

## EVALUATING PAVEMENT SURFACE CONDITION FOR URBAN NETWORK USING MICRO PAVER AND ArcGIS SOFTWARE

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### ABSTRACT

Pavement is one of the fundamental components of the road system and its management is a major issue for organization and pavement engineers in the highway sector. To identify the required maintenance and repair works and to keep it at an acceptable level of serviceability, a vital indicator to evaluate the pavement condition of roadways is the pavement condition index (PCI) which helps to implement an appropriate treatment. The aim of this study is to evaluate the condition of flexible pavement in Duhok city/Iraq urban network by PCI using visual pavement distress surveys. A representative network from flexible pavement of urban road network was considered. Overall, 22 roads covering all functional types with a total length of 65.64 km were selected. They include one principal arterial, one minor arterial, two major collectors, five minor collectors and thirteen local roads. Using Micro PAVER, 7.1 and ArcGIS software, the study results indicate that, based on PCI standard classifications values, 7% of road sections have a "Very poor" condition, 30% of road sections are in "Poor" condition, 32% of road sections have a "Fair" condition, 19% of road sections have a "Satisfactory" condition and 12% of road sections are in "Good" condition. Also, the principal and minor arterial roads had satisfactory condition with average PCI values of 70 and 75, respectively, whereas major and minor collector roads were in fair condition with lower average PCI values of 63 and 61. Local roads had the poorest condition with an average PCI of only 51. It was observed that the climate factor is the main cause of pavement deterioration in the urban network of Duhok city. The study findings will provide further guidance to pavement engineers when considering the maintenance schedules for existing pavements and predicting the future condition and lifespan of a road pavement in the selected urban network.

**KEYWORDS:** Pavement Condition Index, Micro PAVER, GIS, Distress type, Pavement management, Maintenance priority

### 1. INTRODUCTION

The most essential measure for the development of any country is road networks; therefore, it is necessary to continuously maintain the network functional and structural performance. The road condition evaluation should be performed to implement a suitable maintenance and rehabilitation works. Highways and roads are an important component of a cities' transportation network and have a significant impact on the growth of their local economy and development. As the quality of road service declines as a result of the impact of many different factors, there will be a demand to research into the reasons and to identify workable solutions. Inadequate investments or ineffective maintenance techniques lead to an increase in the long-term cost of maintenance and rehabilitation actions. Moreover, the

Pavement Maintenance Management System (PMMS) is regarded as a tool of science for managing pavements and to optimize common benefits or the best use of available resources (Torres-Machí et al., 2014). There are two different category types of failures that appear as distresses on the pavement; namely: functional failure and structural failure. The first type of failure occurs when the pavement does not serve as required in terms of ride quality and safety. The second, occurs when the pavement's structure collapses or when one component or more pavement components fail severely enough that the pavement is no longer capable of holding the loads applied to its surface (Sarsam, 2016).

Structural failure in a flexible pavement can emerge in the surface, base course, sub-base or subgrade due to fatigue, consolidation, or shear. Functional failure primarily depends on the

degree of surface roughness (Zumrawi, 2015). Road pavement needs continuous maintenance and rehabilitation (M&R) works to avoid causing of deterioration by the environmental conditions, repeated traffic loads and other factors. Due to the fund's limitation that is allocated for pavement construction and M&R works, it is very important to manage the available resources. To achieve this, an appropriate approach to implement a systematic process for scheduling works of maintenance and rehabilitation should be prepared, which would help to maximize the benefits to road users and limit costs for pavement maintenance to the responsible agency. This would enable managers and engineers to allocate funds, personnel, and resources in the most possible effective way (Hall et al., 1991).

The U.S. Army Corps of Engineers developed a rating system to rate the quality of the pavement objectively and repeatedly. They developed the PAVER system which is a pavement maintenance management system (PMMS), to make the most of the funding designated for pavement rehabilitation and maintenance. It has now been verified by many studies for use to manage airports, roads, and parking lots (Haas et al., 1994; Obead, 2012; Zhou and Wang, 2012). Furthermore, integrating the system of Micro PAVER with the geographic information system (GIS) is an effective tool in resolving such identified problems. There may be many benefits to integrating this hybrid system, some of which may include practicality, follow-up capabilities, convenience of use, documentation possibilities and digital capabilities, planning and managing the activities, access to numerous activities, updating and archiving (Jendia and Al Hallaq, 2015).

Pavement evaluation requires careful observation and recording of the surface characteristics, structural stability, and overall pavement condition. To assess the condition and evaluate the need for maintenance and rehabilitation (M&R), condition prediction models are used at both the project and network levels (Shahin, 2005). In general, the term "pavement condition" refers to a pavement's ability to preserve a certain serviceability level under specific traffic loads. A number of condition indicators are used to represent the condition of pavement, including: Present Serviceability Index (PSI), Resent Serviceability Rating (PSR), Pavement Condition Index (PCI),

International Roughness Index (IRI), Mean Panel Rating (MPR), Profile Index (PI), Ride Number (RN) and Pavement Condition Rating (PCR) (Huang, 2004). However, the PCI was used in this research. It is a simple, convenient, direct and inexpensive way to be used for evaluating the condition of a pavement and intending an effective management plan. The PCI is a numerical rating of the condition of pavement that ranges from 0 to 100, where 0 represents the worst condition "Failed" and 100 represents the best possible condition "Good".  
 ////To help road agencies in Duhok city/ Iraq, this study is conducted to calculate the PCI and then to evaluate the pavement condition of urban roads, by considering severity and quantity for all distresses in the selected roads and using Micro PAVER software. The software was used to reduce expected errors associated with a conventional evaluating method (hand calculations). Then, Micro PAVER 7.1 software has been connected to the GIS software in order to prioritize network repair and rehabilitation, by utilizing the critical value of PCI.

## 2.RELATED WORKS

The usefulness of PCI in determining pavement conditions has been recognized by numerous researches. Managers can more easily make decisions by analyzing the condition data since it makes it easier to identify the regions that require repair and speeds up the decision-making process. The structure of a GIS database can be a critical factor in the achievement of a management program, especially when it contains georeferenced information. GIS's flexibility can give managers the ability to specialize data, continuously produce cartographic information, and perform updates. Data collection, storage, editing, analysis, and visualization are all possible with the help of GIS, which is created to work with data that is referred by spatial coordinates (Chen et al., 2012). GIS has been used to improve pavement management data with its typical features, such as graphical display of highway network and current and future pavement condition of the selected pavement sections. A great spatial query and analysis capability could be provided by GIS to identify the selected pavement sections in need of immediate maintenance (Niju, 2006).

A pavement condition index (PCI) model was created by Ewadh et al. (2017) using Paver software, version (6.5.7) on a flexible pavement

urban route in the center of Kerbala city in Iraq. The model was developed to evaluate the condition of the pavement and identify places in need of repair and maintenance. The authors reported that by using this model, transportation organizations can more efficiently manage resources, prioritize maintenance and repair activities, and increase the pavement's service life.

By using the PCI and a GIS approach, Al-Neami et al. (2018) assessed the Al-Amarah highway in Al-kut city/ Iraq with the length of 1700m. The study was aimed to assess the condition of the pavement, identify areas that need maintenance and repair, and provided recommendations for pavement management strategies. The study found that the average PCI was 64, indicating a "fair" pavement condition; also, the study presented a simplified and visual way of showing the details of deteriorations on a geographical map, symbolizing each type of distress with a specific sign and each PCI value with a specific color. These findings demonstrate the usefulness of GIS software and PCI in pavement management and planning, which can help optimize maintenance planning and budget allocation.

Obead (2012) developed maintenance alternatives based on the Analytical Hierarchy Process (AHP) optimization technique to predict the best pavement maintenance alternative. Several factors that affect asphalt pavement maintenance, including traffic volume, pavement condition, roughness, safety, pavement strength, budget limitations, and environmental impact, were assessed, estimated, and used as input data for the selected case study in Baghdad city. The study found that the comparison between the results achieved by using the AHP approach and the results obtained by the experts using the prepared questionnaire has a good agreement according to the statistical analyses.

The PAVER system has the ability to analyze the pavement condition in order to determine its condition. According to Faris and Mahir (2012), maintaining transportation assets has become the biggest concern for most transportation agencies worldwide. The decision-making process for roadway pavements was come to be easier by a system that was offered. In order to fully utilize the capabilities of each particular, it is primarily based on the direct interaction between pavement Micro PAVER software and Geographical Information System (GIS) software.

