Journal of Engineering and Sustainable Development
Vol. 29, No. 02, March 2025
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
ISSN 2520-0917
Research Article
https://doi.org/10.31272/jeasd.2544

Leveraging Maintenance Management Techniques to Evaluate Pavement Condition Index: Central Iraq Highway System

Ahmed Aljubory[1], Teba Tariq Khaled[2], Ali Jabbar Kadhim[3], Mohd Fazaulnizam Shamsudin[4], Andrew Minto[5], Rwayda Kh. S. Al-Hamd[6*]

[1]Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq
[2]Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq, and Department of Civil Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia.
[3]Department of Civil Engineering, College of Engineering, Ashur University, Baghdad, Iraq
[4]Department of Civil Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia
[5,6]Department of Built Environment and Life Sciences, Faculty of Social and Applied Sciences, Abertay University, Dundee DD1 1HQ, UK

*Email: r.al-hamd@abertay.ac.uk

Article Info

Received	**04/04/2024**
Revised	**28/11/2024**
Accepted	**17/12/2024**

Abstract

The objective of this paper is to evaluate the maintenance strategies applied to the Latifiya-Musayib highway section to improve the pavement condition that significantly deteriorated due to military operations during and after the third Gulf War. The functional evaluation measured the Pavement Condition Index (PCI) every five years. The measurement relied on a visual survey of the pavement surface by examining different types of distress that varied in severity. PCI values measured from 2005 to 2015 indicated that the pavement surface could be considered satisfactory according to standard and custom PCI rating scales, while results measured in 2020 indicated that PCI values had declined to a critical stage requiring maintenance. PCI was 63% for the Latifiya-Musayib direction and 65.5% for the opposite direction. Therefore, preventive maintenance was carried out to stop this decline, which improved PCI values by 18.5% and 19.4%, respectively. The pavement performance curve created to evaluate the effectiveness of preventive maintenance showed that the pavement life would be extended by 4 years in the Latifiya-Musayib direction and 9 years in the opposite direction. Finally, measuring the PCI at the end of the assumed pavement's design life is recommended to make the best decision.

Keywords: Pavement Condition Index, Pavement Distress, Pavement Maintenance, Pavement Management System, Pavement Performance Curve

1. Introduction

Asphalt pavement is the most important part of transportation. It consists of several layers, and its materials are carefully selected and designed to gradually distribute traffic loading from the pavement surface to underneath the surface layer [1]. The surface layer is the major part of road infrastructures, which experience different traffic loading and weather conditions. These conditions may lead to several types of distress that negatively affect comfortable and safe driving. Therefore, the pavement surface needs maintenance and rehabilitation to provide long-term sustainable service for users [2], [3]. Any delay in the maintenance of pavement distresses is considered one of the main factors contributing to the fast deterioration of pavements. It also reduces the confidence level in transportation systems to deliver efficient pavement performance [4], [5]. Reports also indicated that deteriorating pavement conditions lead to increased user costs, including repair, maintenance, fuel consumption, depreciation, and tire costs [6]. Therefore, the maintenance of paved roads is vital for the smooth transportation of people and freight. The PCI may be useful in scheduling and implementing appropriate pavement maintenance if it is correctly and accurately calculated to evaluate pavement conditions. This indicator is the core component of the pavement management system (PMS). The use of indicators, such as the Pavement Condition Index (PCI), Present Serviceability Rating (PSR), International Roughness Index (IRI), and others, have been commonly used in the existing pavement maintenance strategies [7]. PMS is also considered a program that monitors the existing information on pavement conditions and future performance [8].

1.1 Pavement Management System (PMS)

PMS is an effective tool for efficiently managing the road maintenance system. It is a suitable technique to investigate existing pavement conditions and predict future conditions [9]. It is also used to perform and analyze the most beneficial maintenance strategies to choose which type must be applied to determine the type of failure in flexible pavements as functional or structural [10]. The five major categories of common asphalt pavement surface distresses are:

1. Cracking (alligator or fatigue cracking, longitudinal and transverse cracking, block cracking, slippage cracking, joint reflective cracking, and edge cracking).
2. Surface deformation (rutting, corrugations, shoving, depressions, swell, bumps, and sags).
3. Disintegration (potholes, patching, and utility cut patching).
4. Surface effects (weathering and raveling, bleeding, and polishing).
5. Others (lane/shoulder drop off and railroad crossing).

Table 1 shows the distress of flexible pavement roads and parking [11]. PMS also involves information about the pavement condition, its situation, and the extent of its need for maintenance. Moreover, it becomes easier to determine the priority for the type and maintenance method that can be applied to the pavement based on the road network data [3]. Maintenance management systems are of two main types. The first is a data system designed to collect, organize, and store the data as network information. The second type is decision-support systems. This type comprises applications to process the data and provide the required information to help make and implement a decision [12], [13]. Most formal definitions of a pavement management system agree on the five basic components described below. These components outline the plan's overall framework: Inventory definition, pavement inspection, Condition assessment, Condition prediction, and Condition analysis [14].

Table 1. Classification Distress for Asphalt Roads and Parking Lots.

