serviceability rating and NHS = National highway system.

C. PSI

The PSI was developed in the early 1960s and constituted the first comprehensive effort to establish performance standards based on the ride quality considerations Carey and Irick, [18]. The PSI was based on the values of pavement smoothness, rutting cracking, and patching. A panel of highway users from different backgrounds evaluated several flexible pavement sections and rated them on a five-point discrete scale (0 for poor, 5 for excellent).

D. PCR

The PCR index is performed according to the visual examination of 13 pavement distress types taking into account the extent and severity of each distress. The PCR index is very simple in calculation and can be directly calculated by simply multiplying the weight of a given distress by its severity and extent as shown in Table 4.

Table 4. PCR Distress Weights, Severity and Extent (ODOT, [20]

Distresses	Distress Weight	Severity			Extent		
		L	M	H	O	F	E
Raveling	10	0.3	0.6	1	0.5	0.8	1
Bleeding	5	0.8	0.8	1	0.6	0.9	1
Patching	5	0.3	0.6	1	0.6	0.8	1
Potholes	10	0.4	0.7	1	0.5	0.8	1
Crack Sealing	5	1	1	1	0.5	0.8	1
Rutting	10	0.3	0.7	1	0.6	0.8	1
Settlement	10	0.5	0.7	1	0.5	0.8	1
Corrugations	5	0.4	0.8	1	0.5	0.8	1
Wheel Track Crack	15	0.4	0.7	1	0.5	0.7	1
Block & Transverse Crack	10	0.4	0.7	1	0.5	0.7	1
Longitudinal Joint Crack	5	0.4	0.7	1	0.5	0.7	1
Edge Crack	5	0.4	0.7	1	0.5	0.7	1
Random Crack	5	0.4	0.7	1	0.5	0.7	1

L: Low severity, M: Medium severity, H: High severity, O: Occasional, F: Frequent and E: Extensive

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To determine the deduct values (DV) as given in Equation (1). Then, the PCR is computed by subtracting the sum of deduct values from 100. No corrections or underlying calculations are required as in the PCI method, Figure 4.

$$DV = \text{Distress Weight} \times \text{Extent} \times \text{Severity} \quad (1)$$

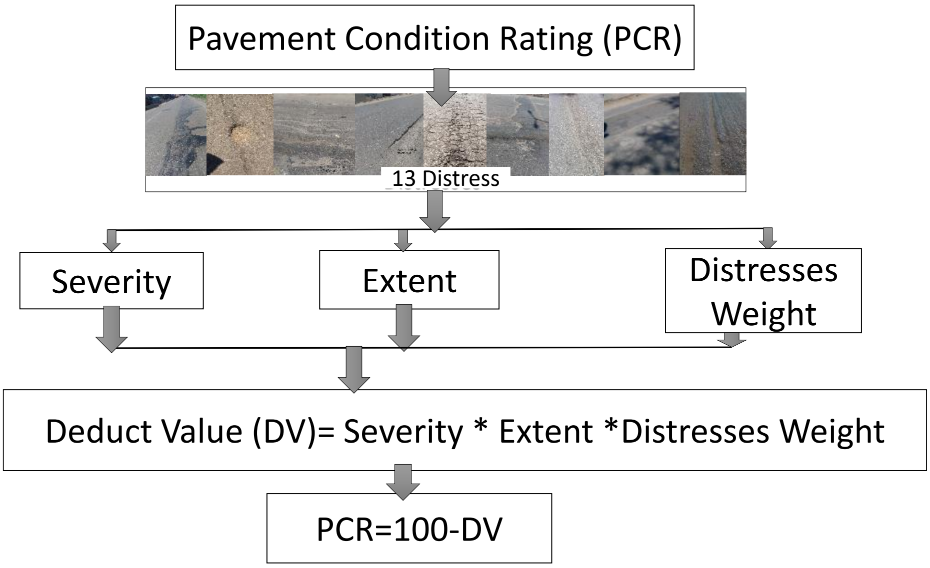

Figure 4: PCR Method

The PCR was originally proposed by the US Army Corps of Engineers and later standardized by the ASTM on a 0 to 100 numerical index system, where 0 denoted extremely poor pavement conditions, and 100 denoted excellent pavement conditions Shahin, [19].