Using Micro Paver software, Hasan et al. (2020) created a pavement maintenance management system for a multi-lane highway in Baghdad city, running from Al-Dora intersection to Al-Mohmudiya quarter and the study area was divided into 20 sections, each section has 1000m length. The study found that the Micro Paver was effective software for enhancing the organization of Iraq's roadway pavement since it helps with prioritize maintenance and repair activities.//////The urban road network in Saudi Arabia was the subject of a study on pavement deterioration prediction. The study conducted by Mubarak (2010) on the use of pavement distress and condition prediction models in pavement management. The study highlights that these models can greatly enhance the capabilities of a pavement management system. The study also notes that pavement age is the most significant factor in predicting pavement deterioration. The age of the pavement can be used as a surrogate for the effect of traffic and drainage in the prediction model. Moreover, the study found that maintenance priority can be determined based on several factors, including traffic level, road classification, maintenance record, cost-effectiveness, and PCI. These factors can help to prioritize pavement maintenance and rehabilitation efforts and allocate resources more effectively.

A study conducted by Li and Huang (2014) investigated the condition of the pavement on several different types of roads in Houston, Texas and compared their findings with the accident data (different types of road collisions). They concluded that the rate of collisions decreased as pavement quality improved. The most collisions occurred on collector roads which were rated as a "very poor" followed by "fair" and "poor" collector roads. Fewer collisions were happened on arterial roads in a "very poor," "poor," and "fair" sections. The "very good" condition had the least number of accidents.

Using the Micro PAVER application, Ali et al. (2016) developed a PMMS for the road network in Central and Eastern of Sudan. The study's objectives were to manage resources effectively and determine the best economical pavement maintenance strategies. A pavement condition assessment module, a maintenance needs assessment module, a decision-making module, and a module for life-cycle cost analysis made up the PMMS. The study found that developing countries with comparable road

networks and limited resources might use the PMMS to manage pavements in a reliable and efficient manner. The study emphasizes the potential advantages of employing the Micro PAVER program for pavement condition evaluation as well as the importance of considering life-cycle costs into account when making decisions about pavement maintenance.

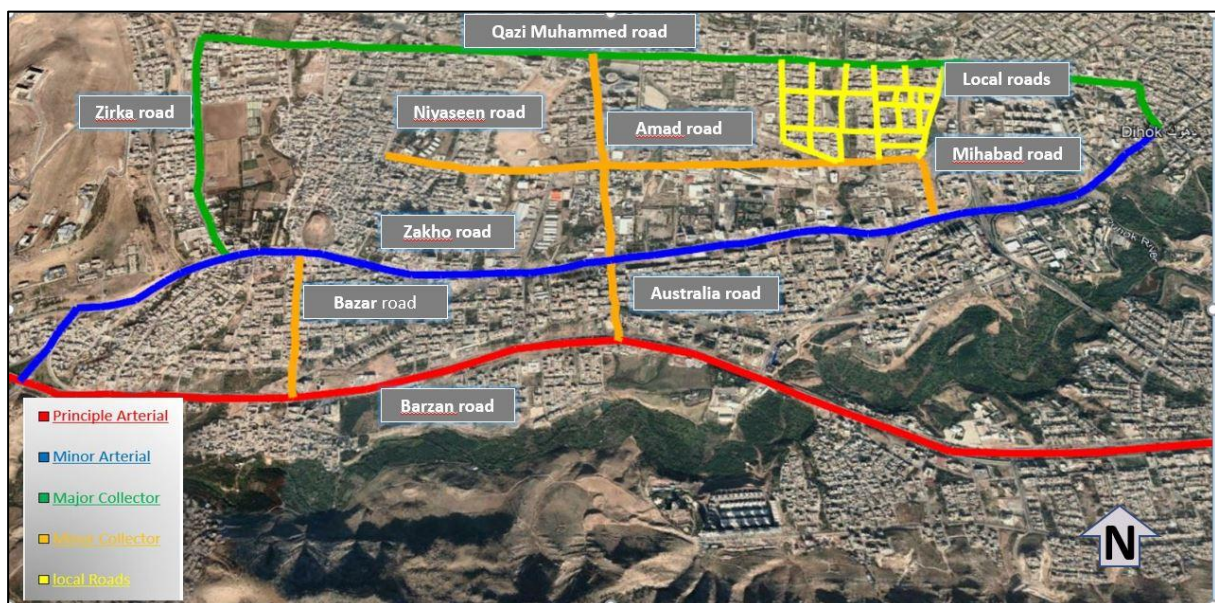
### 3.METHODOLOGY

#### 3.1 Description of the study area

The study area for this research is Duhok city urban road network, located in Kurdistan Region of Iraq. The city's road network extends over hundreds of kilometers, with various road types ranging from major highways to local streets. The road network is characterized by a high volume of traffic, particularly in the city center and along major routes connecting Duhok with other cities in the region. However, the network is also plagued by several issues, including inadequate maintenance, insufficient capacity, and safety concerns. Duhok city roads are being maintained without assessing the

functional performance of pavement and evaluating the economical practicability of performing different types of road maintenance alternatives. Also, the city road agencies do not rely on deterioration models to manage their road network for different functional classification of roadways. This may result in an inaccurate output due to the lack of consideration for pavement impact factors for different road classes.

In this study, the pavement condition has been evaluated by collecting distress data from road sections located in Duhok city urban network, covering five functional classifications of roads (each type of road class is considered as one branch). The roads have been classified based on roads traffic volume, speed limit, and road geometry. A representative sample from 22 roads with a total length of 65.64 km, has been selected for the purpose of data collection. The five road classes include one principal arterial, one minor arterial, two major collectors, five minor collectors and thirteen local roads, as illustrated in Figure 1 and listed in Table 1.



**Fig (1):** Selected study area from Duhok city urban network

**Table (1):** Road classification according to their functional categories

Name of Road	Road Category	Branch ID
Barzan road	Principal Arterial	1
Zakho Road	Minor Arterial	2
Zirka Road and Qazi Mohammed Road	Major Collector	3
Amad Road, Australia Road, Niyaseen Road, Mihabad Road and Bazar Road	Minor Collector	4
Mihabad, Mam, Kurdin, Diyar, Gian, Zin, Kakiza, Pil, Rojvin, Zahaw, Shenava, and Yana streets	Local Road	5

### 3.2 Determining the number of sample units that need to be inspected

Each road has been divided into smaller manageable sections, with the total of (57) sections for the both directions of roads (forward and backward) because these roads do not always have consistent characteristics. Also, this has been an effective aid in data collection and analysis. Road pavement section is consistent throughout their boundaries with respect to their functional and physical characteristics (Shahin, 2005). Each section of a specified road was divided up into sample units for the purpose of inspecting the pavement condition, with the total of (621) sample units. According to the American Society for Testing and Materials (ASTM) standard, a sample unit is an area of  $(225 \pm 90 \text{ m}^2)$  for asphalt-surfaced roadways.

The only factors which were followed during defining the boundary between two sections, include (1) a sudden change in traffic patterns or volume, (2) any change in the number of lanes in the traffic, (3) construction projects completed in the past (various projects represent varying materials, ages, designs, and other characteristics). Moreover, geographic or man-made boundaries, such as intersections of the road and bridges (Shahin, 2005).

The details of data collection include: (a) Information about the section including its identified name, section length (m), section width (m), and road function (arterial, collector, or local) (one or two-way), (b) Data of pavement condition for each section of road, including: distress information (type, density and severity).

Due to resource constraints and budget limitations, a sampling plan was created to enable a reasonable calculation of the PCI (for evaluating a specific road) to be made by evaluating only a portion of the sample units in the road pavement section (Shahin, 2005). To perform the road inspection by sampling, the

first step is to determine the minimum number of sample units (n) that should be surveyed in order to provide a statistically accurate estimate of the PCI of the section (95% confidence level). The following formula is used to determine the statistical sample size in accordance with ASTM standards for the airfield and highways D6433-09 (ASTM, 2009). Rounding up the result to the nearest high whole number:

$$n = \frac{Ns^2}{\left(\frac{e^2}{4}\right)(N-1)+s^2} \dots\dots\dots (1)$$

Where: N: actual number of units; where: N= area of section/ sample unit area

n: represent the minimum sample unit numbers of selected pavement section

e: acceptable error in estimated value of PCI (usually equal to 5)

s: PCI value standard deviation (usually s equal to 10)

By using random sampling, it is possible to determine the spacing between the units. The sampling interval (i) of the units to be sampled was determined using the formula below and rounded to the nearest whole integer on the basis of ASTM D6433-09 (ASTM, 2009):

$$i = N/n \dots\dots\dots (2)$$

### 3.3 Data collection procedure and tools

The following procedure and tools have been used for collecting the data in the study area:

1. The GPS tool with an accuracy of 0.9m was used to locate the start and end of each sample unit selected for the study.

2. The lengths and widths of road sections are obtained by manual measurements using laser tape measure.

3. All available types of distresses on the pavement of the sample unit are measured and recorded on prepared datasheet. The inspection has been conducted using visually survey by walking across the study area and then identifying the distress type, distress severity

level and distress quantity (in m or m<sup>2</sup> for distresses in linear or area measurements, or in number for countable distresses). The tools that have been used to measure distress data are tape, straightedge and ruler.