No.	Types of Distress	Measure Unit	Type of Distress	Cause
1	Alligator Cracking	m^2	Structural	Load
2	Bleeding	m^2	Functional	Other
3	Block Cracking	m^2	Structural	Climate
4	Bumps And Sags	m	Structural and Functional	Other
5	Corrugation	m^2	Functional	Other
6	Depression	m^2	Functional	Other
7	Edge Cracking	m	Functional	Load
8	Joint Reflection	m	Structural	Climate
9	Lane/Shoulder Drop-Off	m	Functional	Other
10	Longitudinal Cracking	m	Structural	Climate
11	Transverse Cracking	m	Structural	Climate
12	Patching and Utility Cut Patching	m^2	Structural and Functional	Other
13	Polished Aggregate	m^2	Functional	Other
14	Potholes	Number	Structural and Functional	Load
15	Railroad Crossings	m^2	Functional	Other
16	Rutting	m^2	Functional	Load
17	Shoving	m^2	Functional	Load
18	Slippage Cracking	m^2	Structural	Other
19	Swell	m^2	Structural and Functional	Other
20	Weathering	m^2	Functional	Climate
21	Raveling	m^2	Functional	Climate

1.2 Pavement Condition Index (PCI)

The assessment of pavement surface distress can be limited if the field evaluation is conducted at the time of assessment. Therefore, the PCI is considered a simple and promising tool for evaluating the pavement surface condition. It is used to measure the condition rating of pavements based on a numerical scale. PCI scale ranges from (0 to 100) as shown in Table 2. The (0) indicates that the level of service of assessed pavements reaches failure, while the (100) indicates that the level of service is excellent [15]. Many agencies and authors use the PCI as an assessment indicator in implementing the PMS to determine maintenance and rehabilitation costs. The US Army Corps of Engineers developed the PCI, which was adopted by the American Public Works Association and the American Society for Testing and Materials [11], [16]. The assessment of PCI depends on the result of a visual survey, which is defined as a method of inspection of pavement surface distress [17], [18]. Therefore, PCI can measure the level of pavement surface service and pavement structural integrity by assessing the overall conditions of the pavement surface. This can help a decision-maker to evaluate and predict the existing and future conditions of the road to find an index for the integrity of pavement layers and the serviceability of its surface [18].

Table 2. Pavement Condition Index (PCI) Rating Scales.

Standard Rating PCI Scale	PCI value	Custom Rating PCI Scale	PCI value
Good	85-100	Adequate	70-100
Satisfactory	70-84		
Fair	55-69	Degraded	55-69
Poor	40-54	Unsatisfactory	0-54
Very Poor	25-39		
Serious	10-24		
Failed	0-9		

1.3 Problem Statement

It is well known that the quality of service provided by an effective road system can improve the quality of life and the growth of businesses and the economy. The decline of these road services may be due to overuse, aging, and improper management. Therefore, the maintenance and protection of such roads after evaluating the condition of pavement layers and assessing the manifestation of distress can take great national notice [19]. According to local design considerations, flexible, rigid, and composite pavements are typically used in major road construction. However, project budget, road function, and importance are the main factors in selecting the appropriate pavement type [20]. Most of these highways were constructed long ago; many have been severely damaged due to traffic loads and weather conditions and need proper maintenance. Highway maintenance in Iraq remains one of the major challenges of pavement management systems because maintenance is usually only carried out when it is urgent. Steps in this area are still limited. For example, implementing a preventive maintenance program is beneficial for highways because it can maximize the performance of the structural section by postponing the need for more expensive rehabilitation and reconstruction. However, preventive maintenance has not been widely implemented in Iraq and is not applied to most highways. Therefore, other maintenance methods are resorted to when the pavement condition surface may have deteriorated to below the acceptable level. Highways in Iraq also require effective management plans and systems; therefore, interest has increased recently in considering road maintenance topics and developing this aspect to achieve long-term sustainability and maintain the infrastructure of the transportation sector. This topic was selected because of the lack of information on the effectiveness of pavement maintenance practices on high-volume roads in Iraq.

1.4 Objectives

This work evaluates the benefit and efficiency of the various maintenance works that were carried out on the section of the highway linking Latifiya to Musayib via Alexandria (part of Routes 8 and 9), which is described in the next section, to improve the condition of the flexible pavement that was severely damaged due to military operations. The PCI was used for functional evaluation, and a pavement performance curve was generated to determine the effect of maintenance on pavement life. Functional assessment was conducted by calculating PCI over a 15-year since the beginning of the renewable service period in 2005 as defined by the Iraqi State Corporation for Roads and Bridges (SCRB). A site survey was performed to collect data to calculate the PCI by determining the types of distress on the pavement surface and their severity. PCI was measured by the SCRB until 2015, and then the authors of this work measured PCI in late 2020 due to the implications of COVID-19. Fig. 1 shows the proposed work plan.

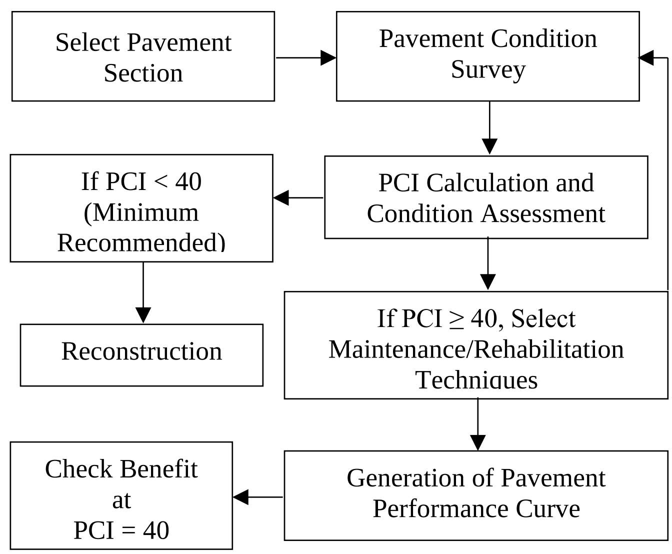


Figure 1. Proposed Work Plan.

