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Developing Priority Program for Pavement Maintenance Management System

A Thesis Submitted to
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the Degree of Master of Science in
Infrastructure Engineering

by
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B.Sc., 2014

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بسم الله الرحمن الرحيم

﴿وَأَنْزَلَ اللَّهُ عَلَيْكَ الْكِتَابَ وَالْحِكْمَةَ وَعَلَّمَكَ مَا لَمْ تَكُنْ تَعْلَمُ وَكَانَ فَضْلُ اللَّهِ عَلَيْكَ عَظِيمًا﴾

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DEDICATION

The deepest words of thanks and appreciation gratitude and dedication go to the great person, if I am where I am today, you are the reason for that and deserves a special mention **my mother**.

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ABSTRACT

The holy city of Karbala is facing big challenges due to the substantial deterioration in its infrastructure of roads network. Improper management method (if existing) leads to increased depreciation. This study aims at developing an optimized priority system within pavement maintenance management system (PMMS) in the network level.

PAVER 6.5.7 software was used to compute Pavement Condition Index (PCI) values for a selected zone of road network in Karbala City. Visual inspection survey was conducted to investigate the type, severity level, and extent of failure at sections and sample units of selected roads. The area under study has 56.8 km length, and contained functionally almost types of urban roads. The data collection is achieved for a total of 109 road sections in; 20 major arterials, 28 minor arterials, 14 collectors, and 47 local sections. Further, the collected data for each section were inventoried and evaluated using PAVER software. Also, analysis and prediction of the PCI curve for different sections were determined for different design lifes and prediction modeling. PAVER software was linked with GIS to layout the established results and show the priority of maintenance and rehabilitation for the whole network using the critical PCI values.

In addition to the simple ranking method by PCI's resulted from the output of PAVER, the study introduces two other measures for each section of roadways. The first is the maintenance priority index (MPI), which is based on multiple measures investigated through expert knowledge about measures that affect prioritization and their irrespective weights due to a pre-designed questionnaire. MPI is related to multiple measures such as the cost of a proper proposed maintenance, easiness of proposed maintenance, average daily traffic and functional classification of the roadway in addition to PCI. The

Second was the Incremental Benefit-Cost Ranking (BCR) analysis which is provide an optimized process due to benefit and cost of maintenance.

The study also introduced efficient display of layout and ranking for the selected zone of roadway system based on MPI index and incremental BCR method. The statistical test shows that there is no significant difference in ranking in all methods of prioritization. The developed method can be used as an extension for pavement condition.

Further more, statistical model of PCI developed showed that 70% of variation in PCI can be explained by multiple regression model in relation with (Age, ADT, SN). The resulted PCI indicated that 35% of roadway sections in the selected study area have good condition (PCI = (85-100)), 26.5 % have satisfactory condition (PCI = (70-85)), 12% have fair condition (PCI = (55-70)), 18% have poor condition (PCI = (40-55)), 6.5% have very poor condition (PCI = (25-40)), 2% have serious condition (PCI = (10-25)), and 0% failed condition (PCI = (0-10)).

It can be concluded that the two optimized methods of prioritization developed in the study can be used successfully in addition to the simple ranking of PAVER. Also, developed models for PCI introduce a good correlation with independent variables of; age, ADT and structure number, can be used to estimate the pavement condition of roadways.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ADT	Average Daily Traffic
APA	Asphalt Pavement Alliance
APC	Asphalt Concrete over Portland Cement Concrete
ASTM	American Society for Testing and Materials
ATR	Airport Transportation Engineering
BCR	Benefit-Cost Ratio
CBD	Central Business District
CDV	Corrected Deduct Value
DCP	Dynamic Cone Penetrometer
DOT	Department of Transportation
FAA	Federal Aviation Administration
F. C.	Functional Classification
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HMA	Hot Mixed Asphalt
IBM	International Business Machines
ICTR	International Center for Technical Research
IRI	International Roughness Index
KCC	Karbala City Center
LR	Laboratory Report
LOC	Library of Congress
M&R	Maintenance and Rehabilitation

LIST OF ABBREVIATIONS

MEPDG	Mechanistic-Empirical Pavement Design Guide
MP	Maintenance Priority
MPI	Maintenance Priority Index of Section.
MPR	Mean Panel Rating
NCHRP	National Cooperative Highway Research Program
PCI	Pavement Condition Index
PCU	Passenger Car Units
PCR	Pavement Condition Rating
PDI	Pavement Distress Index
PI	Profile Index
PMS	Pavement Management System
PMMS	Pavement Maintenance Management System
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
RCI	Riding Comfort Index
RN	Ride Number
SCRB	State Commission for Roads and Bridges
SORB	State Organization for Roads and Bridges
SN	Structural Number
TDV	Total Deduct Value
TRB	Transportation Research Board
UFC	Unified Facilities Criteria
USD	United States Dollar
VDOT	Virginia Department of Transportation
VMA	Voids in Mineral Aggregate
WSDOT	Watsontown State Department Of Transportation

LIST OF SYMBOLS

a, b, c, d, and e	Irrespective Weight Value due to Experts Response
$\mathbf{a_i}$	Layer Coefficients
AGE	Number of Years Since Construction
C	Maintenance cost for each section per square meter.
CI	Garber Condition Index
$\mathbf{CI_1}$	arterial &collector Condition Index developed
$\mathbf{CI_2}$	arterial Condition Index developed
$\mathbf{D_i}$	Actual Thickness of Layer
e	Allowable Error
E	Easiness of Work through Maintenance Sections
F	Functional Classifications
$\mathbf{HDV_i}$	Highest Individual Deduct Value for Sample Unit
i	The Sampling Interval
$\mathbf{m_i}$	Drainage Coefficient
$\mathbf{M_i}$	The Maximum Allowable Number of Deducts
n	The Minimum Number of Sample Units to Be Surveyed
N	Total Number of Sample Units in The Pavement Section
$\mathbf{PV_{benefits}}$	Present Value of Benefits
$\mathbf{PV_{cost}}$	Present Value of Cost
q	Number of deduct with a value $> 2$for surfaced roads
$\mathbf{R^2}$	Coefficient of Determination
s	Standard Deviation
S	Random start

CHAPTER ONE

CHAPTER ONE

INTRODUCTION

1.1 General

Much of the nation's infrastructures were built in the latter half of the 1900's, most notably the interstate highway system. These infrastructures are reached their life spans and are now in need of repair. Cost-competent maintenance and management of civil infrastructures require balanced consideration of both the structure performance and the total cost accrued over the entire life-cycle. Most existing maintenance and management systems are developed on the basis of life-cycle cost minimization only. (Frangopol and Liu, 2007).

Transportation engineering is the application of technology and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods (Roess et al., 2011). Highways system contributes to the economic, industrial, social, and cultural development of any country (Gedafa, 2008). The huge network of roadway within the highway system needs extensive maintenance and repair activities. Also, increasing numbers of motor vehicles during the coming decades need a developed nation's highway system. Accordingly, the increase in demand for new construction, as well, as efficient rehabilitation of the existing system has become a major activity for highway and transportation agencies. For some nation's interstate highway system in developed countries as well as for the case of restricted budgets in develop countries, the focus is shifting from new construction to maintaining, preserving, and rehabilitating highway assets.

Preserving and managing the nation's highways is still a challenge (Garber and Hoel, 2009).

Highway pavements, after a time of construction, will not last forever and signs of wear will appear. A point will arrive where the wear and tear are at an advanced stage that the standard of service provided has diminished (Rogers, 2003). Therefore, the capacity of the road network is constrained structurally deficient due to lack of timely maintenance, rehabilitation and up-gradation. This has adversely affected the traffic movement, resulting in higher operating costs and delays (NIJU, 2006).

According to the World Bank Report (1988, 2005), "The developing countries have lost precious infrastructure worth billions of dollars through the deterioration of roads. The cost of restoring these roads is going to be three to five times greater than the bill would have been for timely and effectively maintenance". Hence, there is a need to manage the roads network more efficiently and by a scientific manner (NIJU, 2006).

Márquez (2007) defined maintenance as a combination of all technical, administrative and managerial actions during the lifecycle of an item intended to retain it in, or restore it to a state in which it can perform the required function (function or a combination of functions of an item which are considered necessary to provide a given service). The broad objective of road maintenance is to keep the roads in the original condition as much as possible. However, the resources made available for road maintenance are limited in most countries (Thagesen, 2006).

The Pavement Maintenance and Management Systems (PMMS) is a set of tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition (Haas et al., 1994). The PMMS consists of two basic components; first, a comprehensive database, which contains current and historical information on pavement condition, pavement structure, and traffic. The second component is a set of tools that allows us to determine existing and future pavement conditions, predict financial needs, and identify and prioritize pavement projects (NIJU, 2006).

The Pavement Management Systems (PMS) is a valuable tool that can save money and maximize benefits for the highway system. It has become increasingly popular among local highway agencies, since many countries have the realized benefits of having a decision-support system that helps them find cost-effective strategies for keeping their pavements in good condition (Fitch et al., 2001; Zhou, 2011), and maintain a highway system at an acceptable level of service that continues to support economic growth with a small amount of resources (Tsai et al., 2004; Kulkarni and Miller, 2003; Kulkarni, 1984; Zhou, 2011).

1.2 Roadway System in Iraq

In Iraq, elements of a high-grade transportation infrastructure were provided by a sustained campaign for economic development in the 1970s. Further, in eastern Iraq, development of roads and railroads supported the war effort against Iran (1980–1988). The United States, in 2004, dedicated 500 USD million in aid for the upgrading of transportation in Iraq (LOC, 2006).

In 2005, the paved roads in Iraq had about 39,000 kilometers, many of which were broad highways constructed for military and commercial use in the 1970s and 1980s. Most damages to roads and bridges were repaired after the Arabic Gulf War in 1991 that targeted transportation infrastructure. The damaged bridges by coalition forces in 2003 were the focus of major repair operations in 2004 (LOC, 2006).

1.3 Holy City of Karbala

Karbala is located in the central region of Iraq on the edge of the eastern plateau bank, west of the Euphrates river, and specifically between longitudes 43, 33 north. It is limited from the north and west by Anbar province and from the east by province of Babylon and from the south by Najaf province. Karbala is one of the main cities of the islamic holy shrines characterized by its standing historical, cultural and specificity urban in Iraq position. Two major city center shrines of Imam Hussein and Imam Abbas peace be upon them exist in the middle center of the city. Karbala city is located within the most densely populated geographical regions in Iraq (ICTR, 2011). Plate (1-1) shown the holy Karbala city in Iraq and the roadway network selection for study area.