4. A digital photograph has been taken to make permanent pavement condition record for each section in the study.

5. The Pavement Distresses Identification Manual (PDIM), published by the Army Corps of Engineers, was used as the reference guide for identifying and classifying pavement distresses during field survey (the type and severity of each distress) using ASTM D6433-09 (ASTM, 2009). The evaluation survey used the 2021 PDIM

edition which provides details of asphalt surfaced distress descriptions, photos, severity levels and how to measure for all standard pavement distresses.

6. Construction and maintenance data are collected from Duhok Municipality Department and Duhok Roads and Bridges Maintenance Department (DMD, 2022; GDRB, 2022).

The pavement distresses with various severity levels (low, medium, high) were identified and measured along the study area roads, by comparing the observed distresses on sample units in the field to examples in the PDIM to categorize them appropriately, as shown in Figure 2.



Fig. (2): Samples of pavement distresses in the case study

#### 4. RESULTS AND DISCUSSION

The PAVER software has the ability to conduct the analysis for determining the pavement condition index. Also, it has the ability to develop prediction models and maintenance priority. Details of study results are described in the following sections.

##### 4.1 Rating of pavement condition

The Pavement Condition Index is a scale of 0 to 100 that is thought to serve as a rating system, with 0 representing the possibly worst condition and 100 representing the possibly best condition. Seven colors for the standard PCI rating scale with different PCI ranges are typically used to evaluate the state of pavement as depicted in Figure 3 (ASTM, 2007).

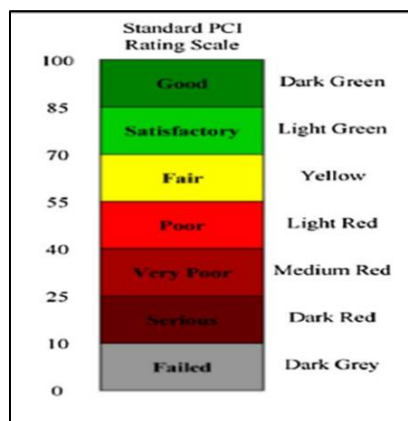


Fig. (3): Standard pavement condition index rating scale

#### 4.2 Calculation of the PCI using PAVER software

Based on the measured distress data (type, severity and quantity), PCI and pavement condition rating were determined using PAVER software. According to Shahin (2005), 20 types of distresses for asphalt-surfaced roads are identified by code number and classified by their

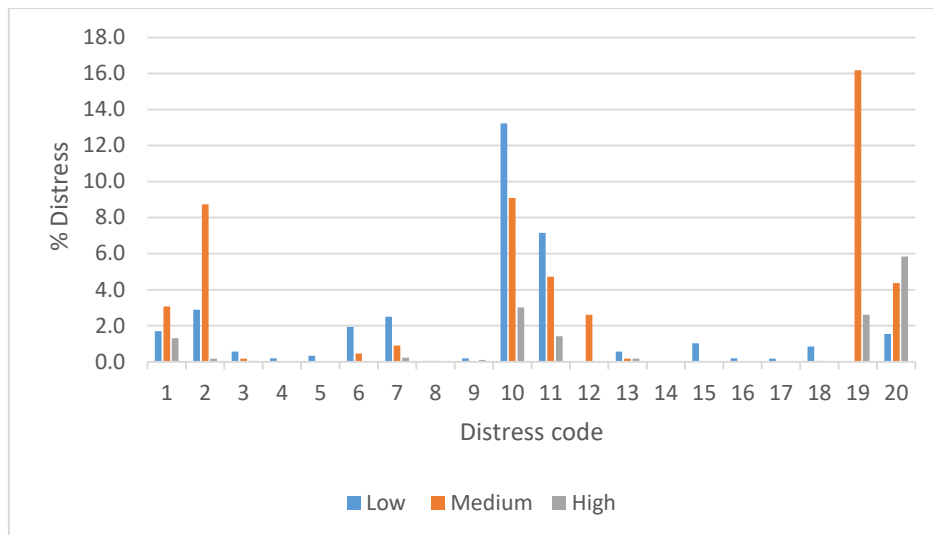
main cause, as shown in Table 2. The PCI for each investigated sample unit is calculated after all information (length, width, inspection date, and construction or last major maintenance or rehabilitation date) for each sample unit of a section has been entered, and then the PCI for the entire pavement section is calculated.

**Table (2):** Pavement distress codes and their causes

Code	Distress	Cause
1	Alligator Cracking	Load
2	Bleeding	Other
3	Block Cracking	Climate
4	Bumps & Sags	Other
5	Corrugation	Other
6	Depression	Other
7	Edge Cracking	Load
8	Joint Reflection Cracking	Climate
9	Lane/Shoulder Drop Off	Other
10	Longitudinal/Transverse cracking	Climate
11	Patch/Utility patch	Other
12	Polished Aggregate	Other
13	Pothole	Load
14	Railroad Crossing	Other
15	Rutting	Load
16	Shoving	Other
17	Slippage Cracking	Other
18	Swelling	Other
19	Raveling	Climate
20	Weathering	Climate

In addition, the percentages of all occurred distresses in the study area with different levels of severity (low, medium and high) are shown in Figure 4. It could be noticed that pavement raveling distress (distress code #19) with medium severity has higher percentage values than other distresses, followed by longitudinal and transverse cracking (distress code #10) with a low severity level then bleeding distress (distress code #2) with a medium severity level. However, this does not mean that these

distresses are the most affected distresses in the pavement condition due to the fact that each distress is measured in a different way (i.e quantity). Also, different modes of distresses with diverse severities have different effects on pavement functional and/or structural conditions. For example, a large quantity of weathering distress with high severity could have less impact on condition and serviceability of the pavement than one pothole with medium severity.



**Fig. (4):** Percentages of all occurred distresses in the study area with different levels of severity (low, medium and high)

### 4.3 Current pavement assessment

Using PAVER software (PAVER, 2021), the PCI value for each sample unit under the study is automatically calculated, the PCI value for the entire area is reported, and the extrapolated distress amounts are determined. PCI results for all branches in current condition are shown in Table 3. Although the procedure for calculating PCI by hand (manual method) is simple but extensive and can be done according to the steps that are described by American Society for Testing and Material (ASTM) standard. The details of the procedure for manually calculating PCI for all sample units of one local road section (27-E&W) within the selected study area are presented in Appendix A. By comparing the results of manual with automated PCI calculations, it is found that the average PCI for the selected section was 57.55 and 57.0 for the manual and automated calculations, respectively. This means that there is no significant difference between the two methods. However, the automated method using PAVER software is preferable because it is faster, more accurate, and less prone to error.

The proportion of deducted values associated to each distress mechanism is the fundamental for determining the main causes (load, climate, and other) of deterioration in pavement. The

other factors includes: construction defects, improper maintenance practices, drainage problems or any other causes that cannot be attributed directly to load or climate condition. Deduct value refers to a numerical value that is subtracted from the overall score of a pavement section or network to reflect the severity of pavement distresses and defects.

Table 3 provides the pavement condition index values for all network branches and displays the distribution of pavement conditions at the time of the inspection by the three main causes. The PCI value for the principal arterial is 70.23 and for the minor arterial is 74.75, these PCI values (refer to Figure 2) indicate that the two branches are classified as a "Satisfactory" condition and the pavement needs preventative maintenance, such as patching and crack sealing. The average PCI value for the major collectors is 63.26 and for the minor collectors is 60.72, which both branches are classified as a "Fair" condition due to their PCI values being between 55-70, and the pavement on these roads need global maintenance, such as surface treatment or surface seal. The PCI value of the local roads is 50.79, and the branch is classified as a "Poor" condition. This means that the pavements of local roads need rehabilitation, such as milling and resurfacing or surface overlay.

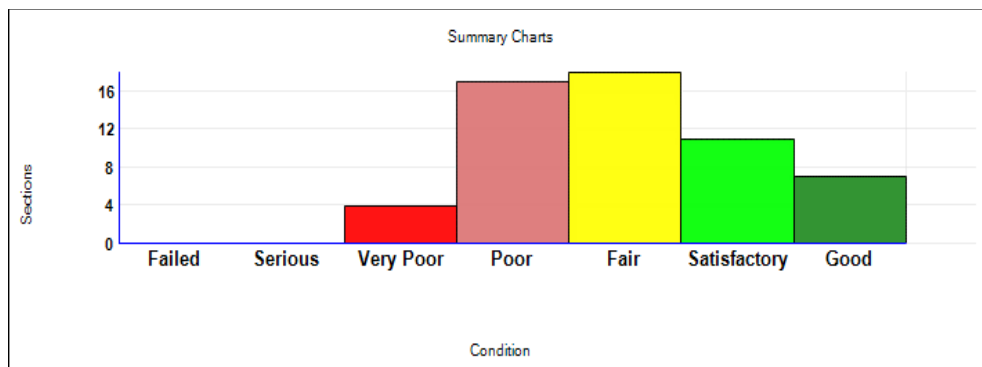
**Table (3):** PCI results for all branches in current condition

Network ID	Branch Category	Branch ID	PCI	PCI Category	PCI % Climate	PCI % Load	PCI % Other
Duhok urban network	Principal arterial	1	70.23	Satisfactory	60	22	18
	Minor arterial	2	74.75	Satisfactory	57	8	35
	Major collector	3	63.26	Fair	59	16	25
	Minor collector	4	60.72	Fair	57	23	20
	Local roads	5	50.79	Poor	65	14	21

Climate, load, and other factors are the three categories of variables that might have an impact on the total score of a pavement section or network when the PCI is assessed. Where the PCI climate relates to environmental conditions, PCI load relates to the traffic volume and load characteristics and PCI other relates to all other factors that can affect the pavement condition and performance, such as construction quality, drainage, and maintenance history (Al-Qadi, 2012). For Branch 1, it can be seen that 60% of pavement deterioration is due to climate factor, 22% is due to load factor and 18% is due to other factors. From the results of the three causes

for all branches (as shown in Table 3), it can be clearly observed that the climate factor is the main cause of pavement deterioration in the urban network of Duhok city.