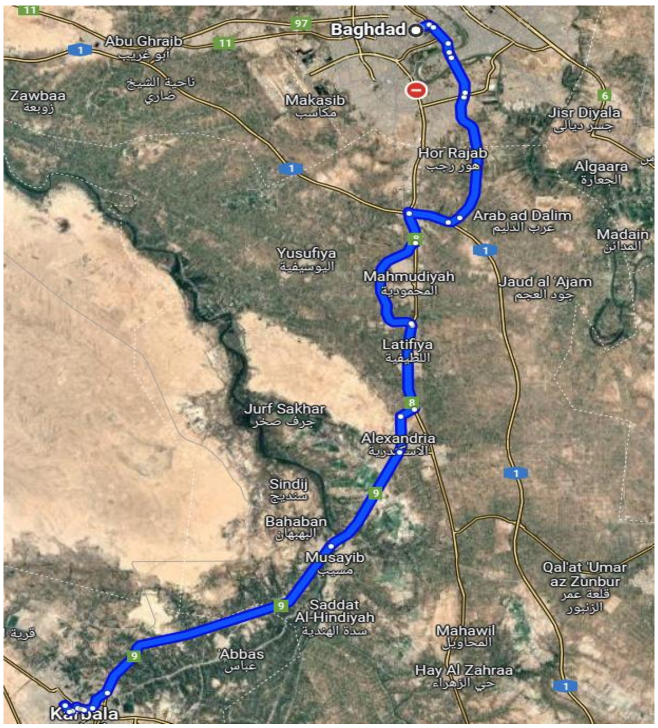
2. Description of Case Study

One of the most important highways in Iraq is the link between the capital, Baghdad, and Karbala Governorate, as shown in Fig. 2-A. It has tourist importance. This highway was constructed in 1980 for a design period of 20 years. It was also reconstructed in 2000, but some parts of this road were damaged during and after the Third Gulf War in 2003. In particular, the section extends from Latifiya (one of the towns administratively affiliated with Mahmoudiyah District, south of Baghdad) to the city of Musayib (one of the most important cities of the Middle Euphrates in Babylon Governorate) ,as shown in Fig. 2-B. This section of road has been classified by the SCRB as having suffered significant damage as a result of military operations, resulting in several accidents, some of which were fatal. The road is part of Baghdad Road/Routes 8 and 9, as rated by SCRB. Its length is 29.6 km. It was chosen as a case study for this work due to its importance. By surveying the pavement condition, different types of distresses, such as ruts, potholes, raveling, and several kinds of pavement cracking, were observed on the selected road surface. These distresses may cause a more significant deterioration if left without proper maintenance. Accordingly, in 2005, due to damage caused by military operations, the SCRB decided to carry out immediate and urgent maintenance on the Latifiya-Musayib highway as follows:

- Reconstruction of the damaged section between Latifiya and Alexandria is approximately 12 kilometers long and marked with the red ring in Fig. 2-C. This section also represents part of the road linking Latifiya to Jurf al-Sakhar (about 60 km southwest of Baghdad and 13 km north of Musayib).

As for the rest of the highway section linking Latifiya to Musayib, the following treatment was taken into account:

- Due to the overload of military trucks, pavements with considerable ruts (deeper than 1/3 inch) were treated. The ruts were leveled and overlaid.
- Patching was applied to potholes of varying severity that were seriously affected by the explosions.
- Sealing was applied to low and moderate cracks to prevent water intrusion into the lower pavement layers.



(a)

(b)

(c)

Figure. 2 Aerial View of the Horizontal Path in the Case Study.

In 2010, hole patching and crack sealing treatment was carried out as part of preventive maintenance. However, it was conducted on a limited basis mainly due to the limited budget and the highest PCI values before maintenance, as shown in Table 3. Therefore, most of the financial provision was spent repairing the damage to the roadsides, medians, guardrails, traffic signs and markings, and lighting. In addition 2015, maintenance was also limited to patching and sealing cracks due to the limited budget and the repercussions of the war against ISIS. Finally, the commencement of pavement degradation explored the importance of managing new maintenance to improve pavement condition in the last five years of the service life as the PCI dropped below 70. Therefore, an intensive preventative maintenance program was also undertaken in late 2020, including using thin surfacing to renew the pavement surfaces and edges for some sections. Deep ruts were also addressed, moisture-damaged holes were patched, and cracks were sealed for other sections.

3. Methodology

Since 2005, the PCI has improved due to maintenance to its initial value of 100%. Therefore, SCRB planned to conduct regular maintenance and measure the PCI every five years. The values of PCI can be divided into two groups. The first one was calculated and provided by the SCRB (between 2005 and 2015), and the second one was determined in this work. The details of the first one are presented in Table 3, while the second one was calculated using the details in the following sections. The following steps explain how the SCRB has determined PCI values:

- The SCRB has measured the PCI values every five years between 2005 and 2015 to maintain the PCI at an acceptable level. During this period, preventive maintenance was carried out. However, the first maintenance performed in 2010 did not affect the PCI values, as no change was observed. The PCI values before and after maintenance were the same. It was 95% for the Latifiya-Musayib direction and 93% for the opposite direction, as shown in Table 3. According to the SCRB, the limited budget and satisfactory PCI values have resulted in limited maintenance strategies.
- In 2015, maintenance was performed to improve the PCI, which increased from 85 and 88 before maintenance to 93.4 and 91.5 after maintenance, as shown in Table 3.