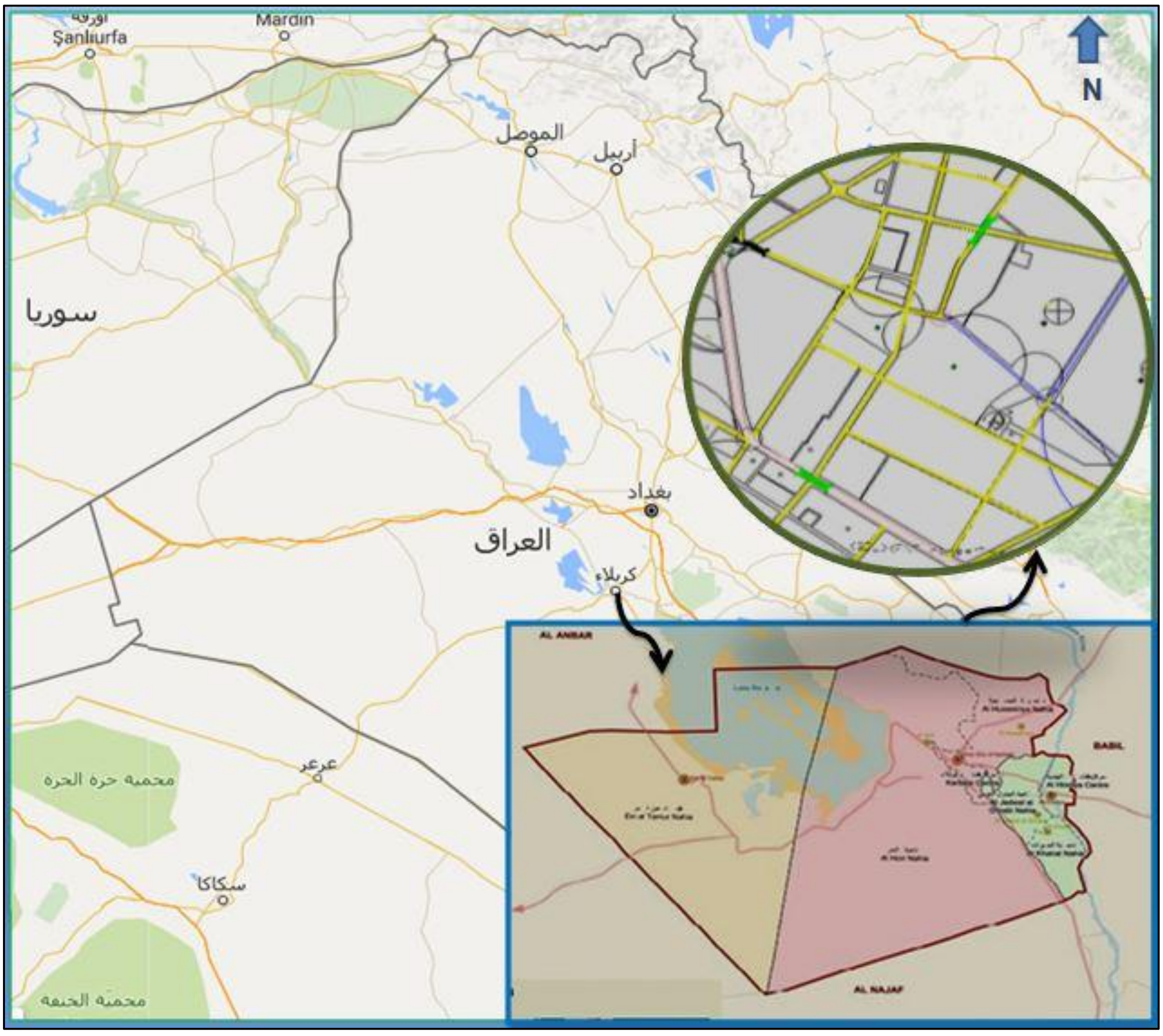


Plate (1-1) The Road Network in Karbala, Iraq.

The importance of the city of Karbala is not only because of the tourist attractions, but also it is the land route leading to the pilgrimage back and forth (ICTR, 2011).

In 2016, Karbala city has 1,741.005 km roads length. The directorate mayor team showed that 999.355 km of the city center roads have 59% paved and 41% unpaved, while the directorate roads and bridges team showed that 741.650 km external roads have 90 % paved and 10 % unpaved.

1.4 Importance of the Study

Karbala city, as other Iraq's governorates is facing a big challenge in dealing with the deterioration of roads. Roadway system of Karbala has been constructed in 20 to 50 years ago, and hence the system is near to the end of its economic life. There is a great demand for achieving an effective pavement management maintenance system in the city.

This study demonstrated an application of PAVER software system integrated with GIS to establish a priority of maintenance for a selected zone in Karbala city. Due to the restricted budget for new construction as well as roadway system demand to maintain, the study make use of existing pavement management system by PAVER software to demonstrate the efficient tool of maintenance to develop an optimized priority system that ensures efficient allocation of the financial resource.

1.5 Aim of the Study

The main aim of this work are:

Developing an optimized priority system that ensures efficient allocation of the financial resource of pavement maintenance at the network level of PMMS.

1.6 Objective of the Study

The objective of this work are:

1- Evaluating pavement performance for a selected zone by using PAVER software and GIS and check the value of pavement condition index with the result of hand calculation.

2- Verification the output of PAVER (PCI) with previously developed models.

3- Developing models to relate PCI with geometric and traffic characteristics of roadway system in Karbala.

4- Investigation of expert knowledge about measures that affect prioritization of sites for maintenance results that, in addition to PCI determined from PAVER system.

1.7 Layout of the Study

The public domain adopted in this work can be summarized as below:

1- Chapter one gives an introduction and a brief idea of the present work.

2- Chapter two is devoted to the literature review. It focuses on the highway functional classification, structure of pavement, pavement distresses, and pavement maintenance and management.

3- Chapter three describes the area and network of study and the methodology of data collection. I also describes the computer programs used in this study (i.e. PAVER software and GIS).

4- Chapter four explains the processes of PAVER application and the analysis of results and developing model.

5- Chapter five demonstrates composition priority of pavement maintenance from PAVER output and combined measures rather than PCI measures only.

6- Chapter six contains conclusions, and recommendations for future work.

CHAPTER TWO

CHAPTER TWO

LITERATURE REVIEW

2.1 General

In this chapter, articles about related topics are introduced. Descriptions of functional system of urban roads, types of pavements, cross section layer of flexible pavement are reviewed. Furthermore, this chapter introduced the types of failure (structural and functional), flexible pavement distresses and repair of pavement deterioration. Also, a brief complementation of: pavement management systems and it is function, pavement maintenance management systems, pavement condition programs used in pavement management, relations and models of pavement condition index (PCI), are also introduced in this chapter.

2.2 Functional System of Urban Roads

In the USA, urban roads comprise highway facilities within urban areas as designated by responsible state and local officials to include communities with a population of at least 5000 people. Some states use other values, for example, the Virginia Department of Transportation uses a population of 3500 to define an urban area. Urban areas are further subdivided into urbanized areas with populations of 50,000 or more and sub urban areas with populations between 5000 and 50,000. Urban roads are functionally classified into principal arterials, minor arterials, collectors, and local roads. A schematic of urban functional classification is illustrated in Fig. (2-1) for an urban environment group (Gerbar and Hoel, 2009).

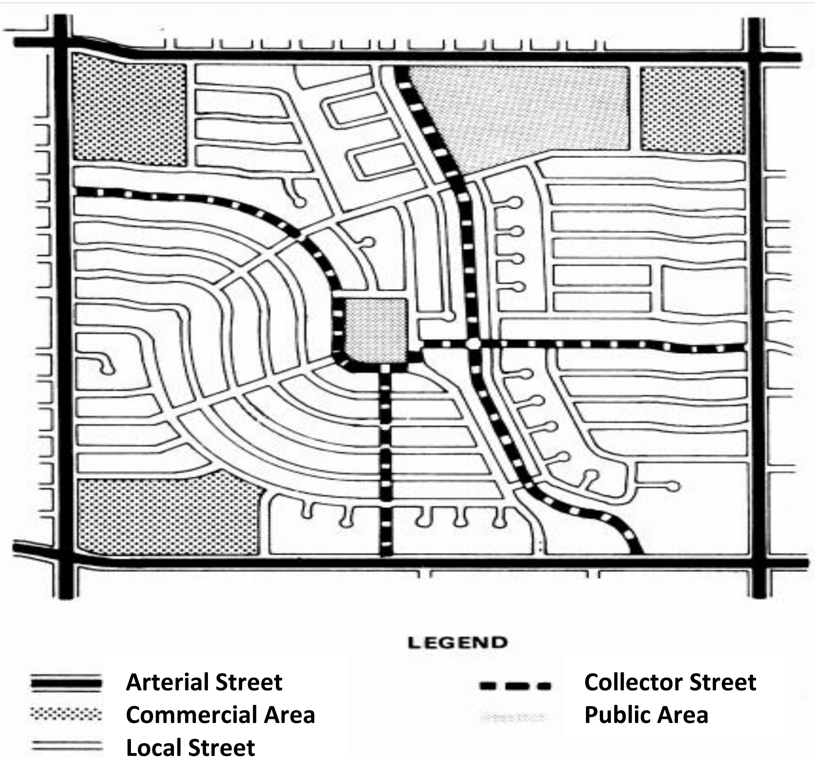


Figure (2-1) Schematic Illustration of the Functional Classes for an Urban Road Network (Source: Garber and Hoel, 2009).

2.2.1 Urban Principal Arterial System: Characteristics of this system are (Gerbar and Hoel, 2009; FHWA, 2013):

- Serve major activity centers, longest trip demands and highest traffic volume corridors.
- Carry high proportion of total urban travel on minimum of mileage
- link and provide continuity for major rural corridors in order to contain trips entering and leaving urban area and movements through the urban area.
- Serve demand for intra-area travel between outlying residential areas and the central business district.

2.2.2 Urban Minor Arterial System: Streets and highways that interconnect with and augment the urban primary areas are classified as an urban minor arterial. Characteristics of this system are as follow: (Garbar and Hoel, 2009; FHWA, 2013):

- Interconnect and augment the higher-level arterials.
- Serve trips of moderate length at a somewhat lower level of travel mobility than principal arterials.
- Distribute traffic to smaller geographic areas than those served by higher-level arterials.
- Provide more land access than principal arterials without penetrating identifiable neighborhoods.
- Provide urban connections for rural collector.

2.2.3 Urban Collector Street System: The characteristics of an urban collector are classified into a major and minor collector as shown in Table (2-1):

Table (2-1) Major and Minor Collector Characteristics (Source: Gerbar and Hoel, 2009; FHWA, 2013).

Major Collectors	Minor Collectors
Serve both land access and traffic circulation in higher density residential, and commercial/industrial areas.	Serve both land access and traffic circulation in lower density residential and commercial/industrial areas.
Penetrate residential neighborhoods, often for significant distances.	Penetrate residential neighborhoods, often only for a short distance.
Distribute and channel trips between local roads and arterials, usually over a distance of greater than three-quarters of a mile.	Distribute and channel trips between local roads and arterials, usually over a distance of less than three-quarters of a mile.
Operating characteristics include higher speeds and more signalized intersections.	Operating characteristics include lower speeds and fewer signalized intersections.