E. SCI

Structural evaluation provides valuable information about the expected behaviors and the responses of pavements and can be used at the network level of pavement management to prioritize projects. The falling weight deflectometer (FWD) can be used to identify the beginning and end of the management sections and group pavement sections that have similar structural capacities. The SCI was developed as a screening tool for pavement network-level evaluation, and FWD data were used to determine the SCI. For the successful implementation of the SCI concept at the network level, one critical concern is the index accuracy. This article evaluates the accuracy of the SCI and discusses the concept and procedure of how to improve the SCI and its algorithm for low-volume flexible pavements. A case study in Texas illustrated that the original SCI algorithm underestimated the existing structural condition, which resulted in overestimated treatments in pavement maintenance and rehabilitation, Nam et al., [21].

F. RCI

RCI is primarily a function of the pavement unevenness and is measured on a scale of 0 to 5, as shown in Table 5.

Table 5: Riding Comfort Index Values

Unevenness Index (mm/km)	Riding Comfort Index
<2500	0
2500–3500	1
3500–5000	2
5000–7000	3

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7000–10000	4
>10000	5

An RCI value of zero indicates a well-constructed new pavement, and an RCI value of five represents an extremely rough pavement. If the unevenness index value of a pavement stretch is known, the RCI value can be obtained directly. The assessment of riding quality is the most important component of the pavement surface condition. In this paper, the riding quality of pavements in the form of RCI has been correlated with the unevenness index values, and Equation 2 was developed.

$$RCI = 2.9897 \times \text{In}(U) - 22.902\ldots,\ R2 = 0.873 \qquad (2)$$

Where; RCI is the riding comfort index, and u is the unevenness in mm/km.

The relationship between subjectively determined RCI values and objectively determined pavement roughness has been determined in various areas of North America for both urban and rural operating environments. Equation 3 was determined by correlating the ride quality ratings to the roughness measurements collected by using the RT-3000 technology for a variety of pavements; this equation was used to convert the IRI-based roughness to RCI values.

$$RCI = 25.3 - 3.62 \times \text{In}(IRI), \qquad (3)$$

Where; IRI is the international roughness index.

RCI values greater than 7.0 generally indicate good ride quality. Values in the 5.0 to 7.0 range indicate that a pavement has marginal riding comfort. An RCI score less than 5.0 indicates poor ride quality, Lashlee, [22].

G. PQI

Minnesota Department of Transportation (Mn/DOT) used three indices to report and quantify the pavement condition, namely, the pavement roughness, the pavement distress, and the OPC. These indices (see Table 6) were used to quantify the present condition of the pavement and predict the future condition, both of which are needed for project planning and programming.

Table 6: Mn/DOT Pavement Condition Indices

Index Name	**Pavement Attribute Measured by Index**	**Rating Scale**
Ride quality index (RQI)	Pavement roughness	0.0–5.0
Surface rating (SR)	Pavement distress	0.0–4.0
Pavement quality index (PQI)	Overall pavement quality	0.0–4.5

Table 7: RQI Categories and Ranges

Numerical Rating	Verbal Rating
4.1–5.0	Very good
3.1–4.0	Good
2.1–3.0	Fair
1.1–2.0	Poor
0.0–1.0	Very poor

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For each index, a higher value means better pavement condition. The PQI is calculated from the ride quality index (RQI) and the surface rating. Equation 4 shows the profile measured by the front lasers on the van.

$$PQI=\sqrt{(RQI) * (SR)}, \quad (4)$$

Where;

PQI pavement quality index;

RQI ride quality index;

SR surface rating.

This international standard simulates RQI by calculating the IRI from the pavement when a standard vehicle travels down the roadway; the RQI is equal to the total anticipated vertical movement of this vehicle accumulated over the section length. The IRI is typically reported in units of inches/mile (i.e., vertical inches of movement per mile travelled). If a pavement were perfectly smooth, the IRI would be zero (i.e., no vertical vehicular movement). To convert IRI to RQI, a correlation needs to be developed. This is done by using a rating panel. A rating panel involves driving people over sections of the pavement and obtaining their opinions as to how good the ride was. The rating panel was last done in 1997; 32 citizens were asked to rate over 120 test sections. The sections included all pavement types and a wide variety of roughness conditions; the sections were 0.25 miles long. Panelists were instructed to disregard the grade, alignment, pavement surface condition, right of way, shoulders, ditch conditions, and all other factors not directly related to the pavement ride. Each rate assigned a numerical value between zero and five to each segment shown in Table 7.