The authors of this work measured the PCI in the last quarter of 2020 due to the repercussions of the Coronavirus. SCRB allocated a budget for maintenance to improve PCI to reach 85% and 88% after maintenance for both directions, respectively, as a target for this phase. The calculation of the PCI 15 years after the commencement of service life in 2005 was performed in this investigation using the manual method described in the next section. The random sampling method was systematically applied to calculate the PCI and assess the pavement condition by conducting visual observation to identify the types of distress and classify their severity. In addition, the following section explains the calculations that have been applied to measure the PCI after 15 years before and after maintenance.

3.1 Calculations of PCI

After selecting the pavement section to be assessed, pavement condition surveys are probably considered the first PMS element to be implemented, as stated by many airport and highway agencies. Most of these agencies carry out periodic surface condition surveys to measure and assess different types of distress [21]. Automatic and manual techniques are commonly used to survey pavement conditions [22], [23]. In this work, the surface distress survey was manually conducted to measure and classify different types, densities, and severity of distress. It was performed by walking along the pavement section and from a moving vehicle. This survey was applied to the pavement section by the PAVER survey method and the method described in the standard practice for roads and parking lots pavement condition index surveys [11], [17]. The following steps must precede the visual survey:

1. Classify the investigated pavement of the Latifiya-Musayib highway into sections and measure the geometric data for each one in both directions. It consists of three lanes per direction, 5000 m long and 3.7 m wide.
2. Each section was divided into inspection units termed sample units [24]. Equation (1) was applied to geometric data measured in step 1 to determine the total area of the section per each direction as follows:

$$\text{The total area of section} = \text{length of road} * \text{width of road} * \text{number of lane} \quad (1)$$

$$\text{Total area of section} = 5000 * 3.7 * 3.0 = 55500\text{m}^2$$

3. The calculated area of the section was divided into two sections, and all sections were subdivided into sample units of 225 ± 90 m² based on the type of pavement [24].
4. Equation (2) was used to calculate the total number of sample units:

$$\text{N} = \frac{\text{Total area of section}}{\text{area of sample units}} \quad (2)$$

$$\text{N} = \frac{555000}{225} = 245$$

5. Determine the minimum number of sample units in the section area to perform the visual survey using equation (3) as follows:

$$\text{n} = \frac{\text{NS}^2}{((\frac{\text{e}^2}{4} * (\text{N}-1)) + \text{S}^2)} \quad (3)$$

$$\text{n} = \frac{245 * 10^2}{((\frac{5^2}{4} * (245 - 1)) + 10^2)} = 15$$

Where:

n = minimum number of sample units,

N= total number of sample units in the pavement section,

e = allowable error of calculations = 5% [24],

S= standard deviation of the PCI, S= 10 based on the type of pavement [24].

Find the sampling interval (i) by using equation (4):

$$i = \frac{\text{N}}{\text{n}} \quad (4)$$

$$i = \frac{245}{15} = 16$$

6. Calculate the random start (s) as the difference between the minimum number of sample units (n) and sampling interval (i).
7. Table 4 presents the key parameters of this work described in previous steps. Table 5 shows that the number of sample units is less than the total number of sample units of pavement under consideration, which means all the section areas have been covered.

Finally, several visible and measurable distress types on the assessed pavement surface were surveyed and classified. The severity of distress was rated, as shown in Table 6, according to the method described by ASTM D 6433-09 [17] to find the PCI of the Latifiya-Musayib highway.

Table 3. Values of PCI Measured by the SCRB for Latifiya-Musayib Highway Section.

Year	Age of Highway	PCI Values			
		Latifiya-Musayib Direction		Musayib - Latifiya Direction	
		Before Maintenance	After Maintenance	Before Maintenance	After Maintenance
2005	0	100 (New Pavement)	-	100 (New Pavement)	-
2010	5	95	95*	93	93*
2015	10	85	93.4	88	91.5

* Note that no change was observed in PCI values due to the maintenance work, according to data provided by the SCRB.

Table 4. Basic Parameter.

Systematic Random	Sampling Parameter
Total Number of Sample Units (N)	245
Minimum Number of Sample Units (n)	15
Sampling Interval (i)	16
Random Start (s)	1

Table 5. Sample Unit Visual Survey.

Min. No. of a Sample (n)	Sample Unit Survey	Sample Unit No.
1	s	1
2	s+i	17
3	s+2i	33
4	s+3i	49
5	s+4i	65
6	s+5i	81
7	s+6i	97
8	s+7i	113
9	s+8i	129
10	s+9i	145
11	s+10i	161
12	s+11i	177
13	s+12i	193
14	s+13i	209
15	s+14i	225
16	s+15i	241

Table 6. Visual Survey on the Highway Section.