2.2.4 Urban Local Street System: The characteristics of this system (Garbar and Hoel, 2009; FHWA, 2013):

- Provide direct access to adjacent land.
- Provide access to higher systems.
- Carry no through traffic movement.
- Constitute the mileage not classified as part of the Arterial and Collector systems.

2.3 Types of Pavement

Historically, pavements have been divided into two broad categories (see Fig. (2-2)). The flexible pavement has multiple layers consist of a relatively thin wearing surface constructed over a base course and the last one constructed over subbase course. These layers rest upon a compacted subgrade. In contrast, the rigid pavements are made up of Portland cement concrete, the base course between the pavement and subgrade (may/may not) found. The primary difference between the two pavement types (i.e. flexible and rigid) is the method in which they distribute the load over the subgrade layer (Yoder and Witczak, 1975; FHWA, 1995).

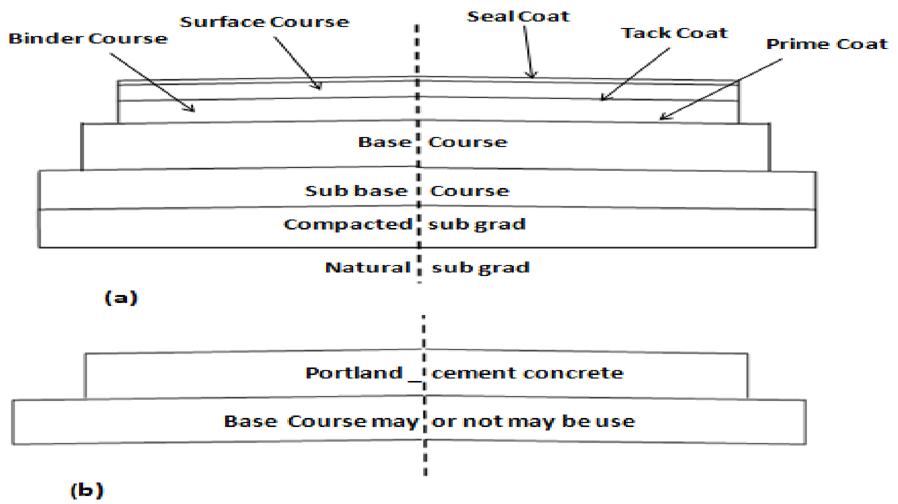


Figure (2-2) Structure Components of (a) Flexible Pavement (b) Rigid Pavement (Source: Yoder and Witczak, 1975).

Flexible pavement constructs the high percent of roads in Karbala city. Hence, in this study, the focus will be concentrated on flexible pavement roads. The load carrying capacity of a truly flexible pavement is brought about by the load distributing characteristics of the layered system. The flexible pavements consist of a series of layers with the highest-quality materials at or near the surface. Hence, the flexible pavement strength is the result of constructing a stiffer layer which helps to distribute the load over the subgrade rather than by the bending effect of the slab. The pavement thickness design is affected by the strength of the subgrade. If an asphalt pavement has high stiffness, it may be considered essentially as a rigid pavement and fatigue of the pavement component especially surface may become critical (Yoder and Witczak , 1975; Fred and Scott, 2013).

2.4 Typical Cross Section of a Flexible Pavement

Flexible pavements support loads through bearing. They include several layers of materials designed to distribute loads gradually from the surface of pavement to the layers underneath. The design ensures that the load transmitted to each consecutive layer does not skip the layer's load bearing capacity and does not exceeds the strength of the layer itself. Fig. (2-3) illustrates a cross section of a typical flexible pavement, that composed of the following:

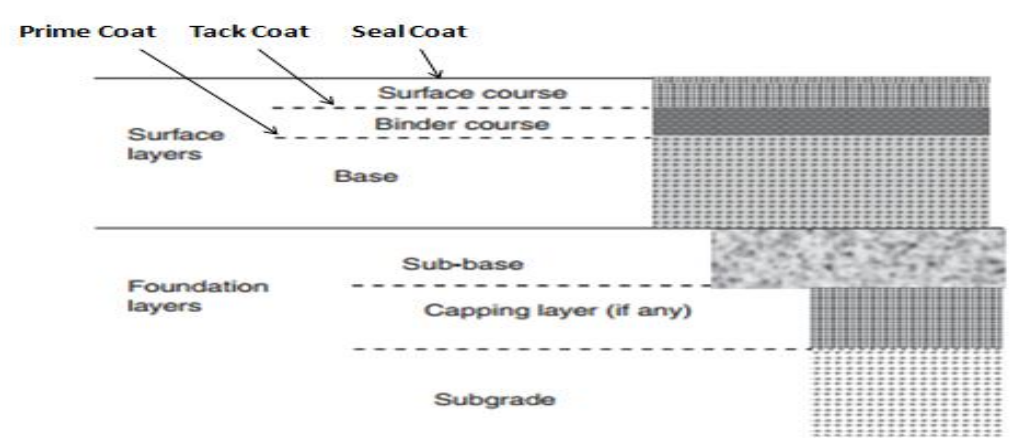


Figure (2-3) Layer of Flexible Pavement (Source: Huang, 2004).

- **Surface Course**: Also called (wearing course) is the upper course of an a flexible pavement, usually built of dense-graded hot mix asphalt (HMA). This course must be of top causality material to resist deformation and provide skid-resistance and smoothness. Also, it must prevent water from penetration to the underlying layers to protect the subgrade from the weakening effect of water. The use of a seal coat is recommended if the above requirements cannot be met (Huang, 2004).
- **Binder Course:** The binder course is the asphalt layer under the surface course. The binder course is used in addition to the first layer (surface course) for two causes. First, if the HMA is too thick to be compacted in one layer, so it must be put in two layers. Second, if the binder course mostly consists of less asphalt with larger aggregates and does not need high quality as the same of surface course, so substitute a part of the surface course by the binder course results to get a more economical design. Generally, the binder course is placed in two layers if it is more than 3 in (76 mm) (Huang, 2004).
- **Base Course & Subbase Course:** The base course is the layer of material immediately under the surface or binder course. It can consist of crushed stone, crushed slag, or other untreated or stabilized materials. The subbase course is the layer of material beneath the base course. The cause of using two different granular materials is for the economy. The base course material is more expensive for the entire layer, which leads to use the subbase course instead of this. The subbase course has local and cheaper materials and can be used on the top of the subgrade. The subbase course with more fines can serve as a filter between the subgrade and the base course if the base course is open-graded (Huang, 2004).
- **Subgrade:** The top 6 in (152 mm) of the subgrade layer should be compacted to the desired density near the optimum moisture content.

The compacted subgrade may be the in situ soil or a layer of selected material (Huang, 2004).

2.5 Types of Pavement Distress

There are two different types of failures as follows (Yoder and Witczak, 1975; D6433, 2011):

1- **Structural distress:** the structural distress includes a collapse or breakdown of the pavement structure components to one or more layer, and become not able to carry the load upon its surface.
2- **Functional distress:** the functional distress may (or may not) be accompanied by structural distress. This distress caused discomfort for vehicle drivers in the driving task.

Structural failure is associated with the ability of the pavement to carry the design load, whereas functional failure is related to ride quality and safety. When structural failure increases in severity, it always results in functional failure as well due to the roughness. Obviously, the degree of distress for both categories is gradational, and the severity of distress of any pavement is largely a matter of opinion of the person observing the distress. However, the difference between the two types of failures is important. Also, engineers should be able to distinguish between them (Yoder and Witczak, 1975). Plate (2-1) shows the factors, sub factors and interaction which can affect pavement deterioration (Hass et al., 2011).

2.6 Pavement Distress Evaluation

Pavement distress is an important component in defining the status of a pavement and can be useful in selecting appropriate preservation treatments. While deflection, roughness, and safety are also components of a pavement’s condition, historically the term condition survey identified the process of evaluating surface distresses.

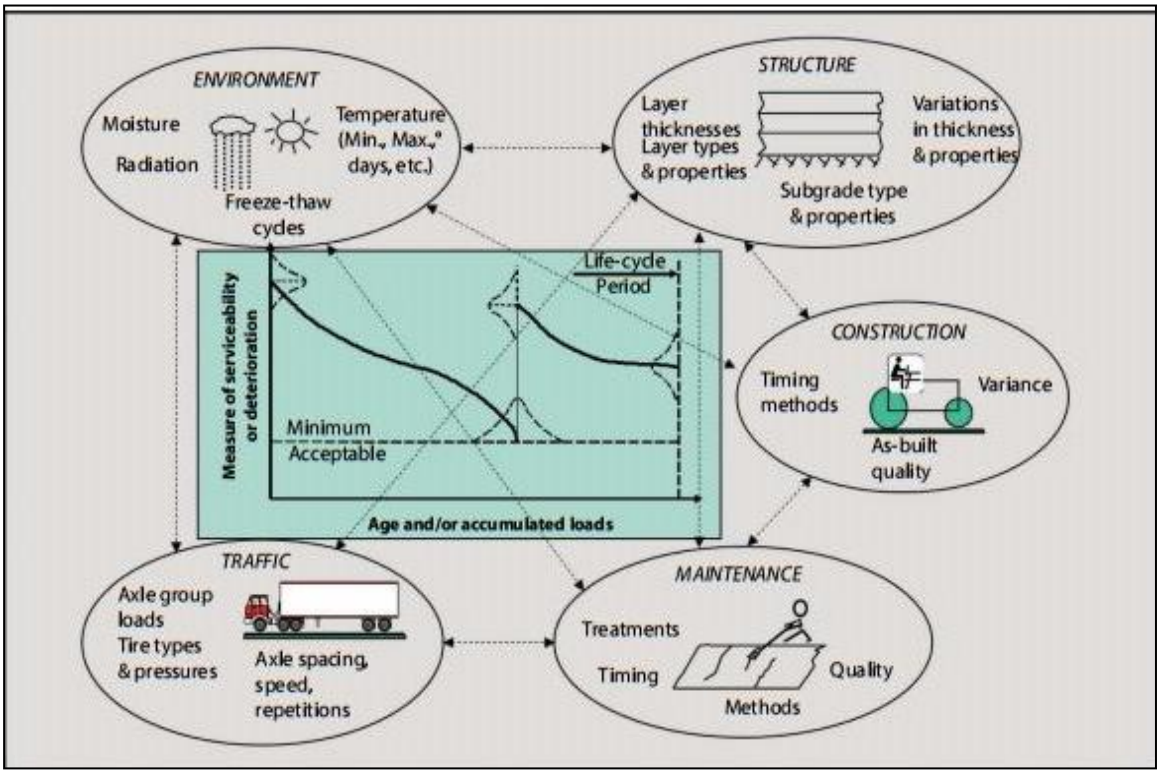


Plate (2-1) Factors, Sub-Factors and Interaction That Affecting Pavement Deterioration (Source: Hass et al., 2011).