Furthermore, out of 57 sections in the study area, it was noted that 4 sections are in a “Very poor” condition and represent 7% of the selected study area, 17 sections are in a “Poor” condition and represent 30%, 18 sections are in a “Fair” condition and represent 32%, 11 sections are in a “Satisfactory” condition and represent 19%, and 7 sections are in a “Good” condition which represent 12% of the total sections in the study area, as shown in Figure 5.



**Fig, (5):** Number of sections with pavement condition in the study area

**4.4 Developing model by PAVER software**

After determining the present PCI for each branch section, the network future pavement condition has been predicted depending on the distress survey data collected from 57 sections for different categories of roads (Principal, collector, arterial and local) for the Duhok city urban network. In cases where there are few historical data available, this pavement condition predicted model is particularly helpful. A nonlinear PCI model is developed as a function

of the independent variable (Age) by PAVER software as presented in Equation 3.

$$PCI = 100 + 0.00002 X - 1.41744 X^2 + 0.15952 X^3 - 0.00667 X^4 + 0.00098 X^5 \dots\dots\dots (3)$$

Where: x is the pavement age.

The model has a high R<sup>2</sup> value of 0.947, which means that it can explain 94.7% of the variation in pavement condition. This is a strong fit for the data. The coefficient of correlation (R) is also high, at 0.973, which indicates a

significant positive relationship between the independent variable (age) and the pavement condition rating. The standard deviation is low, at 4.706, and the mean errors are minimal, at 2.248 absolute mean and 0.073 arithmetic mean. This means that the model residuals are centered tightly around the regression line with little bias. Overall, the model is accurate and reliable for predicting future pavement condition based on the pavement age as input factor.

The predicted pavement condition index model is a useful tool for engineers and planners of the transportation systems because it offers important details about the condition of the pavement network and guides efforts at suitable maintenance and rehabilitation works. Figure 6 shows the output results of the predicted PCI of the study network. The prediction curve indicates that the network pavement condition reaches the critical value (PCI=55) when aged 13 years.

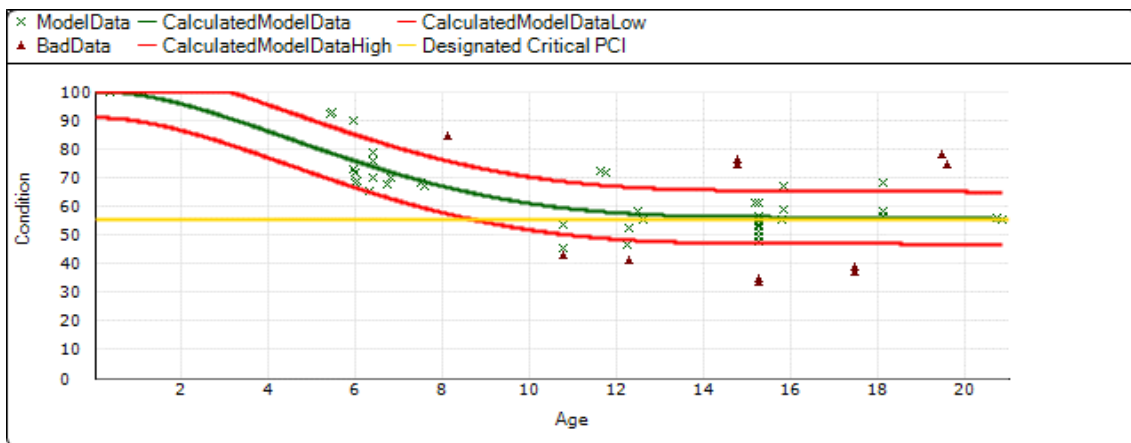


Fig. (6): Prediction of pavement condition index for the study area

**4.5 Linking Micro PAVER with ArcGIS software**

Linking PAVER software with a Geographical Information System (GIS) can provide valuable insights into the pavement management process. The ArcGIS was integrated to the PAVER 7.1 software for displacing the results of each road section condition in the case study area after computing the PCI values by the PAVER 7.1 software. The output data from later is taken as a shape file to ArcGIS. Figure 7 show the output results of the linking ArcGIS to Micro PAVER 7.1 that

displays the PCI of Duhok city urban network at the date of inspection.

The case study area is divided into four separated parts to make the layout of the results clearer and more understandable. Any section is assigned with a specific color by PAVER depending on the evaluated PCI from last inspection for each part separately, as shown in Appendix B. Starting with gray color of PCI between 0 to 10 and referred to a “Failed” condition, to the dark green of PCI ranging from 86 to 100 and referred to a “Good” condition of the section, according to ASTM standard rating colors as shown in Figure 3.

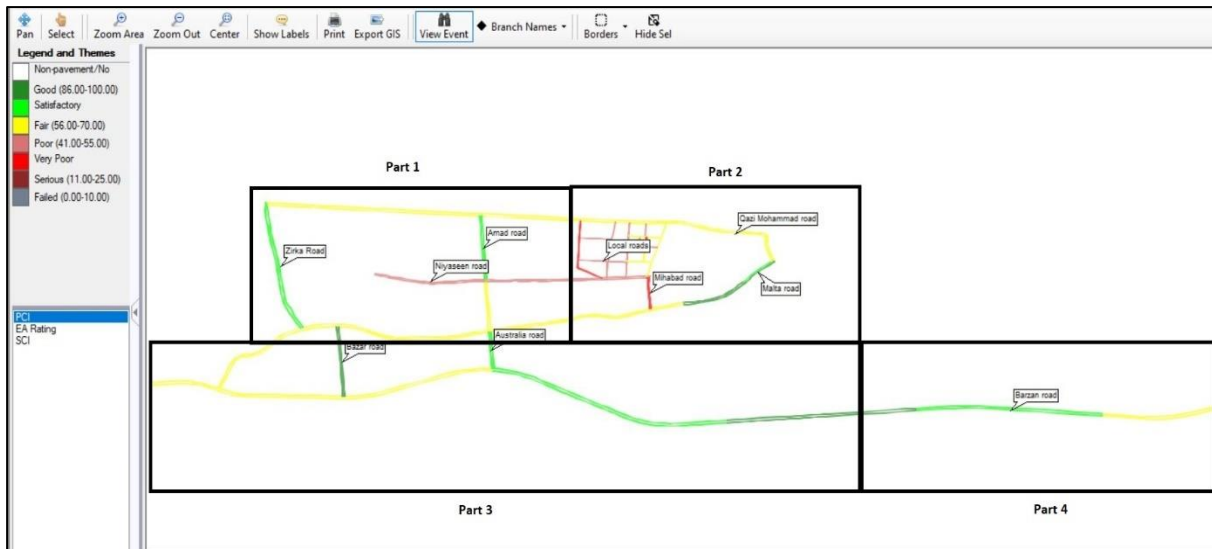


Fig. (7): ArcGIS report layout by PAVER 7.1 for PCI of Duhok city urban network

#### 4.6 Prediction of PCI for the next ten-years

Several factors, such as weather condition, traffic volume, and the material quality of the initial construction, can influence the condition of the pavement, making it difficult to predict its condition over time period. Predictions can be made using a variety of methods, each of which has a range of accuracy. Using pavement management software is one popular technique for predicting how the quality of the pavement will change over time. The PAVER software considers a number of variables, including the age of the pavement, previous maintenance and repair history, traffic volume, and climate conditions (PAVER, 2021). However, only the first two variables are considered in this study as they are only essential variables to predict the

PCI overtime (as a function of pavement age) using PAVER software.

The output of the PAVER program predicts the PCI for all the branches in the case study area for the selected next ten years. It is found that the PCI for branches 1 and 2 will decrease from 70.23 and 74.75 in 2023 to 54.35 and 43.09 in 2032, respectively. The PCI for branches 3, 4 and 5 will decrease from 63.26, 60.72 and 50.79 in 2023 to 43.78, 23.32 and 41 in 2032, respectively, as shown in Figures 8, 9, 10, 11 and 12. This shows that the selected urban road network will be under the critical pavement condition index value and with a “Poor” condition, after the next ten years if it is left without an effective M&R works.