Code	Types of Distress	Units	Severity	
			Latifiya-Musayib Direction	Musayib-Latifiya Direction
1	Rutting	m^2	Low	Medium
2	Alligator Cracking	m^2	Low	Medium
3	Block Cracking	m^2	Low	Low
4	Longitudinal Cracking	m	Medium	Medium
5	Transverse Cracking	m	Medium	Medium
6	Edge Cracking	m	Low	Low
7	Raveling	m^2	Medium	Medium
8	Pothole	N	Medium	Low

4. Results and Discussions

The following steps explain the calculation of PCI. It was manually determined after accomplishing the previous steps of the last part. The distress density was calculated by equation (5) as follows:

$$\text{Density} = \frac{\text{Quantity of Distress Type in m}^2}{\text{Total Area of Sample Unit in m}^2} \times 100 \quad (5)$$

1. Define the deduct value (DV) for each distress kind.
2. Calculate the total deduct value (TDV) as the summation of all deductive values.
3. Adjust the total deduct value to be the corrected deduct value (CDV).
4. Equation (6) was used to calculate the PCI for each inspected sample unit:

$$\text{PCI} = 100 - \text{CDV} \quad (6)$$

5. Equation (7) was applied to find the pavement condition index for all sample units as follows:

$$\text{PCI}_r = \frac{\Sigma \text{PCI}_{ri} * \text{A}_{ri}}{\Sigma \text{A}_{ri}} \quad (7)$$

$$\text{PCI}_r = \frac{212760}{3375} = 63.04$$

For Latifiya-Musayib direction before maintenance.

$$\text{PCI}_r = \frac{221017.5}{3375} = 65.5$$

For Musayib-Latifiya direction before maintenance.

$$\text{PCI}_r = \frac{275220}{3375} = 81.5$$

For Latifiya-Musayib direction after maintenance.

$$\text{PCI}_r = \frac{286425}{3375} = 84.9$$

For Musayib-Latifiya**,** direction after maintenance.

6. Equation (8) was used to find the pavement condition index for the additional sample, PCI_a, using a minimum number of samples equal to 5:

$$\text{PCI}_a = \frac{\text{PCI}_a * \text{A}_a}{\text{A}_a} \quad (8)$$

$$\text{PCI}_a = \frac{13590}{225} = 60.4$$

For Latifiya-Musayib, the direction before maintenance is as follows (See Table 7).

$$\text{PCI}_a = \frac{14062.5}{225} = 62.5$$

For Musayib-Latifiya direction before maintenance (See Table 8).

$$\text{PCI}_a = \frac{18472.5}{225} = 82.1$$

For Latifiya-Musayib direction after maintenance (See Table 7).

$$\text{PCI}_a = \frac{17820}{225} = 79.2$$

Musayib-Latifiya**'s** direction after maintenance is as follows (See Table 8).

7. Finally, the pavement condition index for all road sections was calculated using equation (9):

$$\text{PCIs} = \frac{\text{PCI}_r(\text{A} - \Sigma \text{A}_{ai}) + \text{PCI}_a(\Sigma \text{A}_{ai})}{\text{A}} \quad (9)$$

$$\text{PCIs} = \frac{63.04(55500-225)+(60.4*225)}{55500} = 63.03$$

For Latifiya-Musayib direction before maintenance.

$$\text{PCIs} = \frac{65.5(55500-225)+(62.5*225)}{55500} = 65.5$$

For Musayib-Latifiya direction before maintenance.

$$\text{PCIs} = \frac{81.5(55500-225)+(82.1*225)}{55500} = 81.5$$

For Latifiya-Musayib direction after maintenance.

$$\text{PCIs} = \frac{84.9(55500-225)+(79.2*225)}{55500} = 84.9$$

For Musayib-Latifiya**,** direction after maintenance.

Results obtained from the calculation of PCI for both directions of the highway are presented in Fig. 3. It shows that the PCI value before maintenance for both directions was in the range of 55-70. It was 63 for the Latifiya-Musayib direction and 65.5 for the opposite direction, decreasing from 93.4 and 91.5, respectively. These results indicate that the condition of the pavement surface can be classified as a fair condition compared to the standard and custom PCI classification scales shown in Table 9. Therefore, the pavement surface condition can be accepted in both directions. However, it was observed that the decrease in PCI gives the impression that the pavement performance has fallen to a critical stage (beginning of degraded performance). According to these data, maintenance was scheduled for this highway to improve PCI values up to targets of 85% and 88% for both directions. The results also indicate that the condition of the pavement surface in both directions improved to the appropriate level due to maintenance, which led to PCI values rising from 63 and 65.5 to 81.5 and 84.9, respectively, as shown in Fig. 3. However, the PCI values are still slightly below the target level. The reason for not accurately achieving the objectives set by the SCRB may be due to failure to identify the appropriate pavement section that would benefit most from preventive maintenance or not choosing the proper timing to perform preventive maintenance, which is very important. Accordingly, the PCI rating values obtained in this work of 81.5 and 84.9 falls within the ranges (70-85) and (70-100) defined by the standard and custom PCI rating scales, as shown in Table 9. Therefore, the pavement condition in both directions is satisfactory. That means the maintenance improved the pavement surface from fair condition to satisfactory condition.

To clarify the implications of the results, the pavement performance curve shown in Figs. 4 and 5 was created to show the effect of preventive maintenance on extending pavement life. The benefit from the maintenance work carried out on the highway section was calculated using this curve from the difference between the age of the pavement at which the PCI value equals 40 (minimum recommended condition) before and after maintenance [23], [25]. The estimated pavement life at which the PCI equals 40 was calculated using equations presented in Table 10. These equations were based on the PCI values calculated in this work and those provided by the SCRB. Figs. 4 and 5 indicate that pavement in both directions is expected to reach poor condition (PCI = 40) at 19 and 20 years if left unmaintained.

In contrast, it is expected to reach the same PCI values at 23 and 29 years, respectively, due to maintenance. This means there is an expected increase in the pavement life of 4 and 9 years in both directions, respectively, which can be achieved due to maintenance work. These results reflect the importance of systematic and continuous road maintenance strategies to increase the useful life of these roads and manage national resources effectively.