Distress evaluation, generally, considers three factors: the type, severity, and extent of damage (FHWA, 2003; Miller, 2003). The particular distress evaluation methods vary among agencies. Both ASTM and AASHTO have published standards for distress evaluation. The relevant AASHTO standards are (Hass et al., 2015):

- AASHTO R 48, Standard Practice for Determining Rut Depth in Pavements.
- AASHTO R 55, Quantifying Cracks in Asphalt Pavement Surface.
- AASHTO PP 67, Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods.
- AASHTO PP 68, Collecting Images of Pavement Surfaces for Distress Detection.
- AASHTO PP 69, Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profile.

- AASHTO PP 70, Collecting the Transverse Pavement Profile.

2.6.1 Types of Flexible Pavement Deterioration

Pavement distress is caused by various factors or a combination of factors including lack of structural capacity, poor design, inferior material quality (Kaloush et al., 2006), poor construction techniques and/or lack of preventive maintenance (Al-Mansour and Al-Mubaraky, 2007). The five major categories of conventional asphalt pavement surface distresses are (Miller, 2003; Adlinge and Gupta, 2015):

2.6.1.1 Cracking:

The most common types of cracking are: (1)Alligator cracking (Fatigue cracking), (2) Longitudinal and transverse cracking, (3) Block cracking, (4) Slippage cracking, (5) Joint reflective cracking, and (6) Edge cracking (Adlinge and Gupta, 2015).

2.6.1.2 Surface Deformation:

Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard. The basic types of surface deformation are: (1) Rutting (2) Corrugations (3) Shoving (4) Depressions (5) Swell (6) Bumps and Sags (Adlinge and Gupta, 2015).

2.6.1.3 Disintegration:

The progressive breaking up of the pavement into small, and loose pieces is called disintegration. If the disintegration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are: (1) Potholes, (2) Patching and utility cut patching (Adlinge and Gupta, 2015).

2.6.1.4 Surface Defects:

Surface defects are related to problems in the surface layer. The most common types of surface distress are: (1) Weathering and raveling (2) Bleeding, and (3) Polishing (Adlinge and Gupta, 2015).

2.6.1.5 Other:

1. Lane /shoulder drop off.
2. Railroad crossing (Adlinge and Gupta, 2015).

The way of survey for each type of distress is presented in Appendix (A). Table (2-2) lists all possible types of distress or failure in flexible pavements and indicates whether they are structural or functional failures and cause (load, climate, or other).

Table (2-2) PAVER Software Classification Distress for Flexible Pavement Roads and Parking (Source: Shahin, 2005; Yoder and Witczak, 1975).

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

2.7 Highway Pavement Maintenance

Highway pavement maintenance consists of those activities, which preserving the network of roads and footpaths, retaining or enhancing the performance of each part by comparison with identified minimum service standards and ensuring that they provide a positive contribution to the environmental and transport needs of the area (World Bank, 1988).

Maintenance reduces the rate of pavement deterioration. It lowers the cost of operating vehicles on the road by improving the running surface, and it keeps the road open on a continuous basis. Factors affecting the need for maintenance include increases in road mileage, the growing number and weight of commercial vehicles, demands for higher standards of maintenance and performance, together with the impact of public utility works and the variability of weather conditions including the impact of climate change (Walsh et al., 2011). Current maintenance needs can be identified using the maintenance unit system. In the case of deferring the M&R activities, the identification of future maintenance needs is crucial in the planning and cost allocation of Maintenance and Rehabilitation (M&R) activities. The performance prediction is a critical requirement for the identification of future pavement preservation needs. Pavement performance depends on many local factors and is not easily transferable from a location (agency) to another. Therefore, identifying the future maintenance needs is considered a key challenge in the management cycle (Beauvais et al., 2003; Hajek et al., 2004; VDOT, 2006; Cuelho et al., 2006).

Maintenance activities may be classified in terms of their operating frequencies into:

A. **Routine maintenance:** Routine maintenance covers activities that must be carried out frequently, i.e. once or more per year. They are typically small scale, or simple, and often widely dispersed. Some of them can be estimated and planned in advance, e.g. vegetation control on shoulders and slopes. Other activities are harder to plan in advance, e.g. roadway pothole patching (Rijn, 2006).

B. **Periodic maintenance & Reconstructions:** Periodic maintenance is considered all repairs that hold out less frequent. This type of maintenance includes all types of repairs including resurfacing, overlays, and pavement construction (base and even subbase course). The intervals of periodic maintenance vary according to the needs and may be irregular, and it depends on the quality of the construction. To obtain the most cost-effective one, planners should play with various scenarios of periodic maintenance. They can choose for more repeated but less efficient and cheap repairs, i.e. five year periods or to work with bigger periods selecting techniques of rehabilitation that are very effective but also expensive. The interval sets performance requirements to the routine maintenance budget activities. Ideally planners would choose the scenario that has the most cost-effective (Rijn, 2006).

C. **Emergency maintenance:** repairs are all activities of maintenance that have to carried out instantly to save lifes or prevent the disastrous effect of deteriorated infrastructure. Structural damages to flyovers due to accidents are one of typical examples of such emergencies. Departments of maintenance requirement to unrestricted access to budgets of emergency maintenance that allow them to carry out repairs that relieve immediate risks. Some senior management may wish to control access to emergency maintenance for work with more long-term focus (Rijn, 2006).

2.7.1 Forms of Pavement Maintenance

Maintenance can be either minor or major for a flexible roads (Rogers, 2003).

A. Minor maintenance takes the form of patching. It permits defective materials, especially those in the pavement surface courses, to be changed. If it is done exactly, it can return the stability and riding quality of the surface of the pavement, arresting its deterioration and widening its serviceable life. It is an integral part of highway maintenance and produces sound economic significance (Rogers, 2003).

Patching can repair the following troubles (Rogers, 2003):

- Substandard drainage or some other problem with regards to the subgrade that will cause the failure in the foundation of the pavements
- The asphalt surface ageing, causing its breakup with the consequent formation of potholes and crack areas
- Decreased load bearing capacity of the pavement due to the water entry and deterioration due to frost.

Patching includes the repair of random areas of substandard pavement, not continuous dimension (widths/lengths).

B. Major maintenance of asphalt pavements may include removing all or part of the surface using a planer and resurfacing the road, or laying a course of the asphalt over the present one. The process of overlaying is transacted with in detail within this text as asphalt pavements are designed under LR1132 on the basis that, at the end of their design life, their structural safety is such that the implementation of an overlay will significantly provide their serviceable life (Powell et al., 1984). Both overlaying and resurfacing are carried out for the following common reasons (HD 31/94) (DoT, 1994):

- To strengthen the highway pavement
- To replace defective materials
- To restore skidding resistance
- To improve riding quality.

The design of an overlay (minimum 50 mm thick) involves estimating the thickness required to deliver the required additional life to the pavement slab (Rogers, 2003).

2.7.2 Repair of Flexible Pavement Distress

Each type of distress needs a different type of repair based on distress severity as shown in Table (2-3) (Shahin, 2005; UFC, 2004).

Table (2-3) Asphalt Concrete Pavement Distress Types and Maintenance & Rehabilitation (M&R) Alternatives (Source: Shahin, 2005; UFC, 2004).

Distress Type	Severity Levels	Maintenance and Rehabilitation (M&R)		
		Density		
		≤ 10%	between 11%--50%	> 50%
Alligator/ Fatigue Cracking	Low	Do Nothing	Slurry seal	Slurry seal
	Medium	Deep Patching	Deep Patching	Deep Patching
	High	Deep Patching	Deep Patching	Reconstruction
Block Cracking	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Crack Sealing	Crack Sealing	Slurry seal
	High	Slurry seal	Slurry seal	Thin Overlay
Long /Transverse Cracks *	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Crack Sealing	Crack Sealing	Crack Sealing
	High	Slurry seal	Slurry seal	Thin Overlay
Patching	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Deep Patching	Deep Patching	Deep Patching
Potholes **	Low	Surface Patching	Surface Patching	Surface Patching
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Deep Patching	Deep Patching	Deep Patching

(*)Measured amount deformation by Linear meter
(**)Measured amount deformation by Number of drilling
Other Measured by Square meter.

Table (2-3) Asphalt Concrete Pavement Distress Types and Maintenance and Rehabilitation (M&R) Alternatives (Source: Shahin, 2005; UFC, 2004) (continued).

Distress Type	Severity Levels	Maintenance and Rehabilitation (M&R)		
		Density		
		≤ 10%	between 11%--50%	> 50%
Depression	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	high	Deep Patching	Base Repair & Repave	Base Repair & Repave
Shoving	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Deep Patching	Deep Patching	Deep Patching
	High	Deep Patching	Deep Patching	Deep Patching
Rutting	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Milling & Repave	Milling & Repave	Milling & Repave
	High	Deep Patching	Deep Patching	Reconstruction
Asphalt Bleeding	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Do Nothing	Hot Sand Blotting	Milling & Repave
	High	Milling & Repave	Milling & Repave	Milling & Repave
Reflection Cracks *	Low	Do Nothing	Crack Sealing	Crack Sealing
	Medium	Crack Sealing	Crack Sealing	Crack Sealing
	High	Surface Patching	Surface Patching	Surface Patching
Lane/ Shoulder Drop *	Low	Refill Shoulder	Refill Shoulder	Refill Shoulder
	Medium	Refill Shoulder	Refill Shoulder	Refill Shoulder
	High	Refill Shoulder	Refill Shoulder	Refill Shoulder
Slippage Cracks	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Deep Patching	Deep Patching	Deep Patching
Swell	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Deep Patching	Deep Patching	Deep Patching
	High	Deep Patching	Deep Patching	Deep Patching
Railroad Crossing	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Surface Patching	Surface Patching	Surface Patching
Weathering / Raveling	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Slurry Seal	Slurry Seal	Slurry Seal
	High	Thin Overlay	Thin Overlay	Thin Overlay
Polished Aggregates	——	Do Nothing	Slurry Seal	Slurry Seal
Bumps& Sags *	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Deep patching	Deep patching	Deep patching
Corrugations	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Base Repair & Repave	Base Repair & Repave	Deep patching
Edge Cracks *	Low	Do Nothing	Do Nothing	Do Nothing
	Medium	Surface Patching	Surface Patching	Surface Patching
	High	Repair Shoulder/Deep Patch	Repair Shoulder/Deep Patch	Repair Shoulder/Deep Patch

(*)Measured amount deformation by Linear meter

(**)Measured amount deformation by Number of drilling

Other Measured by Square meter

2.8 Pavement Management System (PMS)

Pavement management is a systematic process for maintaining, upgrading, and operating physical pavement assets in a cost effective manner. The process combines applications of established engineering principles with sound business practices and economic theory, thus assuring an organized and scientific approach to decision making (Garbar and Hoel, 2009).