H. RSLI

The concept of remaining service life used by the Colorado Department of Transportation (CDOT) allows them to predict the time in which the pavement condition deteriorates and becomes poor. The CDOT system equates an individual index value of 50 as a failed surface. The age in which the individual index is 50 is the threshold age. The RSLI concept was used to predict the time in which the pavement deteriorates and becomes poor. The road quality indicators were evaluated by IRI, rutting, fatigue cracking, transverse cracking, and longitudinal cracking on a scale of 0 to 100. Colorado has state-wide minimum and maximum distresses to use in this equation and categories of Remaining Service Life (RSL). An RSL greater than 10 years is rated as good, 6–10 years is fair, and less than 6 is rated as poor service life. The road quality indicators evaluated by CDOT are IRI, rutting, fatigue cracking, transverse cracking, and longitudinal cracking.

I. PDI

PDIs are introduced to assess the distress conditions based on the combined geographical characteristics of the cracks. The index formulation is based on two types of information: (a) individual distress ratings along the nominal lengths of the pavements and (b) a set of weighting values associated with the various distress types and severity–extent combinations. The PDI is used as a condition measure in various other analytical methodologies within the PMS of the New York State Thruway Authority. PDIs represent the location, orientation, length, and width of the cracks. PDI is a mathematical expression for the PCR that is keyed to observe the surface distresses in Wisconsin. The PDI number (0 for the best condition and 100 for the worst) is used to summarize the level of distress and is also used primarily for network-level evaluation (in WisDOT’s PDI Survey Manual).

J. CCI

CCI is a function of time and category of the last M&R activity. CCI is computed as the lesser of the load-related and no-load-related distress indices and is defined on a scale of 0 to 100 (with 100 being the best condition). CCI on urban interstates greater than 85 is excellent, 70–89 is good, 60–69 is fair, and 50–59 is poor, and ≤ 49 is very poor. The CCI and IRI indices of the data include downward-

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facing and front-facing images, types of cracking, distress types, and global positioning system coordinates.

4. Rutting Index

Rutting is the depression in the wheel paths in asphalt pavements and is one of the common surface distresses collected by state agencies. The National Cooperative Highway Research Program Synthesis 5 reported that all 55 agencies surveyed had reported collecting the rut depth. The proposed RI uses the rut depths available in the database. Using a similar approach as in the previous indices, a threshold value of 12 mm (anything above this level is considered a safety concern and needs to be addressed) is set to a 0-index value, and the values below 12-mm were scaled down proportionally on a scale of 100.

A. CI

The Iowa DOT collects transverse, longitudinal, longitudinal-wheel path, and alligator cracks in extent (e.g., count, ft/m, and ft2/m2) and severity (e.g., low, moderate, high). Each cracking type is assigned to a computed sub index defined by a specific crack type, then sub-indices are combined into the CI. The sub CIs for the AC pavements (i.e., four sub-indices) were formulated: transverse cracking index, longitudinal cracking index, longitudinal-wheel path (or wheel path) cracking index, and alligator cracking index. The CI is calculated by using the following equation:

CI = S1 + 0.5S0.5 + 0.25S0.25,

where

CI cracking index (i.e., the number of transverse cracks per 100-m length);

S1 number of transverse cracks per roadway width (i.e., per 100-m length);

S1/2 number of transverse cracks per half of the roadway width (i.e., per 100-m length);

S1/4 number of transverse cracks per quarter of a roadway width (per 100-m length). The CI was rated according to the obtained value of the cracking index into the following four groups:

(i) uncracked CIs having index values below 0.2, which corresponded to less than one transverse crack per 500-m roadway length;

(ii) slightly cracked CIs having index values between 0.2 and 1.0, which corresponded to not less than one and not more than five transverse cracks per 500-m roadway length;

(iii) moderately cracked CIs having index values between 1.01 and 5.0, which corresponded to more than five transverse cracks and not more than twenty-five transverse cracks per 500-m roadway length;

(iv) heavily cracked CIs having index values more than 5.01, which corresponds to more than twenty-five transverse cracks per 500-m roadway length. Table 8 shows the values of the cracking indices.