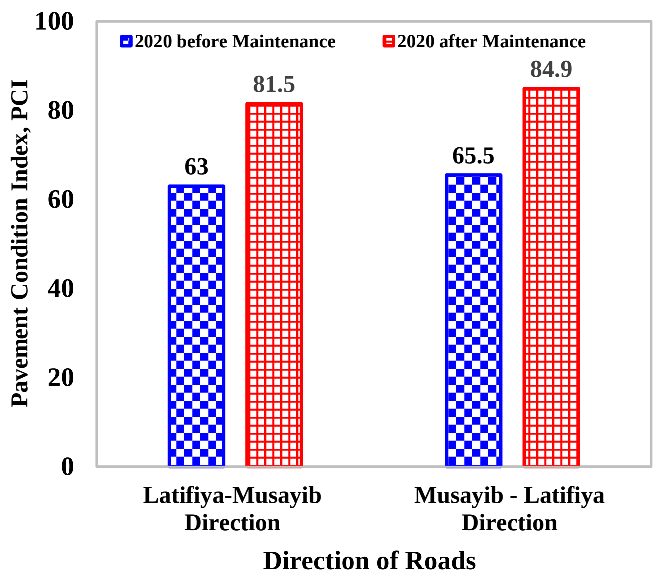


Figure 3. PCI Values for Latifiya-Musayib Highway.

Table 7. PCI Values of Latifiya-Musayib Direction.

Min. No. of Sample (n)	Sample Unit No.	Before Maintenance			After Maintenance		
		PCI	Area(m²)	PCI*Area	PCI	Area(m²)	PCI*Area
1	1	60.1	225	13522.5	83.2	225	18720
2	17	62.3	225	14017.5	83.5	225	18787.5
3	33	65.2	225	14670	81.1	225	18247.5
4	49	61.3	225	13792.5	82.3	225	18517.5
6	81	66.1	225	14872.5	82.5	225	18562.5
7	97	64.4	225	14490	85.1	225	19147.5
8	113	66.2	225	14895	80.1	225	18022.5
9	129	59.8	225	13455	82.2	225	18495
10	145	67.1	225	15097.5	82.9	225	18652.5
11	161	64.1	225	14422.5	81.7	225	18382.5
12	177	60.7	225	13657.5	82.1	225	18472.5
13	193	60.5	225	13612.5	81.8	225	18405
14	209	60.2	225	13545	79.3	225	17842.5
15	225	63.1	225	14197.5	77.3	225	17392.5
16	241	64.5	225	14512.5	78.1	225	17572.5
Sum.		**1871**	**3375**	**212760**	**1223.2**	**3375**	**275220**
Addition Sample (5)	**65**	**60.4**	**225**	**13590**	**82.1**	**225**	**18472.5**

Table 8. PCI Values of Musayib-Latifiya Direction.

Min. No. of Sample (n)	Sample Unit No.	Before Maintenance			After Maintenance		
		PCI	Area (m²)	PCI*Area	PCI	Area (m²)	PCI*Area
1	1	65.3	225	14692.5	85	225	19125
2	17	64.2	225	14445	83.4	225	18765
3	33	62.8	225	14130	88.2	225	19845
4	49	67.3	225	15142.5	79.3	225	17842.5
6	81	65.1	225	14647.5	77.4	225	17415
7	97	69.5	225	15637.5	80.2	225	18045
8	113	65.8	225	14805	85.3	225	19192.5
9	129	66.4	225	14940	87.3	225	19642.5
10	145	68.1	225	15322.5	88.9	225	20002.5
11	161	62.2	225	13995	84.2	225	18945
12	177	62.7	225	14107.5	87.4	225	19665
13	193	68.1	225	15322.5	82.5	225	18562.5
14	209	65.5	225	14737.5	88.3	225	19867.5
15	225	65.2	225	14670	86.4	225	19440
16	241	64.1	225	14422.5	89.2	225	20070
Sum.		**982.3**	**3375**	**221017.5**	**1273**	**3375**	**286425**
Addition Sample 5	65	62.5	225	14062.5	79.2	225	17820

Table 9. PCI Results vs. PCI Scales.

Condition	Good	Satisfactory	Fair	Poor	Very poor	Serious	Failed
Standard scale	100-85	84-70	69-55	54-40	39-25	24-10	<10
Custom scale		100-70	69-55	54-0			
PCI for Latifiya-Musayib		81.5 after maintenance	63 before maintenance				
PCI for Musayib-Latifiya		84.9 after maintenance	65.5 before maintenance				

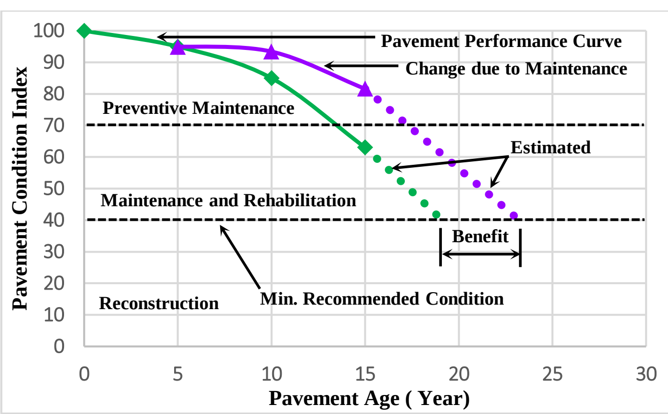


Figure 4. Pavement Performance Curve for Latifiya-Musayib Direction.