A pavement management system must serve different management needs or levels, and it must interface with the broader highway, airport, and /or transportation management system involved. Fig. (2-4) shows a PMS consists of alternately reacting components such as programming, planning, design, construction, maintenance, and rehabilitation.

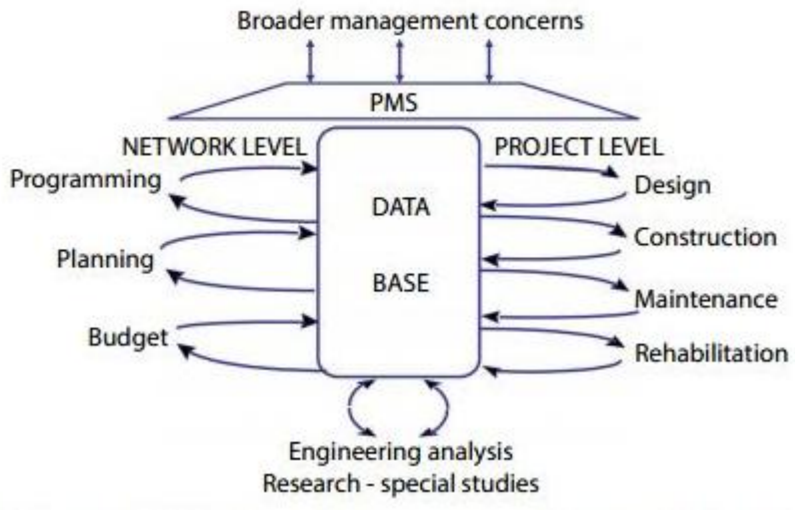


Figure (2-4) Major Component of a Pavement Management System (PMS) (Source: Hass et al., 2015)

Further, PMS prepares a logical and profitable approach to operations of pavement maintenance. PMS that evaluates several alternatives use the expected maintenance and rehabilitation treatments impact on the performance of the future pavements. To support fund requests and justify maintenance and rehabilitation programs, PMS also extend all the information needed (Huang, 2004). However, the PMS components have significant but changing effects in terms of an influence level (Barrie and Paulson, 1992).

The PMS concept shows that the impact on the total life cycle cost of a project reduces as the project reduces, as shown in Fig. (2-5). The bottom division of the Figure appears the time length of each major component acts on the life pavement. The upper division shows rising costs and decreasing influence on the life of a pavement. Cost through the planning step is small compared with the total cost. Similarly, the principal costs for construction are a portion of the operating and maintenance costs related to the life cycle of the pavement. However, the decisions made through the early phases of a project have far major proportional effect on subsequently required expenditures than several of the following activities.

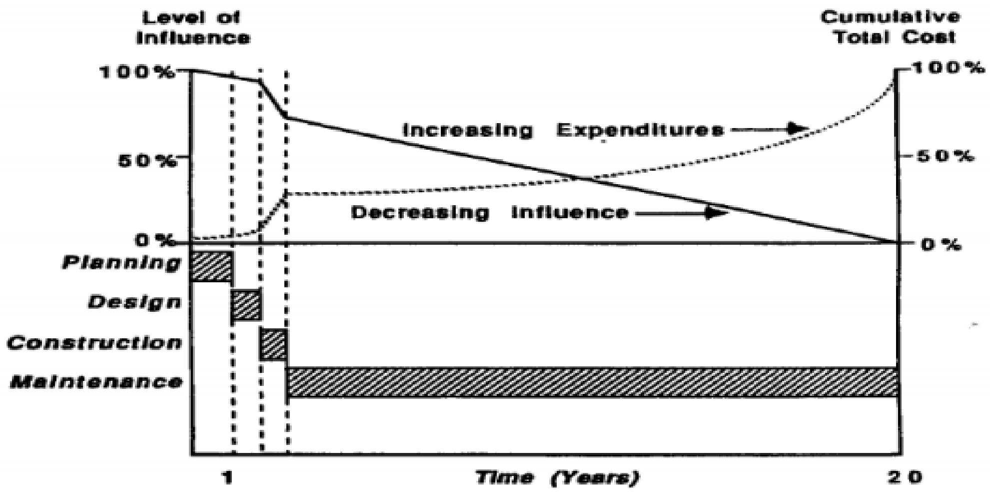


Figure (2-5) Influence Level of PMS Subsystems on the Total Costs (Source: Hass et al. 1994).

2.8.1 Function of Pavement Management System (PMS)

The goal of most PMS is to maximize the effectiveness of pavement maintenance and rehabilitation by using maximum benefits of the available fund (Shahin, 2005). The function of a PMS is to improve the efficiency of decision making, expand the scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization. PMS can provide several benefits for highway, airport, and other facilities at both the network and project levels. At the network level, agency-wide programs of new construction, maintenance, or rehabilitation are developed to have the least total cost, or greatest benefit, over the selected analysis period. At the project level, detailed construction is given to alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within the overall program (Haas et al., 1994).

In order to realize the full benefits of such a management system, the following steps must be taken into consideration: (1) Proper information for each management level must be collected and periodically updated, (2) Decision criteria and constraints must be established and quantified, (3) Alternative strategies must be identified, (4) Predictions of the performance and costs of alternative strategies must be made, and (5) Optimization procedures that consider the entire pavement life cycle must be developed (Haas et al., 1994).

2.8.2 Activity Levels of Pavement Management System (PMS)

Activities of pavement management are conducted at two special levels: network level, and project level (Haas et al. 1994). First, the network level is "a global view of the pavement infrastructure and addresses the overall budget and planning issues". Second, the project level has a local focus on a bounded component of the larger network. The project level is where specific decisions on strategies of maintenance and funding divisions are made (Huang, 2004).

Before any data is collected, it is important to understand the differences between network and project level pavement management. A network level pavement management system is related to program and policy issues for the entire network; therefore, a network level analysis will be of the most use and interest to the manager, budget director, etc. A project level Pavement Management System analysis is a series of steps to determine the cause and extent of pavement deterioration in local agencies (WSDOT, 1994; shahin, 2005).

The purpose of the network level management process is normally related to the budget process. At the project level, the purpose is to provide the best original design, maintenance, or rehabilitation strategy possible for a selected section of pavement for the funds available. The primary results of the project level analysis include an assessment of the cause of deterioration, identification of the possible design, maintenance and rehabilitation strategies, and selection of the "best" strategy within imposed constraints. This requires a considerable quantity of detailed data. In this study, the project level pavement management system is used.

2.8.3 Pavement Maintenance Management System (PMMS)

Pavement Maintenance Management System (PMMS) should not be confused with Pavement Management System (PMS). PMMS is a part of the PMS program, i.e. they overlay rather than replace one to another. Fig. (2-6) shows PMMS versus the PMS and the concept of the overlay between them (Abo –Hashema et al., 2006; Kotb, 1996). A PMMS provides the framework for decision making in pavement maintenance based upon an objective approach.

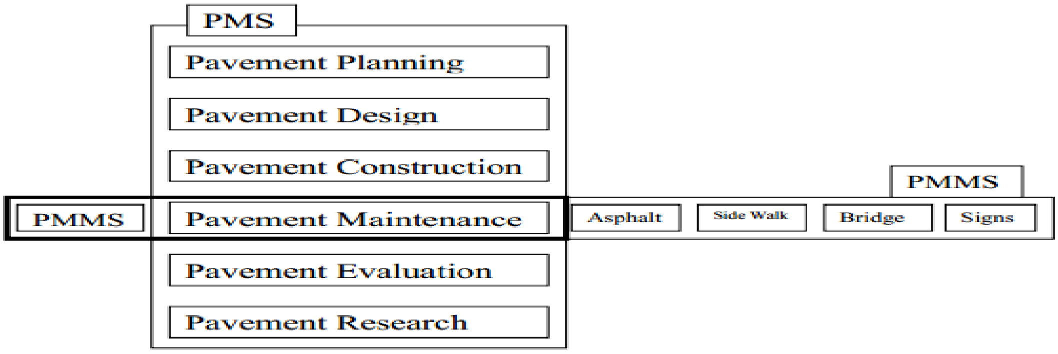


Figure (2-6) Pavement Maintenance Management System (PMMS) Versus Pavement Management System (PMS) (Source: Abo –Hashema et al., 2006).

The complexity of highway maintenance cannot be reduced to a series of mathematical expressions, as it should be subjected to a rigorous systems approach to ensure that policies are developed on the basis of need, that performance is monitored and proper financial control is exercised (Sharaf et al., 2003). There is a logical sequence of steps in the preparation of a pavement maintenance program. PMMS follows the sequence (Sharaf et al., 2003): (1) Establish objectives, (2) Define standards, (3) Assess needs, (4) Determine resources and programs, (5) Implement, (6) Monitor and review performance.

The goal of PMMS system is to produce activities through the available resources, information and the performed evaluations in order to increase the maintenance effectiveness. The improved system consists of some components including recognizing the road sections, recording and collecting the data about the pavement, pavement evaluation method, selecting the activities of the maintenance, choosing the maintenance needs, identifying the priorities and the future programs of the maintenance. PMMS starts with network classification and moves through data collection, data analysis, maintenance decisions and finally the supervision and directions. Fig. (2-7) shows a general methodology for roads maintenance and rehabilitation works (Abo-Hashema et al., 2006; Abo-Hashema and Sharaf., 2009).

2.9 Pavement Condition

Pavement condition is "a generic phrase to describe the ability of a pavement to sustain a certain level of serviceability under given traffic loadings". It is usually represented by various types of condition indices such as Present Serviceability Index (PSI), Present Serviceability Rating (PSR), Mean Panel Rating (MPR), Pavement Condition Index (PCI), Pavement Condition Rating (PCR), Ride Number (RN), Profile Index (PI), and International Roughness Index (IRI).