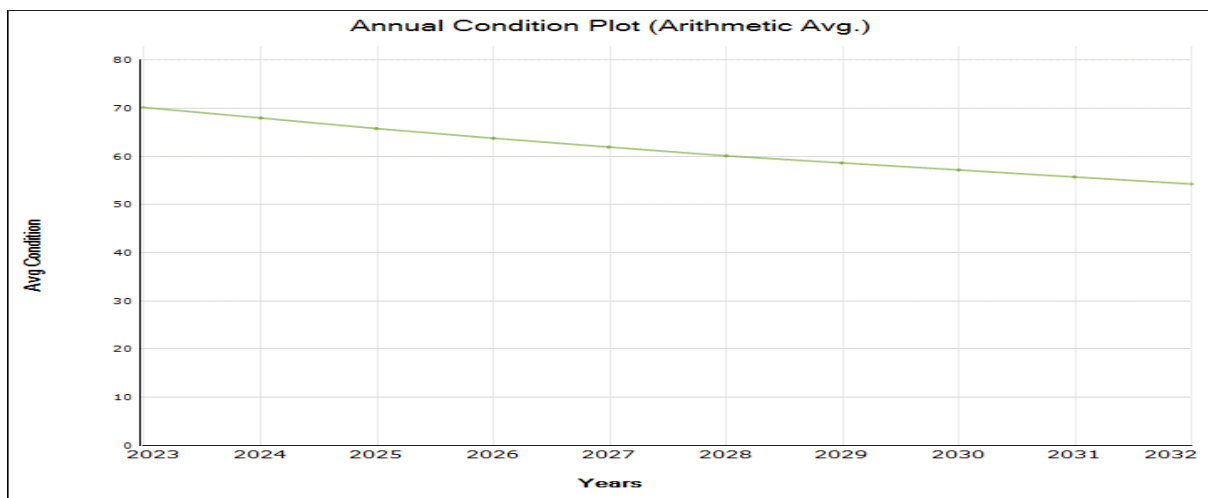
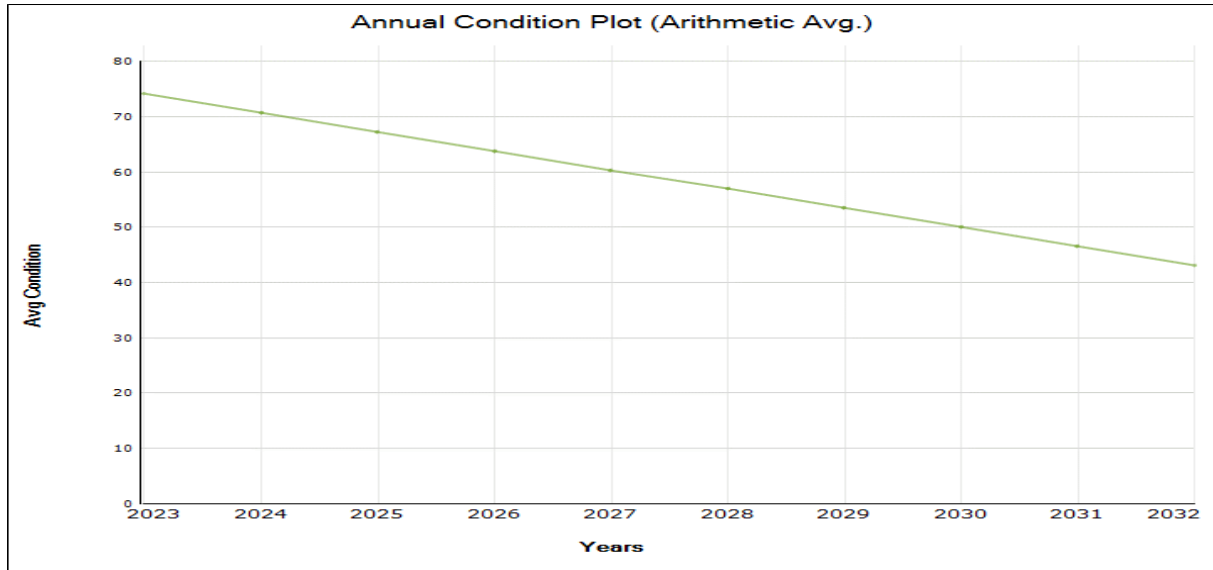
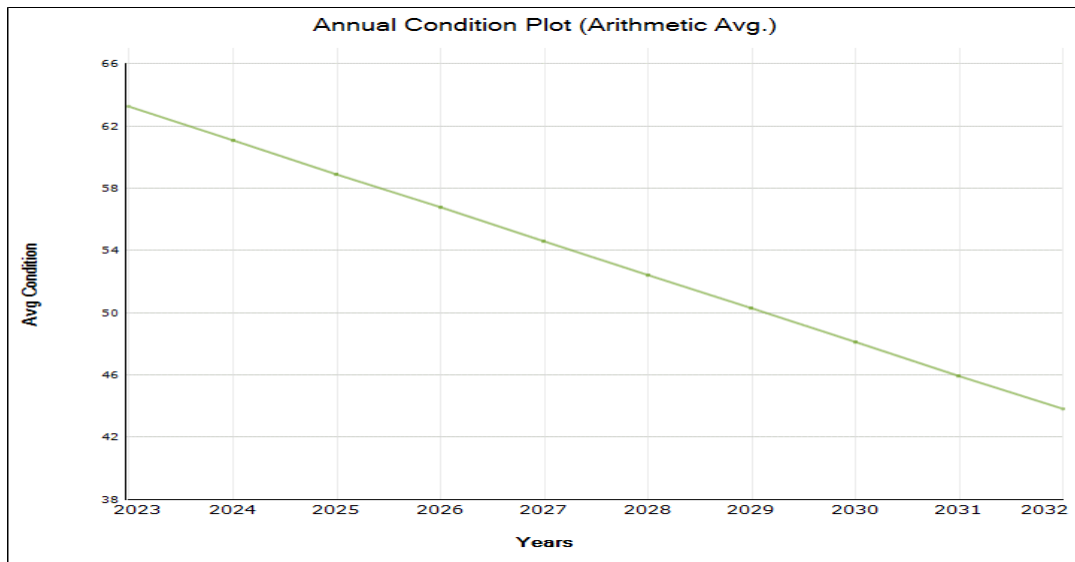


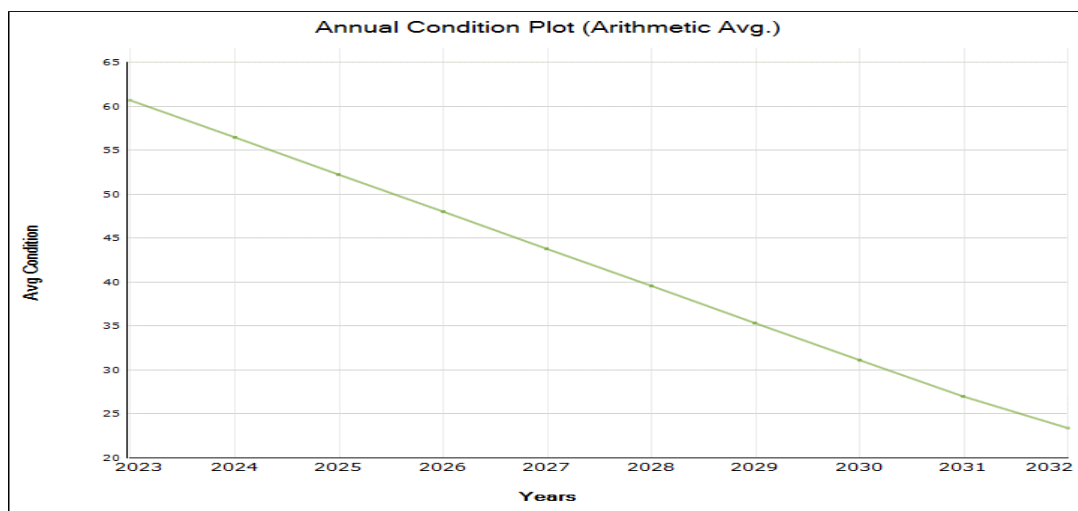
Fig. (8): Future ten-year pavement condition for branch 1 (Principal arterial)