Table 8: Cracking Indices

	Type 4 (AC) interstate	Type 4 (AC) primary
Transverse Cracking (count/km)	300	300
Longitudinal Cracking* (m/km)	500	500
Wheel-path Cracking (m/km)	500	500
Alligator Cracking (m2/km)	360	360

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B. PPI

The method is based on the priority-ranking model. It consisted of assigning relative weights (or deducting points) to various levels of flexible pavement distress types and obtaining a combined condition score that showed the current condition of a roadway. The major advantage of this model was its simplicity and ease of use. The PPI was the sum of the products of the ratings and weightages of each deteriorating parameter. The rating of each pavement-deteriorating parameter could be obtained from the distress survey and a visual inspection of the shoulder-condition drainage characteristics. The weightage needed to be obtained from an expert survey. Equation 5 presents the PPI value. The PPI value was in the range of 0–5. A PPI value of 0 represented bad road performance; 1 represented very poor performance; 3 represented fair performance; and 5 represented very good performance.

$$\text{PPI} = \sum Ri \times Wi, \quad (5)$$

Where; PPI pavement performance index;

Ri rating of each deteriorating parameter;

Wi weightage of each deteriorating parameter.

C. SDI

SDI is particularly important for maintenance engineers because it provides the first visual indication of pavement deterioration. South Dakota Department of Transportation uses the surface condition index which is on a 0–5 scale. The SCI is compiled of multiple indexes. The individual distress indexes for flexible pavements are fatigue cracking and patching, transverse cracking, block cracking, rutting, and roughness. Visual inspection of the individual distress indexes for flexible pavements are alligator cracking index, transverse cracking index, longitudinal cracking index, rutting index and patching/pothole index. The SCI consists of multiple indexes.

D. DMI

DMI is a subjective evaluation of the pavement condition rated by trained and experienced pavement evaluators. DMI is used to support PCI and is favored by regions that have poor quality roads. Equation 6 was used to calculate the DMI index. The DMI model was evaluated by using automated distress evaluation data in Southern Ontario, Canada Tighe, [23]. The randomized block design approach was used for hypothesis testing. A hypothesis test was performed to determine the differences in the DMI model based on automated evaluation data Gautam, [24]. Table 9 shows the performance measures and indicators used in pavement management in Ontario.

$$\text{DMI} = \Sigma niwi\ (si + ei), \quad (6)$$

where

I distress type I;

wi weighting factor assigned to distress I;

si severity of distress I;

ei extent of distress i.

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Table 9: Performance Measures and Indicators Used in Pavement Management

in Southern Ontario, Canada Gautam, [24].

Performance Measure	Performance index	Remark
Assessment of overall pavement condition, structural strength and functional serviceability of both network and individual pavement sections	Pavement condition index (PCI)	PCI is currently used by regions to generate an annual pavement maintenance program and investment planning strategies
Overall pavement surface condition for individual pavement sections and network	Distress manifestation index (DMI)	DMI is used to support PCI and is favored by regions that have lower class roads
Evaluation of pavement riding quality in terms of roughness or smoothness	International roughness index (IRI)	Pavement roughness data is collected by use of high-speed inertial profilers
Evaluation of pavement riding quality in terms of user comfortableness	Riding comfort rating (RCR)	RCR was collected prior to IRI data
Pavement surface skid resistance	Skid number	Measured at project level on a request basis
Transverse profiles and rutting measurement	Rut depth in mm measured in both left and right wheel paths	Rutting is measured at network level using high-speed equipment
Assessment of pavement structural strength or service life	Structural adequacy index or deflection value measured by FWD equipment	Currently used at project level