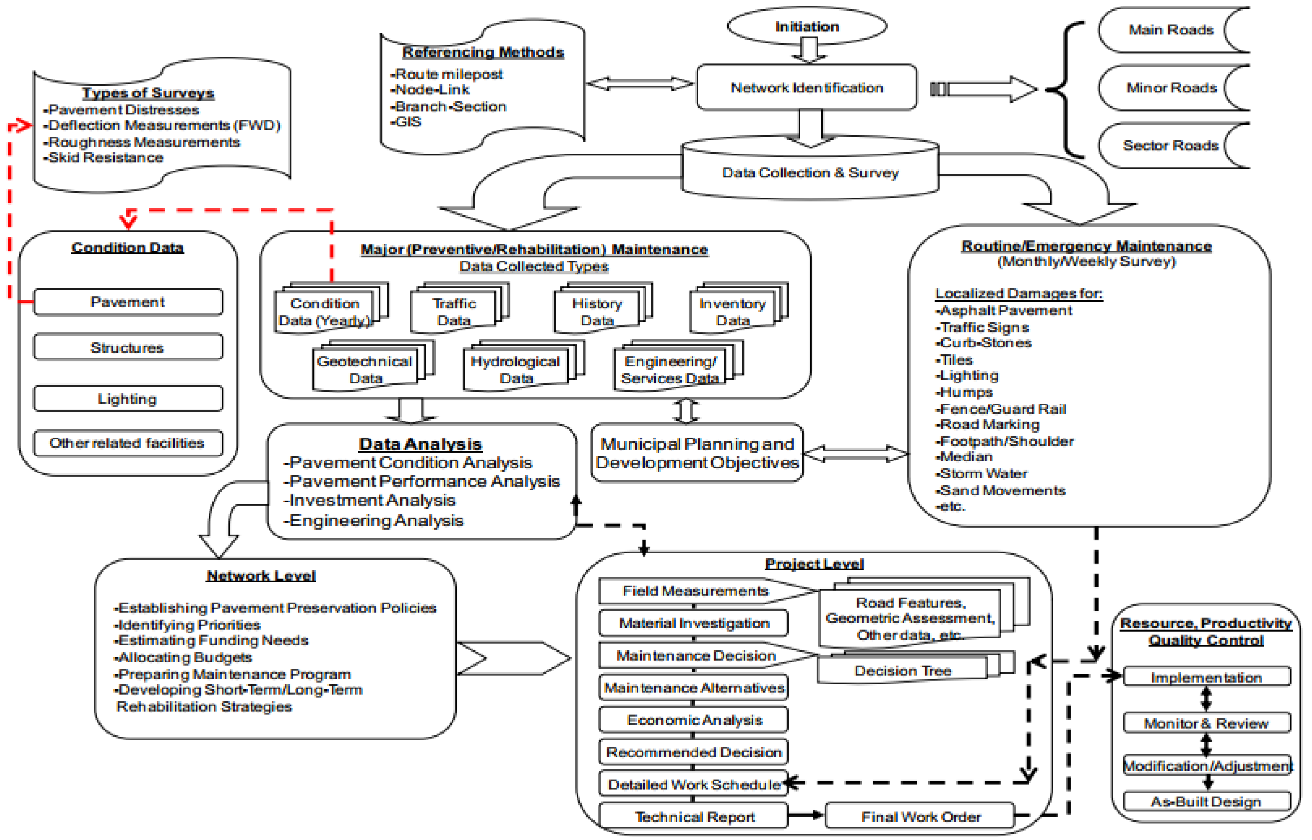


Figure (2-7) General Methodology for PMMS Activities (Source: Abo-Hashema, 2009)

These indices can be classified into two groups. First, roughness is defined as the difference in elevation of the surface that results in vibrations in traversing vehicles in ASTM E867 (ASTM E867, 2012). Several measures of roughness are generally used: IRI, RN, and PI. Second, distress-based condition ratings, such as PCI and PCR, estimate the overall condition of a road by classifying the surface distresses of the pavement by type, frequency, and dimension. A PCI or PCR pavement condition is elevated by deducting the total of all distresses from 100 (Shahin, 2005). Thus, both PCI and PCR are numerical ratings of the pavement condition that range from 0 to 100; with 0 being the worst possible condition and 100 being the best possible condition (Shahin, 2005). In this study, PCI is used to describe the pavement condition.

2.9.1 Factors Affecting Pavement Condition

The most affecting factors on pavement procedures of pavement design considers performance as an important factor to predict it accurately. The designer should consider the same factors in the models of condition prediction (Lytton, 1987). These factors could be summarized as materials, types of treatment, traffic loading, pavement condition before treatment, pavement structure and climates. For practical reasons, choosing factors is depending on data availability. Available data determines the development of prediction models. In the following sections, those factors will be discussed.

2.9.2 Pavement Condition Index (PCI)

The PCI is an evaluation process that is determined in accordance with procedures contained in ASTM D 6433 (ASTM D6433, 2011), standard test method for Pavement Condition Index Survey. This procedure is used worldwide to provide a measurement of the condition of pavements taking into account the functional performance with implications of structural performance. Periodic PCI determinations on the same pavement will show the change in performance level with time. Because the PCI procedure is designed to be objective and repeatable, it can also be used to predict condition. The condition ranges from a PCI of 0 “Failed” to 100 “Good”, with an “Good” condition corresponding to the pavement at the beginning of its life cycle, and a “Failed” condition representing a badly deteriorated pavement with virtually no remaining life. Table (2-4) shows the general description for each pavement condition (ASTM D 6433, 2011).

Table (2-4) Description for Pavement Condition Level (Source: ASTM D6433, 2011).

Condition	PCI Range	Description
Good	86 - 100	No significant distress.
Satisfactory	71 - 85	Little distress, with the exception of utility patches in good condition, or slight hairline cracks; may be slightly weathered.
Fair	56 - 70	Slight to moderately weathered, slight distress, possibly patching.
Poor	41 - 55	Severely weathered or slight to moderate levels of distress generally limited to patches and non-load-related cracking.
Very Poor	26 - 40	Moderate to severe distresses including load-related types, such as alligator cracking.
Serious	11 - 25	Severely distressed or large quantities of distortion or alligator cracking.
Failed	0 - 10	Failure of the pavement, distress has surpassed tolerable rehabilitation limits.

2.10 Expert System Used in Pavement Management

Pertinent research publications obtainable in the implementation of expert system techniques to solve problems in the pavement management area have been consulted and offered hereafter. Tables (2-5) and (2-6) provide a list of the developed existing expert systems that have been used in pavement management and rehabilitation.

Table (2-5) Summary of Expert Systems Applied in Pavement Management (Source: Norlela Ismail et al., 2009a).

Expert System	Reference	Facility Use	Pavement Type	Development Tools	Hardware	Number of Rules
ROSE	Hajek et al. 1987	Highway	Flexible	EXSYS	IBM-PC	360
SCEPTRE	Ritchie et al. 1987	Highway	Flexible	EXSYS	IBM-PC	140
PERSERVER	Haas et al. 1989	Highway	Flexible	OPSS	Mainframe	Not available

Table (2-5) Summary of Expert Systems Applied in Pavement Management (Source: Norlela Ismail et al., 2009a) (continued).

Expert System	Reference	Facility Use	Pavement Type	Development Tools	Hardware	Number of Rules
ERASME	Allez et al. 1988	Highway	Flexible	French Shell Insight2+ Expert System Shell	IBM-PC	210
EXPEAR	Hall et al. 1989	Highway	Rigid	SAVOIR	IBM-PC	Not available
PAVEMENT EXPERT	Al-Shawi et al. 1989	Highway	Rigid	Not available	IBM-PC	Not available
PARES	Ross et al. 1990	Highway	Flexible	Not available	Not available	278
PMAS	Hanna 1994	Highway	Flexible Rigid	EXSYS Professional Instant Expert Plus	IBM-PC Macintosh	170 (EXSYS) 225 (Instant Expert)
PMDSS	De Cabooter et al. 1994	Highway	Flexible	Not available	IBM-PC	1200
PAVER	Shahin and Walther 1990	Highway Airfield	Flexible Rigid	Mainframe	IBM-PC	Not available
AIRPACS	Seiler 1990 Seiler et al .1991	Airfield	Rigid	Not available	Not available	Not available

Table (2-6) Comparison between Expert Systems (Source: Norlela Ismail et al., 2009b).

Expert System	Surface Distress Consideration	Independent Variable	M&R Strategies
ROSE	All cracks except alligator cracking	• Type and severity of crack • Pavement serviceability • Pavement structure • Presence of pavement distress • Availability of maintenance treatment	Maintenance • Routing and sealing
SCEPTRE	Alligator cracking, Longitudinal cracking, transverse cracking and rutting	• Type, amount and severity of surface distress. • Existing pavement Performance. • Traffic levels • Climate	Rehabilitation • Do nothing • Fill cracks • Fog seal • Friction course • Chip seal • Double chip seal • AC overlay (thin, medium or thick) • Mill and replace

Table (2-6) Comparison between Expert Systems of Pavement Management (Source: Norlela Ismail et al., 2009a) (continued).

Expert System	Surface Distress Consideration	Independent Variable	M&R Strategies
PERSERVER	Alligator cracking, Progressive edge cracking, and Distortion	• Type, severity and density of surface distress • Section size cost	Not available
ERASME	Not available	• Pavement structure • Deflection Nature and data of pavement repair • Surface condition	Rehabilitation
EXPEAR	• Rutting • Reflection cracking • Structural overlay • Faulting • Transverse cracking • Joint deterioration • Longitudinal cracking • Wheel path cracking • Corner break • Transverse break	• structural adequacy • roughness drainage • joint deterioration foundation movement • joint sealant condition • skid resistance • joint construction concrete Durability • load transfer • loss of support shoulders	Major Rehabilitation • Structural overlay • Restoration • Reconstruction
PAVEMENT EXPERT	12 distress in 4 categories • Surface deterioration • Patching • Pumping joint spalling • Cracking	Incidence, severity, and the extent of distress	Not available
PARES	Not available	• Overall pavement rating value (PMV) • Individual distress type, severity and extension • ADT PARES Not available • Roughness	Rehabilitation
PAVER	• 19 distresses for AC-surfaced road • 19 distress for PCC-surfaced road airfield	• Type, severity and extent of surface distress • History of pavement condition	Routine Maintenance • Do nothing
	• 16 distresses for AC-surfaced • 15 distresses for PCC- surfaced airfield	• Pavement age	• Cracks sealing • Joint sealing
PMAS	• Alligator cracking • Transverse cracking • Rutting	• Type, severity, and the density of surface distress • Riding Comfort Index (RCI) • Traffic Volume • Climate • Cost comparison	• Do nothing • Cracks sealing • Pothole patching • Rout and seal • Surface replacement • Hot mix recycled patching • Hot mix patching • Cold mix patching • Reconstruction
ESPRESSO	• Distresses in 4 categories • Surface deterioration • Pavement support • Cracking • Joints	• Type, severity and extent of surface distress • Pavement condition rating (PCR) and structural deduction	•Maintenance • Minor Rehabilitation • Major Rehabilitation

Table (2-6) Comparison between Expert Systems of Pavement Management (Source: Norlela Ismail et al., 2009b) (continued).