**Fig. (9):** Future ten-year pavement condition for branch 2 (Minor arterial)



**Fig. (10):** Future ten-year pavement condition for branch 3 (Major collector)



**Fig. (11):** Future ten-year pavement condition for branch 4 (Minor collector)

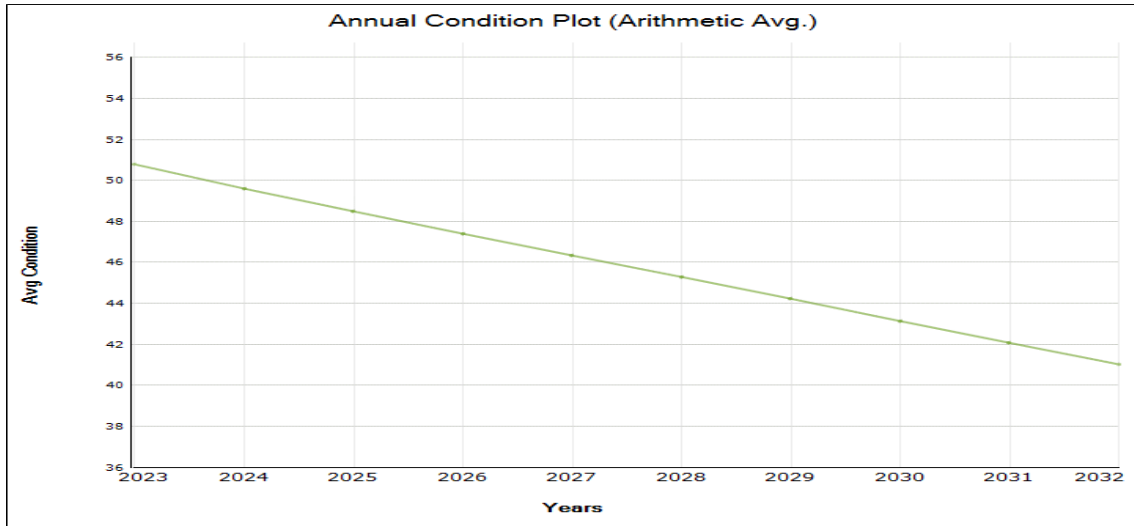


Fig (12): Future ten-year pavement condition for branch 5 (Local roads)

**4.7 Maintenance priority**

The priority of maintenance works is typically determined based on the condition of the pavement and the type of maintenance required. By using the set of essential PCI values, PAVER 7.1 enables the pavement manager to select maintenance and rehabilitation (M&R) portions of roads and define priorities of work. The concept of a work priority enables the user to specify priorities of work in relation to facility utilization, a critical value of PCI, or a

type of pavement that is used by the module of M&R. Figure 13 depicts the PCI priority scale that is typically used to select appropriate M&R activities. Regarding to the maintenance activities for all sections in the case study area of Duhok urban network, 28% needs preventive maintenance, 64% needs rehabilitation and 8% requires reconstruction. Figure 14 illustrates the PCI scale-based on priority of the M&R works for the selected study sections.

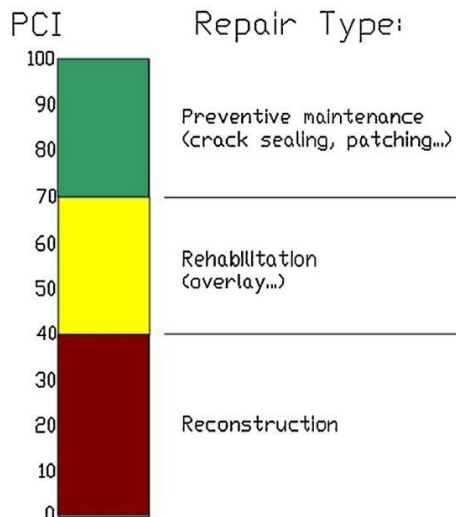


Fig. (13): M&R types vs PCI level (Services, 2011)

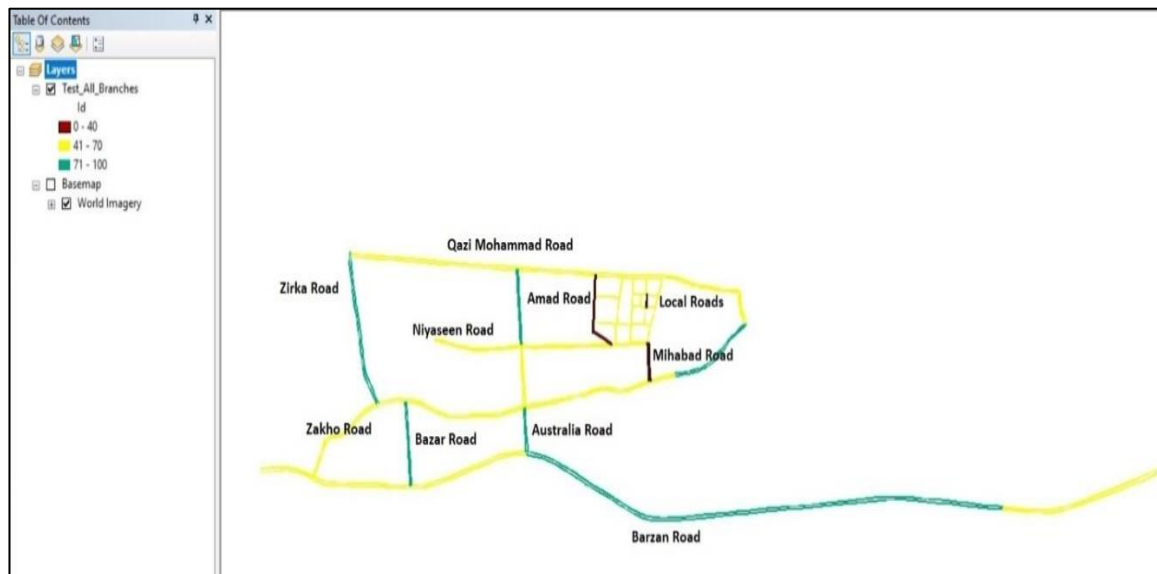


Figure 14: M&R priority of sections in Duhok city case study

## 5. CONCLUSIONS

The following conclusions have been drawn from the study results forevaluating the pavement surface condition for the selected urban network in Duhok city:

- 1- The Micro PAVER 7.1 software is capable to estimate the pavement condition index with greater accuracy and reduce the predicted mistakes associated with the traditional manual method.
- 2- It is worth mentioning that this study is the first attempt to compute the PCI for Duhok city urban roads and to evaluate network condition. Therefore, it is crucial to develop a database system that comprises the annual road deterioration data and the changes in PCI values.
- 3- The study found that from 57 selected road sections, there are 7% of sections that have a "Very poor" condition, 30% of sections are in a "Poor" condition, 32% of sections have a "Fair" condition, 19% of sections have a "Satisfactory" condition and 12% of sections are in a "Good" condition.
- 4- Using PAVER software in integration with GIS software would help to simply layout the PCI results and to identify road sections that require specific M&R works.
- 5- The study shows that the principal and minor arterials have the better pavement condition with the highest value of PCI; whereas the local roads have the worst pavement condition with the lowest value of PCI.
- 6- Ten-year PCI prediction results show that there is a decline in PCI value from 70.23 in

2023 to 54.35 in 2032 for principal arterial and from 74.75 in 2023 to 43.09 in 2032 for minor arterial.

- 7- Data for road construction and maintenance documents show that numerous areas of the pavement were left unmaintained for many years, resulting in severely damaged pavement that needed extensive rehabilitation efforts.
- 8- From the values of PCI, it is concluded that 28% of road sections need preventive maintenance, 64% of road sections need rehabilitation and 8% of road sections require reconstruction.
- 9- The study predicted a PCI model as a function of age and indicates that the network pavement condition reaches the critical value (PCI=55) when aged 13 years.
- 10- The study shows that the selected urban road network will be under the critical pavement condition index value and with a "Poor" condition, after the next ten years if it is left without an effective M&R works.
- 11- The study findings will provide further guidance for pavement engineers when considering the maintenance schedules for existing pavements and predicting the future condition and lifespan of a road pavement in the selected urban network.

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**APPENDIX (A)**

This appendix presents the details of the manual procedure for calculating PCI for sample units of only one local road section (27-E&W) from branch (5) in the selected study area. The road section has been divided into 21 sample units (N) and the minimum sample units (n) that are required to be inspected were 9 sample units. The results of visual inspection and measured distresses for the 9 selected sample units with an interval of (i=2) are tabulated in Table A1.

Density of the occurred distresses in asphalt pavement, is calculated using the following equation (A1):

$$\text{Distress Density (\%)} = (\text{Total Quantity of Distress} / \text{Area of Sample Unit}) * 100 \dots\dots\dots (A1)$$

Densities of all inspected sample units are calculated and depicted in Table A1. The deduct values (DV) (weighing factors from 0 to 100 that indicate the impact each distress has on pavement condition) are determined from the deduct curves for each distress type and severity level (Shahin, 2005). An example of deduct curve for Alligator cracking distress is shown in Figure A1. Table A1 includes deduct values for all inspected sample units of the selected section.

The allowable number of deducts (Mi) is determined, using the following equation:

$$M_i = 1 + (9/98) (100 - HDV_i) \dots\dots\dots (A2)$$

HDV<sub>i</sub> : highest individual deduct value for sample unit, i.