E. UDI

A network is divided into intersections and sections. The intersection extends to 50 m in all directions, and the remaining segments are divided into sections of 100 m each. The UDI value varies from 0 to 100 as shown in Table 10. The UDI is based on the classification of pavement distresses into categories according to their shapes, their effect on vehicular traffic, their causes, and their rate of development. In addition to measuring the structural capacity of the pavement layer sand that measures the surface roughness, the Saudi Aramco Company uses the performance index based on the effect of some distresses on the pavement performance, such as segregation, alligator cracking, rutting, bleeding, patching, and block cracking. The Royal Authority of Al Jbeil depends on the classification of the pavement distresses and the changes in the pavement surface for evaluating the overall pavement performance by deducting points according to each distress and summing up the distress deduct point. Then, the pavement surface condition is predicted by calculating the pavement distress-based rating. The pavement performance models for estimating the future UDI values in Riyadh depend on four factors: pavement age, traffic volume, surface drainage, and treatment type. Equation 7illustrates the UDI values. Table 11 shows the pavement performance model used in Riyadh Bardeesi, [25].

$$UDI = 100 - 20 * \sum \frac{Tij * Di}{100}, \qquad (7)$$

Where; Tij denotes the deduct points, and Di denotes the distress density.

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Table 10: Pavement Condition Rating in Urban Distress Index Method

UDI	Pavement condition rating
90–100	Excellent
70–89	Good
40–69	Fair
0–39	Poor

Table 11: Future Pavement Performance Estimation Models used in Riyadh Amana

Amana	Maintenance Type	Pavement Performance Models
Riyadh	No Maintenance	$UDI = 80.6 - 0.37age^2$
	Routine	$UDI = 88.6 - 0.2\ age^2 - 5ADT + 6.26DR$
	Overlay	$UDI = 98.8 - 0.107age^2 - 2.15\ ADT + 0.83DR$
	Routine	$PSI = 3.87 - 0.00459age^2 - 0.383ADT + 0.155DR$
	Overlay	$PSI = 3.67 - 0.00134age^2 - 0.161ADT + 0.153DR$

Where; UDI urban distress index;
Age pavement age;
DR surface drainage;
ADT average daily traffic;
PSI present serviceability index.

F. PSC

The PSC is a combined index of the various distresses on the pavement surface, which is computed using both the production rating and the sample rating, which are compared for any statistical differences. The scale ranges from 0 for poor conditions to 100 for no distress. The PSC is also a single value that is used to specify the pavement conditions in terms of the severity and extent of distress. The PSC is calculated differently in rigid and flexible pavements. For flexible pavements, the PSC is calculated by using equation 8. Each distress type is converted into an equivalent cracking number based on its extent and severity. The equivalent cracking is the sum of defects obtained after summing up the defects that have been assigned numerical values. Table 12 shows the PSC rating.

$$PSC = 100 - 15.8EC0.5, \quad (8)$$

Where; PSC is the pavement structural condition.

Table 12: Pavement Condition Rating of Pavement Structural Condition

PSC	Pavement condition rating
75–100	Excellent
50–75	Good
25–50	Fair
0–25	Poor

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G. OPC

The overall pavement index is based on the modified distress rating (MDR). The MDR is also based on the PSI, which is derived from the IRI. This was employed in the PMS implementation for Nigerian Federal Roads. Equations (9 to 11) explain the OPI.

PSI = 5e0.198 − 0.000261(IRI) (9)

MDR = 20(PSI) (10)

OPI = MDR (PSR\5)0.22, (11)

Where; PSI present serviceability index;IRI international roughness index;

MDR modified distress rating.

H. MU

A simplified innovative decision tree system, Maintenance Unit (MU), was developed by Abo-Hashema and Sharaf, [32]. The MU system specifies M&R tasks in terms of the density of distress repair techniques (not the density of individual distresses). Plus, it treats the sophisticated combination between distress standards and maintenance alternatives. Predicting maintenance decisions is also a vital constituent for analysis over years, which is considered a complex procedure. A maintenance decision model (MDM) using the MU system, was developed to predict the future maintenance decisions. Due to the complexity of such a decision system, automated implementation is vital and needed [32]. Table 13 presents the recommended maintenance decision with MU for major highways.