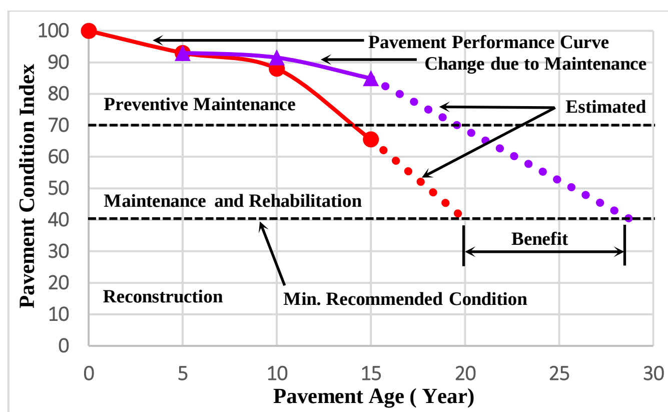


Figure 5. Pavement Performance Curve for Musayib-Latifiya Direction.

Table 10. Equations Describe the Relationship Between PCI and Pavement Age.

Highway Direction	**Equations**
Latifiya-Musayib Direction	
Before maintenance	$PCI = -0.17X^2 + 0.13X + 99.65$
After maintenance	$PCI = -0.204X^2 + 2.74X + 86.4$
Musayib-Latifiya Direction	
Before maintenance	$PCI = -0.155X^2 + 0.155X + 99.025$
After maintenance	$PCI = -0.102X^2 + 1.23X + 89.4$

5. Conclusions

According to the findings of this paper, the main conclusions that can be drawn are as follows: The progression of distresses of varying severity and types without proper maintenance management may lead to a significant deterioration in the pavement condition. The decline in PCI values gave the impression that the pavement condition had dropped to a critical stage if left unmaintained. It was found that the PCI values measured in 2015 decreased in 2020 from 93.4 to 63 for the Latifiya-Musayib direction and 91.5 to 65.5 for the opposite direction. This necessitated maintenance work in late 2020, which improved the condition of the pavement surface in both directions to an adequate level, resulting in PCI values increasing from 63 and 65.5 to 81.5 and 84.9, respectively. However, the increase was less than the desired target. It was also concluded that there is an opportunity to extend the life of the pavement because of the maintenance work carried out in 2020. The pavement life is expected to extend by 4 and 9 years to reach the recommended minimum condition (PCI = 40). If left unmaintained at this stage, it would be expected to reach the same condition (PCI = 40) at 19 and 20 years. Therefore, measuring PCI at the end of the assumed pavement design life in 2025 is recommended to compare results and make the best decision for the next step.

Acknowledgment

The authors are thankful to Mustansiriyah University (https://www.uomustansiriyah.edu.iq) and the State Corporation for Roads and Bridges (SCRB) for their help and cooperation in completing this work.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Ahmed Aljubory and Rwayda Kh. S. Al-Hamd: Finding the problem statement, analyzing and interpreting the results.

Teba Tariq Khaled and Ali Jabbar Kadhim: Collected data and site visits and described the methodology.

Mohd Fazaulnizam Shamsudin and Andrew Minto: Verified the analytical methods and evaluated the results.

All authors reviewed the results and approved the final version of the manuscript.

References

[1]. F. L. Mannering, and S. S. Washburn, "Pavement Design," in *Principles of Highway Engineering and Traffic Analysis*, 5th ed. New Jersey, USA: John Wiley and Sons, 2013, Ch. 4, sec. 4.2, pp: 97-99. https://www.wiley.com/enie/Principles+of+Highway+Engineering+and+Traffic+Analysis%2C+5th+Edition+SI+Version-p-9781118471432

[2]. Y. Deng, Y. Zhang, X. Shi, S. Hou, and R. Lytton, "Stress-strain dependent rutting prediction models for multi-layer structures of asphalt mixtures," *International Journal of Pavement Engineering*, vol. 23, no. 8, pp. 2728- 2745, Jan. 2021, doi: https://doi.org/10.1080/10298436.2020.1869974

[3]. A. Shtayat, S. Moridpour, B. Best, and S. Rumi, "An overview of pavement degradation prediction models," *Journal of Advanced Transportation*, vol. 2022, no. 1, pp. 1-15, Jan. 2021, Art. no. 7783588, doi: https://doi.org/10.1155/2022/7783588

[4]. S. Wu, A. Haji, and I. Adkins, "State of art review on the incorporation of fibres in asphalt pavements," *Road Materials and Pavement Design*, vol. 24, no. 6, pp.1559-1594, 2022, doi: https://doi.org/10.1080/14680629.2022.2092022

[5]. S. A. F. Al-Arkawazi, "Flexible pavement evaluation: a case study," *Kurdistan Journal of Applied Research*, vol. 2, no. 3, pp. 292-301, 2017, doi: https://doi.org/10.24017/science.2017.3.33.