Table A1 also includes the maximum allowable number of deduct values for inspected sample units. The maximum corrected deduct value (CDV) is determined iteratively following steps explained by ASTM and Figure A2 (Shahin, 2005). A total deduct value (TDV) is computed by summing all individual deduct values. Table A2 presents the results of TDV and CDV.

The PCI is computed from the maximum corrected deduct value (CDV) for each inspected sample unit by using the following equation A3:

$$PCI = 100 - CDV \dots\dots\dots (A3)$$

The PCI for the selected section is determined by averaging the PCI of its sample units, as depicted in Table A3. It is found that the average PCI for the selected section was 57.55 and 57.0 for the manual and automated calculations, respectively. This means that there is no significant difference between the two methods. However, the automated method using PAVER software is preferable because it is faster, more accurate, and less prone to error.

**Table (A1):** Results of the distress density, deduct values(DV) and the maximum number of deducts (M<sub>i</sub>) for each inspected sample unit in section (27-E&W)

Sample unit ID	Distress Code	Type of Distress	Level of Severity*	Quantity	Density %	DV	Mi
2	19	Weathering	M	225	100.00	43.5	6.14
	1	Alligator Cracking	L	5	2.22	17	
4	11	Patching & Utility Cut	L	1.5	0.67	1.5	6.51
	19	Raveling	M	172.5	76.67	40	
6	19	Raveling	M	192	85.33	41.5	6.37
	11	Patching & Utility Cut	L	1	0.44	1	
	2	Bleeding	M	1.16	0.52	3	
8	2	Bleeding	M	46	20.44	28	6.46
	19	Raveling	M	179	79.56	40.5	
	1	Alligator Cracking	M	0.12	0.05	6.5	

10	2	Bleeding	M	38.5	17.11	6.75	6.60
	19	Raveling	M	164	72.89	39	
	5	Corrugation	L	18	8.00	11.75	
12	19	Raveling	M	219	97.33	43	6.23
	11	Patching & Utility Cut	L	3	1.33	2.5	
14	19	Raveling	M	225	100.00	44	6.14
16	19	Raveling	M	96.6	42.93	12.25	8.30
	11	Patching & Utility Cut	L	3.45	1.53	3.5	
	2	Bleeding	M	55.2	24.53	20.5	
18	19	Raveling	M	215	95.56	42.75	6.26
	1	Alligator Cracking	M	3	1.33	6	
	6	Depression	L	4	1.78	5.5	

\*Where:L: Low level, M: Medium level, H: High level.

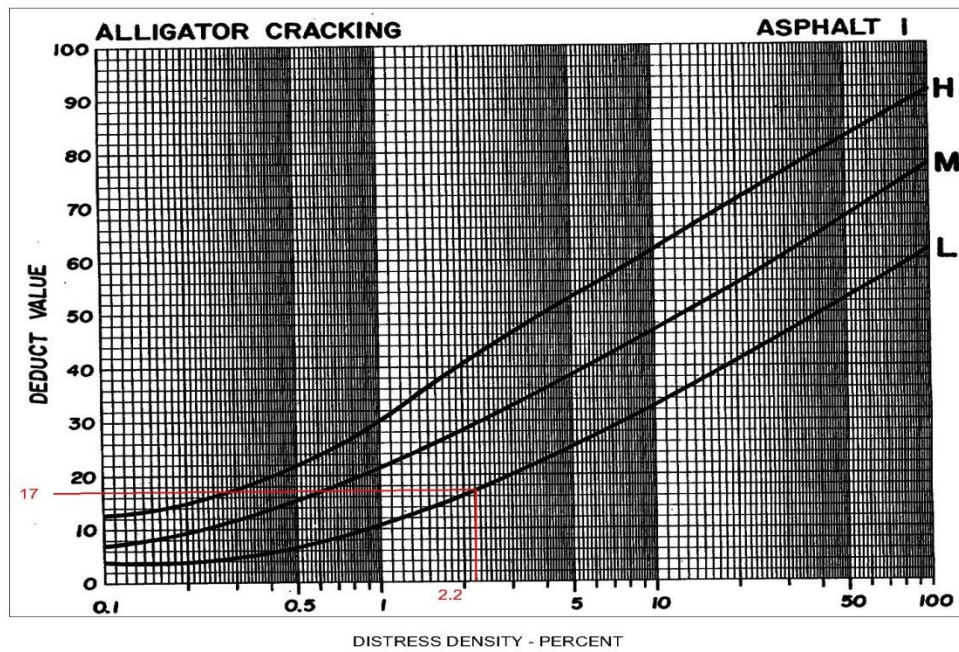


Fig. (A1): Alligator cracking distress deduct value curve (Shahin, 2005)

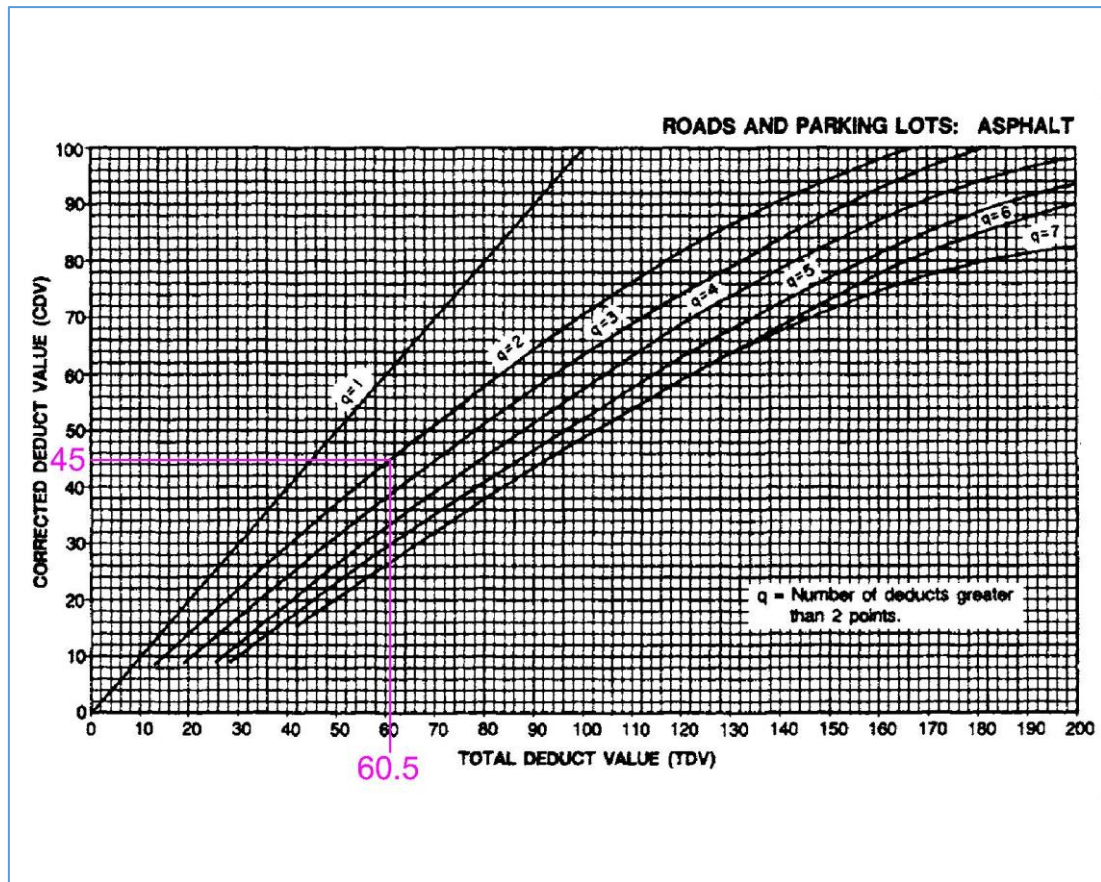


Fig. (A2): the correction curve for asphalt-surfaced road pavements (Shahin, 2005)

Table (A2): Results of TDV and CDV for each inspected sample units in section (27-E&W)