Table 13: Some Current Pavement Indices and Description by Abo-Hashema and Sharaf, [31]

MU	M&R Actions
MU> 20	Reconstruction up to subgrade
15<MU≤ 20	Reconstruction of asphalt layer
12<MU≤ 15	Structure overlay after milling
10<MU≤ 12	Thin overlay after milling
8<MU≤ 10	MST (Multiple surface treatment)
5<MU≤ 8	Slurry seal
3<MU≤ 5	Thin overlay without milling
2<MU≤ 3	Sand seal
MU≤ 2	Surface preparation only (distress by distress)

I. MPCR

Modified pavement condition rating (MPCR) method describes pavement condition value on a scale from 0 to 100 where pavement condition is divided into six states namely: very good, good, fair, fair to poor, poor and very poor. The MPCR index is very easy in calculation and can be directly calculated by simply multiplying the weight of a given distress by its severity and extent to determine the deduct values (DV) as given in Equation (12). Then, the MPCR is computed by subtracting the sum of deduct values from 100 according to Equation (13) as in the traditional PCR method. No corrections or underlying calculations are required as in the PCI method, Ibrahim et al., [31].

$$DV = \text{Distress Weight} \times \text{Extent} \times \text{Severity} \quad (12)$$

$$MPCR = 100 - \sum DV \quad (13)$$

It should be noted that the sum of the modified distress weights is not equal to 100 as for the original weights. This warranted the researcher to add some conditions so that no negative values show up.

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The following two conditions should be applied to make sure that all MPCR values are in the range of 0 to 100: For 100 ≤ DV ≤ 120; the MPCR is 7, and For DV ≥ 120, the MPCR is 0.

The MPCR method presents an objective evaluation of pavement condition. In order to compute the MPCR, the distresses for all sections of roads must be collected by Ibrahim, et al., [33]. The distress types, weight, extent, and severity used in the MPCR method are shown in Table 14.

Table 14: MPCR Distress Weights, Severity, and Extent, Ibrahim et al., [33]

Distresses	Distress Weight	Severity			Extent		
		L	M	H	O	F	E
Ravelling	25	0.3	0.6	1	0.5	0.8	1
Bleeding	40	0.8	0.8	1	0.6	0.9	1
Patching	15	0.3	0.6	1	0.6	0.8	1
Potholes	55	0.4	0.7	1	0.5	0.8	1
Crack Sealing	5	1	1	1	0.5	0.8	1
Rutting	40	0.3	0.7	1	0.6	0.8	1
Settlement	10	0.5	0.7	1	0.5	0.8	1
collapse of roads side slopes	30	0.5	0.7	1	0.5	0.8	1
Corrugations	5	0.4	0.8	1	0.5	0.8	1
Wheel Track Crack	30	0.4	0.7	1	0.5	0.7	1
Block & Transverse Crack	15	0.4	0.7	1	0.5	0.7	1
Longitudinal Joint Crack	5	0.4	0.7	1	0.5	0.7	1
Edge Crack	15	0.4	0.7	1	0.5	0.7	1
Random Crack	5	0.4	0.7	1	0.5	0.7	1
Polished Aggregate	40	1	1	1	0.5	0.8	1
Shoving	25	0.3	0.7	1	0.6	0.8	1

Once the pavement condition is surveyed and the distresses are determined, several indices are currently available to evaluate pavement performance as shown in Table 15 (Hafez [26], Nam et al. [21], Jannat and Tighe[27], Reza et al. [28], Papagiannakis et al. [29], Al-Mansour [30], Smith et al. [31], Abo-Hashema and Sharaf, [32] and Ibrahim et al., [33]). After selecting one or more index, pavement performance can then be evaluated. Pavement performance shows the highway deterioration and thus allows the proper selection of the suitable maintenance alternatives according to the available budget to reserve the highway network.