[6]. S. Islam, and W. G. Buttlar, "Effect of pavement roughness on user costs," *Transportation research record*, vol. 2285, no. 1, pp. 47–55, 2012, doi: https://doi.org/10.3141/2285-06

[7]. N. S. P. Peraka, and K. P. Biligiri, "Pavement asset management systems and technologies: A review," *Automation in Construction*, vol. 119, no. 3 p. 103336, 2020, doi: https://doi.org/10.1016/j.autcon.2020.103336

[8]. D. Iskandar, S. P. Hadiwardoyo, R. J. Sumabrata, and I. N. Fitriasari, "Road maintenance strategy with characteristics of drainage condition based on pavement performance," In *AIP Conference Proceedings*, vol. 1977, no. 040010, pp 1-8, 2018, 2018, doi: https://doi.org/10.1063/1.5042980

[9]. S. D. Nguyen, T. S. Tran, V. P. Tran, H. J. Lee, M. J. Piran, and V. P. Le, "Deep learning-based crack detection: A survey, *"International Journal of Pavement Research and Technology*, vol. 16, no. 4, pp. 943-967, 2023, doi: https://doi.org/10.1007/s42947-022-00172-z

[10]. Z. He, X. Qin, H. Wang, and C. Comes, "Implementing practical pavement management systems for small communities: a South Dakota case study," *Public Works Management and Policy*, vol. 22, no. 4, pp. 378-391, 2017, doi: https://doi.org/10.1177/1087724X17721714

[11]. *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*, American Society for Testing and Materials Standard ASTM D-6433-23, United States, 2023. https://www.astm.org/d6433-23.html

[12]. O. Kaya, H. Ceylan, S. Kim, D. Waid, and B. P. Moore, "Statistics and artificial intelligence-based pavement performance and remaining service life prediction models for flexible and composite pavement systems, *"Transportation Research Record*, vol. 2674, no. 10, pp. 448-460, 2020, https://doi.org/10.1177/0361198120915889

[13]. A. Ji, X. Xue, X. Luo, Y. Wang, and H. Wu, "Scientometric analysis of pavement maintenance: a twenty-year review," *Journal of Civil Engineering and Management*, vol. 29, no. 5, pp. 439-462, 2023, doi: https://doi.org/10.3846/jcem.2023.19031

[14]. B. Bezak, C. Gascon, P. Hadley, and M. McCormick, "Pavement Management Plan," City of San Diego Transportation Department, San

Diego, USA, 2024. https://www.sandiego.gov/sites/default/files/2024-01/pavement-management-plan-report.pdf

[15]. M. Y. Shanin, "Pavement Condition Survey and Rating Procedure," in *Pavement Management for Airports, Roads and Parking Lots*, 2ed. Chapmab & Hall, New York, USA: Springer, 2005, Ch. 3, sec. 3.2 and 3.3, pp 19-23. https://api.semanticscholar.org/CorpusID:108413581

[16]. F. A. R. Temimi, A. H. M. Ali, and A. H. F. Obaidi "The Pavement Condition Index (PCI) Method for Evaluating Pavement Distresses of the Roads in Iraq- A Case Study in Al- Nasiriyah City," *University of Thi Qar Journal for Engineering Sciences*, vol. 11, no. 2, pp. 17-23, 2021, doi: https://doi.org/10.31663/tqujes.11.2.394(2021)

[17]. A. Ragnoli, M. R. De Blasiis, and A. Di Benedetto, "Pavement distress detection methods: A review," *Infrastructures*, vol. 3, no. 4, p. 58, 2018, doi: https://doi.org/10.3390/infrastructures3040058.

[18]. G. Loprencipe, and A. Pantuso, "A specified procedure for distress identification and assessment for urban road surfaces based on PCI. *Coatings*, vol. 7, no. 5, p. 65, 2017, doi: https://doi.org/10.3390/coatings7050065

[19]. F. M. Karim, K. A. H. Rubasi, and A. A. Saleh, "The road pavement condition index (PCI) evaluation and maintenance: a case study of Yemen," *Organization, Technology, and Management in Construction: An International Journal*, vol. 8, no. 1, pp. 1446-1455, 2016, doi: https://doi.org/10.1515/otmcj-2016-0008

[20]. A. J. Abed, A. H. Albayati, and Y. Wang, "Effect of Surface Pavement Type on Traffic Noise," *Journal of Engineering*, vol. 29, no. 04, pp.1-13, 2023, doi: https://doi.org/10.31026/j.eng.2023.04.01

[21]. W. Zeiada, S. A. Dabous, K. Hamad, R. Al-Ruzouq, and M. A. Khalil, "Machine learning for pavement performance modeling in warm climate regions," *Arabian Journal for science and engineering*, vol. 45, no. 5, pp. 4091-4109, 2020, doi: https://doi.org/10.1007/s13369-020-04398-6

[22]. A. Fares, and T. Zayed, "Industry-and academic-based trends in pavement roughness inspection technologies over the past five decades: a critical review," *Remote Sensing*, vol. 15, no. 11, p. 2941, 2023, doi: https://doi.org/10.3390/rs15112941

[23]. D. Hein, and J. M. Croteau, "The impact of preventive maintenance programs on the condition of roadway networks," In *Annual Conference of the Transportation Association of Canada*, *Toronto, Canada,* 2004, *pp*. 19-22. https://api.semanticscholar.org/CorpusID:56002991

[24]. M. Y. Shahin, M. I. Darter, and S. D. Kohn, "Development of a pavement maintenance management system Volume I. Airfield pavement condition rating," Air Force Engineering Services Center, Tyndall Air Force Base, Florida, USA, Rep. CERL-TR-C-76-vol 1 Final Rpt., 1976. https://api.semanticscholar.org/CorpusID:108675020

[25]. A. Al-Mansour, K-W. W. Lee, and A. H. Al-Qaili, "Prediction of pavement maintenance performance using an expert system," *Applied Sciences*, vol. 12, no. 10, pp. 4802-4815, 2022, doi: https://doi.org/10.3390/app12104802