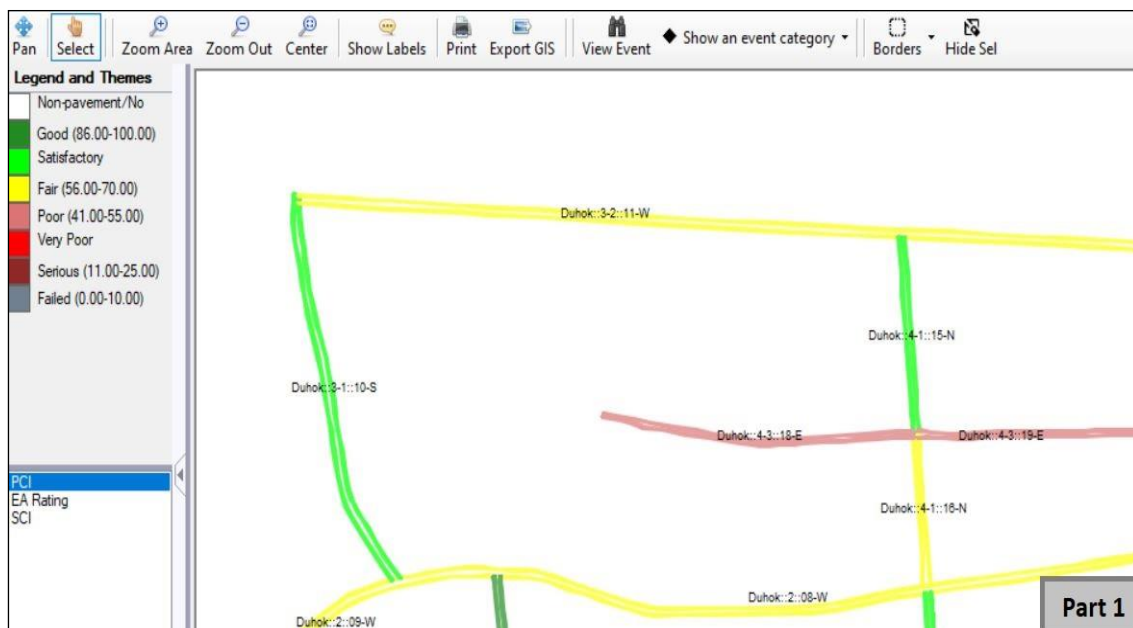
Sample units	q	TDV			CDV			Max. CDV	PCI
		q=3	q=2	q=1	q=3	q=2	q=1		
2	2	—	60.50	46.00	—	45	46	46	54.00
4	1	—	—	41.5	—	—	41	41	59.00
6	2	—	45.5	44.5	—	33	44	44	56.00
8	3	75	70.5	46.5	48	51.5	46.5	51.5	53.50
10	3	57.5	52.75	43	36.5	39	42.75	42.75	57.00
12	2	—	45.5	45	—	33.75	44.75	44.75	55.25
14	1	—	—	44	—	—	43.89	43.89	56.11
16	3	36.25	34.75	24.5	21.5	25.90	24.25	25.90	74.10
18	3	54.25	50.75	46.75	34.25	38	47	47	53.00
The average PCI of sample unites									57.55

**Table (A3):** A comparison between manually and automatically calculating the value of the PCI of section (27-E&W) of local road

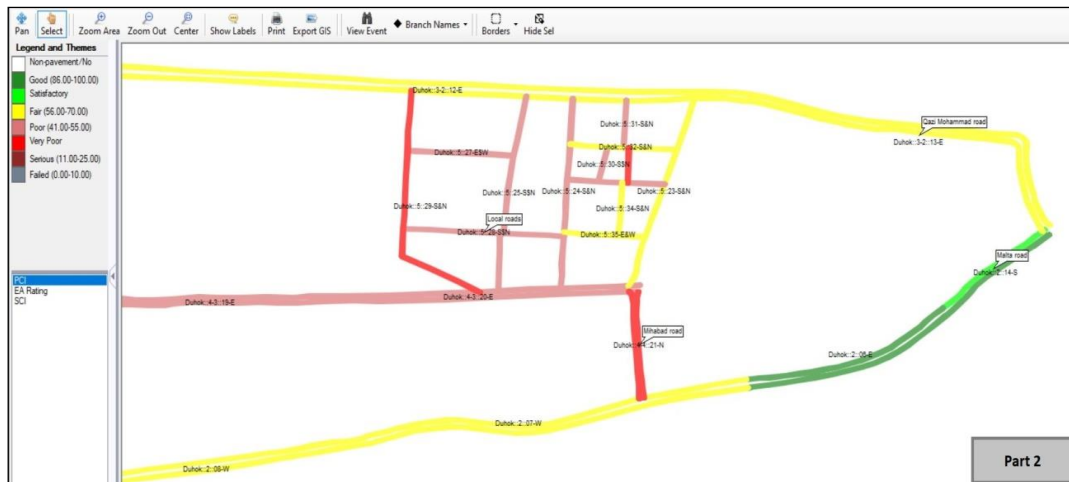
Sample Number	Automated PCI	Manual PCI
2	53.90	54.00
4	58.10	59.00
6	55.20	56.00
8	54.90	53.50
10	56.20	57.00
12	54.30	55.25
14	55.90	56.11
16	72.00	74.10
18	52.50	53.00
Average of PCI	57.00	57.55

**APPENDIX (B)**

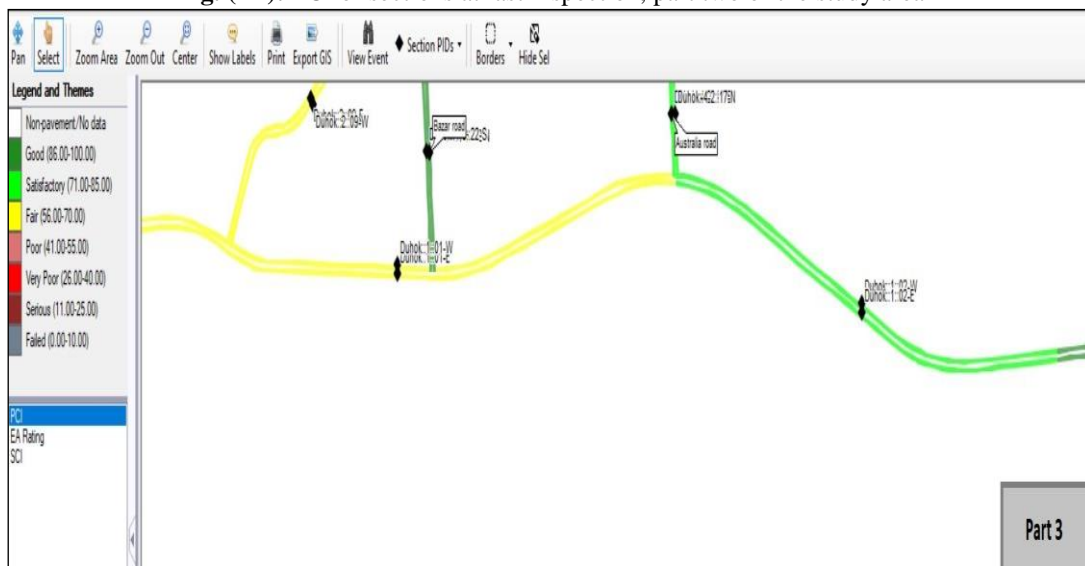
This section presents the PCI of selected road sections at last inspection for the four parts of the study area.



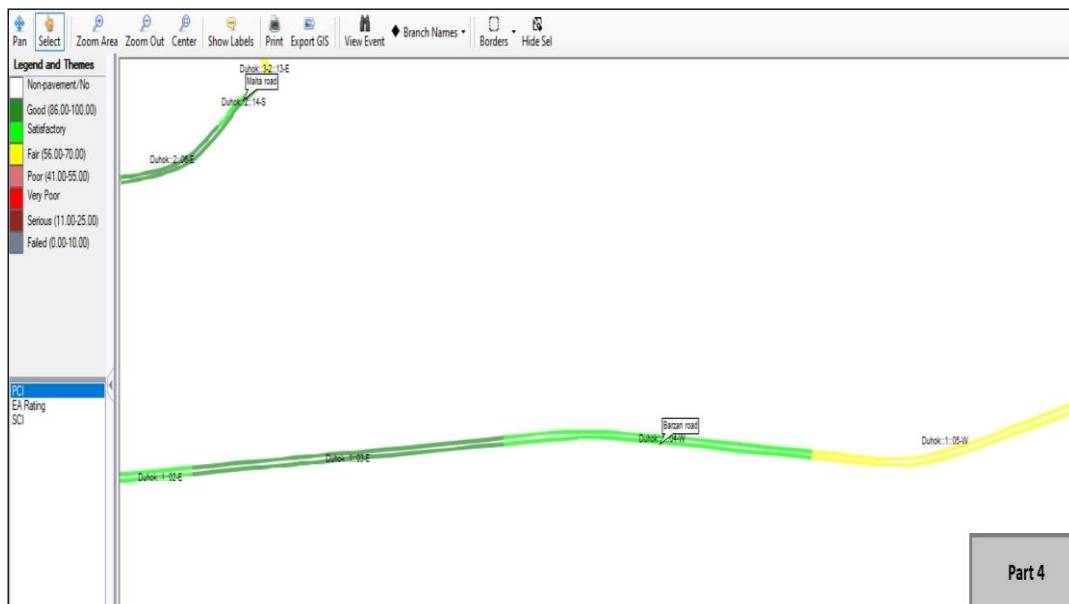
**Fig. (B1):** PCI of sections at last inspection, part one of the study area



**Fig. (B2):** PCI of sections at last inspection, part two of the study area



**Figure B3:** PCI of sections at last inspection, part three of the study area



**Fig. (B4):** PCI of sections at last inspection, part four of the study area