Table 15: Comparison between indices

Index	Scale\Scale Description	Remarks	Reference
Pavement Condition Index (PCI)	(0-100) (Failed to Good)	Function of 19 different distresses such as rutting, cracks, bleeding, potholes, etc.	[11]
International Roughness Index (IRI)	(0.95-3.6) m\km Acceptable (0-2.7) m\km, Less than acceptable (>2.7) m/km	Function of ride quality.	[26,31]
Present Serviceability Index (PSI)	(0-5), (poor to excellent),	Function of smoothness, rutting, cracking and patching	[26]
Pavement Condition Rating (PCR)	(0-100) (Very Poor to Very Good)	Function of 13 different distresses such as rutting, cracks, bleeding, potholes, etc.	[20]

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Structural Condition Index (SCI)	(0-100) (Worse – best)	Function of FWD data	[21]
Riding Comfort Index (RCI)	(0-10), (V. poor – V. Good)	Function of ride quality	[27]
Pavement Quality Index (PQI)	(0-100), Poor, Fair, Good, Excellent	Function of ride quality index (RQI), IRI and surface rating (SR)	[26]
Remaining Service Life Index (RSI)	(0-100), (Good-Fair –Poor)	Role of IRI, rutting, fatigue cracking, transverse cracking, &longitudinal cracking.	[29]
Pavement Distress Index (PDI)	(0-100) (V. poor – V. Good)	According to the geographical properties of every crack	[26]
Critical Condition Index (CCI)	(0-100) (V. poor – excellent)	Function of pavement age	[29]
Rutting Index (RI)	(0-5) (Acceptable – Unacceptable)	Function of rut depth	[26,31]
Crack Index (CI)	(0.2-5.1) Uncracked, slightly & moderately cracked	Function of transverse, longitudinal, longitudinal-wheel-path and alligator cracks	[29]
Pavement Performance Index (PPI)	(0-5) (V. poor – V. Good)	Function of levels of flexible pavement distress types	[29]
Surface Distresses Index (SDI)	(0-5) (good-poor)	Function of Fatigue cracking, patching, transverse cracking, block cracking, rutting, and IRI.	[29]
Distresses Manifestation Index (DMI)	(0-10) (poor – excellent),	consolidate PCI at poor class roads, DMI is employed to support PCI and is preferred by poor roads areas	[27,31]
Urban Distresses Index (UDI)	(0-100) (poor – excellent),	Function of discrimination, alligator cracking, rutting, bleeding, patching, and block cracking	[30]
Pavement Structural Condition (PSC)	(0-100) (poor – excellent),	Combined index of the various distresses on the pavement surface	[26]
Overall Pavement Condition (OPC)	(0-100) (poor – excellent),	In terms of the PSI which actually is deduced from the IRI.	[29]
Maintenance Unit (MU)	$2 \leq MU \leq 20$	Specifies M&R tasks in terms of the density of distress repair techniques.	[32]
Modified Pavement Condition Rating (MPCR)	(0-100) (Very Poor to Very Good)	Function of 19 different distresses such as rutting, cracks, bleeding, collapse of road side slopes, etc.	[33]

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5. Conclusion

Conclusion should be written in this style and it is highly recommended to add future work direction for your research.

This study investigated the comparison between flexible pavement indices. These indices are very important to evaluate the pavement condition. The pavement condition is one of the most important factor that used to select the best maintenance alternatives as a part of PMS. From this comparison, the author can select the simplest, easiest and most accurate index that cover all distresses that finding in roads. The following conclusions can be presented from the results of the current study

- The PCI method based on visual examination of the pavement distress type, extent and severity. Egyptian Code of Practice for Urban and Rural Roads (ECP-2008) included PCI to evaluate the pavement conditions.
- The IRI constituted the smoothness, safety, and the ease of the driving path and it described the suspension motion of a moving vehicle over a travelled distance, usually in meters per kilometer or inches per mile.
- The PSI based on the values of pavement smoothness, rutting cracking and patching. References.
- The PCR based upon the summation of deduct points for each type of observable distress. Deduct values are a function of distress type, severity, and extent. And this index cover all distresses comparing with PCI but PCR is simpler and easier at calculations.
- The (SCI) was developed as a screening tool for the pavement network-level evaluation, and the FWD data are used to determine the SCI.
- RCI is primarily a function of pavement unevenness.
- The RSI Concept allow to predict the time in which the pavement deteriorates into a poor condition.
- The (PDI) are introduced to assess the distress conditions based on the geographical characteristics of each crack in combination.
- The CCI is computed as the lesser of the load-related and non-load related distress indices.
- The (MPCR) method presents an objective evaluation of pavement condition. In order to compute the MPCR, the distresses for all sections of roads must be collected.

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