Expert System	Surface Distress Consideration	Independent Variable	M&R Strategies
PMDSS	• Alligator cracking • Block cracking • Longitudinal and Transverse cracking • Patching • Faulting • Joint crack • Rutting • Flushing • Transverse distortion • Longitudinal joint distortion • Edge and surface raveling • Slab breakup • Longitudinal distortion PMDSS • Pavement deterioration	• Type, severity and extent of distress • Pavement distress index (PDI) • Pavement serviceability index (PSI) • Emphasis of pavement • Pavement type • Pavement age	• 12 treatment categories for flexible pavement • 12 treatment categories for rigid pavement

2.11 PAVER and Micro PAVER

PAVER and Micro PAVER (Shahin and Walther, 1990) are export systems developed to extend engineers with a systematic process in order to determine maintenance and rehabilitation (M&R) needs and priorities for pavement management. While Micro PAVER executes on a microcomputer; PAVER is the mainframe version. The PAVER is developed to optimize the use of funds allocated for pavement M&R. Micro PAVER is utilized to manage all types of the driveway (roads, streets), parking lots, and airfield pavement. The PAVER system is depended on the PCI survey and evaluation procedure. Also, needs to create a database in the network inventory to perform network and project analysis. The last one expand the users with detailed of current PCI survey information, possible alternatives for M&R. It is used for a current year or near term needs. Network analysis, which is used for forecasting long-term M&R needs supply the users with the future PCI, budget planning and project priorities. The PAVER system is written in FORTRAN and C languages, and design resides in IBM or compatible with the personal computer.

PAVER provides users with the ability to customize the PCI condition rating categories as show in Fig. (2-8).

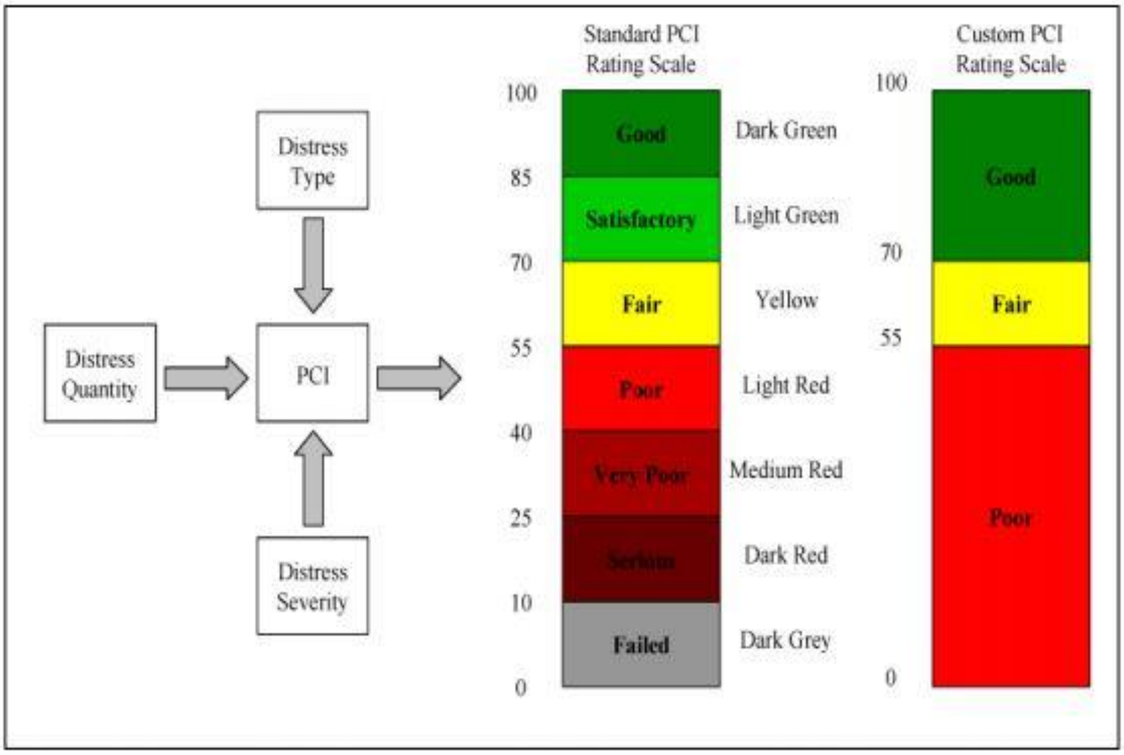


Figure (2-8) Pavement Condition Index (PCI) ranges (Source: U.S Army Corps of Engineers, 2012).

2.12 Determination of PCI

The PCI is calculated for each inspected sample unit. The PCI for the entire pavement section cannot be calculated before calculating the PCI of sample units. Deduct values determine the PCI calculation and factors should be weighted from 0 to 100 to indicate the impact on pavement conditions by each distress. For example, deducting value of (100) means that there is extremely serious distress affecting the structural integrity of pavement and/or surface operational conditions while deducting value of (0) means that there is no effect of distress. The PCI can then be calculated using either a software program (Using PAVER System) or by hand based on well-established formulas in Shahin (2005).

2.13 Geographical Information Systems (GIS)

A GIS is a computerized data base management system for accumulating, storage, retrieval, analysis and display of spatial (i.e. locationally defined) data. A GIS contains two broad classifications of information, geocoded spatial data and attribute data. A GIS can expand the decision making on repair strategies and project scheduling by incorporating such diverse data as accident histories, economic needs hazardous materials shipment and vehicle volumes (NIJU, 2006).

GIS has been used to enhance pavement management information with its typical features, such as graphical display of highway network and current and future pavement condition of the selected pavement sections. GIS also provides an excellent spatial query and analysis capability to select the candidate pavement sections in need of immediate maintenance (NIJU, 2006).

2.14 Maintenance Priority

The mean priority is a comportment of PMMS in the network level. After application of PAVER, a list of pavement condition for the network sections is prepared. In most cases, limited financial resources make it is impossible to perform all sections of low pavement condition indices. In this circumstance prioritizing and optimizing will be needed in order to prepare a maintenance and rehabilitation program. The following is a list of methods for establishing priorities. However, alternate methods can be developed based on an agency's policies and managerial decisions (WSDOT, 1994).

• The matrix method can be depended on many factors such as traffic and condition; i.e., the pavements in the worst condition and has the heaviest traffic is given the highest priority.

• The condition index method can be depended on comparative scores, which ranked from 0 (for worst) to 100 (for better). In order to develop a final list of projects, priorities can integrate condition score with many factors such as traffic or functional class.

• In the benefit-cost ratio process, the sections would have the highest priority when it has the highest benefit-to-cost ratio. Whereas the previous methods are likely to favor a "worst-first" policy, the benefit-cost rationale can prepare high priorities for pavements in fair-to-poor condition rather than always beginning with the pavements in the worst condition.

• The cost-effectiveness procedure is the same to benefit-cost except that the function is to maximize the performance of the sections while considering cost. Performance, in this case, is a measure of the effectiveness of a particular strategy on a segment over time. Each segment in the agency's network can then be ranked against each other to arrive at a list of maintenance and rehabilitation options. This method does not require a "worst first" approach.

• The maximum benefits procedure is inherent in most optimization methods. This method is useful in the field of lifecycle costs and prioritization. Hence, if there is a project, which between many candidates could present the maximum amount of benefit-cost ratio or effectiveness upon cost for some budget, it would be selected for M&R treatments.

In this study, a set of maintenance prioritization methods is proposed to achieve efficient alternatives to maximize cost effectiveness for a limited financial resource.

2.15 Relation and Models of PCI

Predictions model for maintenance and rehabilitation treatment alternatives are essential for priority programming (Hass et al., 2015). Fig. (2-9) illustrates how deterioration prediction would be applied to an existing pavement section to estimate the rate of future deterioration and rehabilitation alternatives (Hass et al., 1994). The basic requirements for any prediction model are represented in the figure.

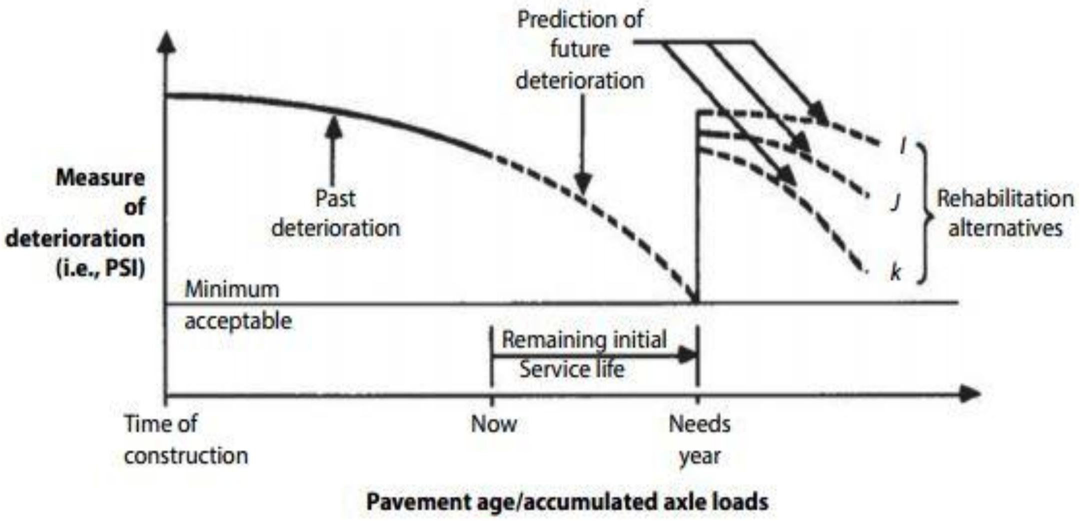


Figure (2-9) Predict Model of Future Deterioration of an Existing Pavement (Source: Hass et al., 1994).

The concept of modeling the deterioration of long life pavements for flexible pavements requires that the surface distresses to be monitored periodically (Newcomb, 2010). It is most likely for the wearing course to have deterioration than the deeper courses in the pavement structure, as well as any failure in the deep courses would reflect to the surface. As a result, when design criteria are satisfied, for example reaching limiting cumulative strain, performance, or deterioration modeling can show need for scheduled maintenance and rehabilitation interventions to yield the required design life. While design methods such as the Mechanistic-Empirical Pavement Design Guide (MEPDG) software (AASHTO, 2008) can be used in prediction of deterioration, although it's not so accurate due to its lack of accuracy over the longer term. Four basic types of prediction models presented: (1) purely mechanistic, (2) mechanistic-empirical, (3) regression based, and (4) subjective.

The most common method to develop deterministic empirical models is the regression models. Analysis of that method is used to establish a relationship between two or more variables. Usually pavement condition is considered as the independent variable and the other factors act as dependent variables, and mostly the fit of the model is described by coefficient of determinant (R^2). This coefficient ranges between 0 and 100. Whenever it is high, it indicates better fitting for the model and the data. But R^2 not always the right indicator especially in non linear regression (Peter et al. 1995).

The general process of developing pavement condition indices consists of assigning deduct points to specific types, severity and extent (density) of distress. These deduct points are summed up and subtracted from a constant number (usually 100). This process results in a single value index, which describes the pavement condition. This pavement condition indices are the professional judgment of the agency, which assigns what is important to them from the distress types and weighted pavement condition factors.

PMMS typically employs a pavement rating system known as pavement condition index (PCI) as the basis for evaluation of current and future pavement conditions. Fig. (2-10) shows the family curve represents the pavement's anticipated performance over time. This curve can then be used to predict future performance. According to the predicted future pavement condition, multiple budgets and maintenance strategies can be run to determine the most cost effective maintenance treatment for the pavement (TRB, 2005).

Table (2-7) shows the literature review of other studied using PAVER, maintenance priority, predicting modeling to determine PCI of flexible pavement.

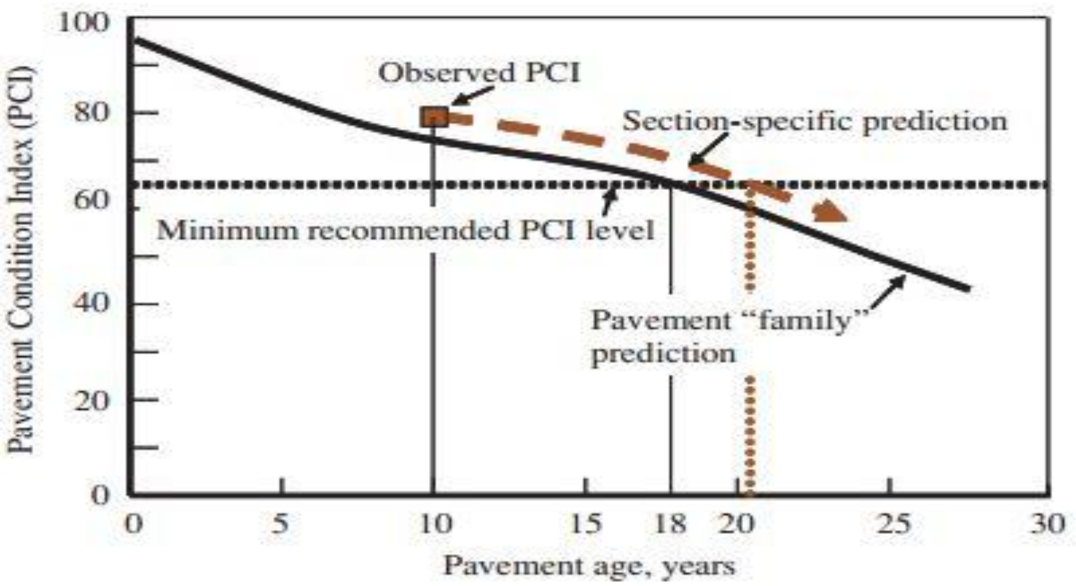


Figure (2-10) Typical Performance Curve (Source: Hajek and Hein, 2011).

Table (2-7) Literature Review of Previous Researches in Maintenance Priority and Modeling.

Author(s)	Year	Topic Addressed	Methodology	Key Finding
Al-Suleiman et al.	1991	Effects of Pavement age and traffic on Maintenance effectiveness	An evaluation of the effects of pavement age and traffic loading on Routine maintenance effectiveness was presented	Maintenance effectiveness for a relatively high traffic loading level was found higher than that for a low level. The Effectiveness of maintenance category was also examined
Madanat and Mishalani	1998	Selectivity bias in Modeling highway pavement Maintenance effectiveness	Presents a structured econometric approach for estimating the effectiveness of pavement M&R activities.	develop a model system that includes a discrete choice model of M&R activity selection by the highway agency and separate continuous response models for the different activities. The effect of the activity in retarding deterioration or improving condition would still be a more important factor in the decision making process
Al-Hallaq	2004	Development of a Pavement Maintenance Management System for Gaza City	integration between Micro PAVER pavement software and GeoMedia GIS software in order to fully exploit the capabilities of each individual package.	PMMS which is based on the direct integration between Micro PAVER and Geo Media Professional can be used to facilitate the decision making process for managing Gaza city pavements.

Table (2-7) Literature Review of Previous Researches in Maintenance Priority & Modeling (continued).

Author(s)	Year	Topic Addressed	Methodology	Key Finding
Niju.	2006	GIS Based Pavement Maintenance & Management System (Gpmms)	a GIS based system that provides information for use in implementing cost –effective reconstruction, rehabilitation, and preventive maintenance programs and results in pavement design to accommodate current & forecasted traffic and pavement deteriorations, in a safe، durable, and a cost-effective manner	PMMS which is based on the direct integration between GeoMedia Professional can be used to facilitate the decision making process for managing pavements.
Garg and Deshmukh	2006	Maintenance management: Literature review and directions	systematically categorizes the published literature and then analyzes and reviews it methodically.	finds that important issues in maintenance management range from various optimization models, maintenance techniques, scheduling, and information systems etc. A new shift in maintenance paradigm is also highlighted.
Ahmed et al.	2008	Development of Pavement Condition Index Model For Flexible Pavement in Baghdad City	develop the prediction model for pavement condition index (PCI) for flexible pavement.	the developed models shows that, this model is adequate to be used for the prediction of pavement condition for flexible pavements within the range of data.
Kirbas and Gursoy	2010	Developing the Basics of Pavement Management System in Besiktas District and Evaluation of the Selected Sections	A pavement management system (PMS) arranges tools and methods to be used for determining the best maintenance schedule for the decision makers in a given period	at the end of all evaluations, in 12 sections of total 20, the pavement condition can be accepted as good, in 7 sections the pavement needs some maintenance and rehabilitation, and finally, only in 1 section the pavement needs total renewal.
Mubaraki	2010	Predicting Deterioration for the Saudi Arabia Urban Road Network	Pavement distress prediction and pavement condition prediction models can greatly enhance the capabilities of a pavement management system.	Pavement age is most significant in the predicting pavement deterioration. Age can be a surrogate for the effect of traffic and drainage in prediction model. Maintenance Priority (MP) can be found through some factors for traffic level, road classification (RF), maintenance record (MF), and cost effectiveness (CEF)، and PCI .
Kmetz	2011	GIS Based pavement Maintenance: A Systematic Approach	using a Geographic Information Systems (GIS) can help cities better manage their roads by graphically representing the MIP.	implement the maintenance plan and use a GIS to track the plan are examined.

Table (2-7) Literature Review of Previous Researches in Maintenance Priority & Modeling (continued).

Author(s)	Year	Topic Addressed	Methodology	Key Finding
Ferreira et al.	2012	Cracking Models for Use in Pavement Maintenance Management	The cracking area evolution for a set of representative Portuguese pavements structures and traffic conditions	provide a good solution to the pavement maintenance management problem. The Indian and HDM-4 models were considered to produce acceptable results.
Jagadeesh, and Harikeerthan	2012	Development of pavement deterioration models for urban roads	fifth cycle of data is collected for use in Pavement Management system for urban roads.	Prioritize the rehabilitation and reconstruction works and develop a framework for the pavement management system for urban roads.
Shah et al.	2012	Evaluation of Prioritization Methods for Effective Pavement Maintenance of Urban Roads	Determines the best ranking list of candidate sections for maintenance based on several factors	out of 21 road sections, 10 sections were in good pavement condition with RCI value 1–5, 7 sections were in good condition with few isolated problems having road condition index (RCI) value 5–8 and 4 sections were in deteriorated condition and require urgent attention with RCI value 10-12. The sections were then prioritized for maintenance in the order of higher maintenance priority index (MPI) values
Obead	2012	Development of Pavement Maintenance Alternatives Based on Multi-Criteria System	Evaluating pavement maintenance alternatives and finding the optimum maintenance strategy for defective pavement segments	"Fair" pavement condition and critical PCI for the selected case study. Comparison between the results obtained by the experts through designed questionnaire and the results obtained by applying AHP approach has been conducted. Statistical analyses show a good agreement between these two different results.
Obaidat and Al - Mestarehi	2012	Integration of Geographic Information Systems and PAVER System to A ward Efficient Pavement Maintenance Management System(Pmms) –Case Study-Irbid City-Jordan	Information System (GIS) and PAVER System for the purpose of flexible pavement distresses classifications and maintenance priorities.	Statistical models were developed to quantify PCI values. These models utilized influencing variables including ADT, climate condition, socio-economical characteristic and pavement age. It was found that ADT and Pavement age variables played the most significant factors in the distresses quantification.

Table (2-7) Literature Review of Previous Researches in Maintenance Priority & Modeling (continued).

Author(s)	Year	Topic Addressed	Methodology	Key Finding
Mapikitla	2012	Development of Pavement Management System For Road Network Maintenance	developing and testing pavement management system for road network maintenance	contributory factors to the deterioration of the route understudy are environmental and traffic loading oriented. PMS developed addresses the timing effect of M&R requirements and provide key performance indicators to assist with decision support system. PMS developed is suitable for road network applications ranging from national roads, provincial roads, regional or district arterial and collector / distributor networks in South Africa (S.A.).
Ali et al	2012	Use of Micro PAVER Program for Pavement Maintenance Management System (PMMS) of Roads in Central and Eastern Sudan	PMMS incorporates a systematic procedure for pavement evaluation using PCI. And the effective and economic management of maintenance expenditures	the current status is in urgent need of an emergency program for pavement maintenance, rehabilitation and reconstruction
Wu et al.	2013	Evaluation of MEPDG Flexible Pavement Design Using Pavement Management System Data: Louisiana Experience	evaluate the performance of typical Louisiana flexible pavement structures and compared it to the existing pavement performance data available in the pavement management system	fatigue cracking and IRI models in the MEPDG seemed to be adequate for most projects selected. Finally, a special optimization approach was introduced to determine a set of preliminary local calibration factors for the MEPDG rutting models for two types of flexible pavements in Louisiana in USA.
Amin and Amador-Jiménez	2014	A Performance Based Pavement Management System for the Road Network of Montreal City – a Conceptual Framework	presents a conceptual framework of a dynamic PMS for the road network of Montreal City	Study proposes a PMS for different categories of road groups with different pavement performance curves for each group.

CHAPTER THREE

CHAPTER THREE

METHODOLOGY AND DATA COLLECTION

3.1 General

This chapter presents the description of methodology of the study, the study area, the methods used for data collection, dividing the network into manageable units. All other data necessary to determine PCI for units and sections. Further, data for establishing priority of maintenance, and incremental benefit-cost analysis. Other data for PCI modeling is also investigated and collected.

3.2 Methodology of the Study

The research methodology is presented in Fig. (3-1). Which show the steps of: the road network selection, pavement network division in to
Brunch and section, data collection for each of PAVER software (type of distress, diminution and severity) by using measurement tool and GPS. And data collection for developing model and establish priority (average daily traffic (ADT), structural number (SN)). Compare the result of developing model and priority with PAVER PCI result.

3.3 Study Area Description

The study area represents a selected zone of urban streets for seven neighborhoods in Karbala city as previously shown in Fig. (3-2). These streets are classified depended on Karbala directorate mayor team information into: major arterial, minor arterial, collector, and local as shown in Fig. (3-2). The study area includes many active centers such as (schools, governmental buildings, and religious places), excessive traffic volume, structure failure of pavement, and climatic conditions.

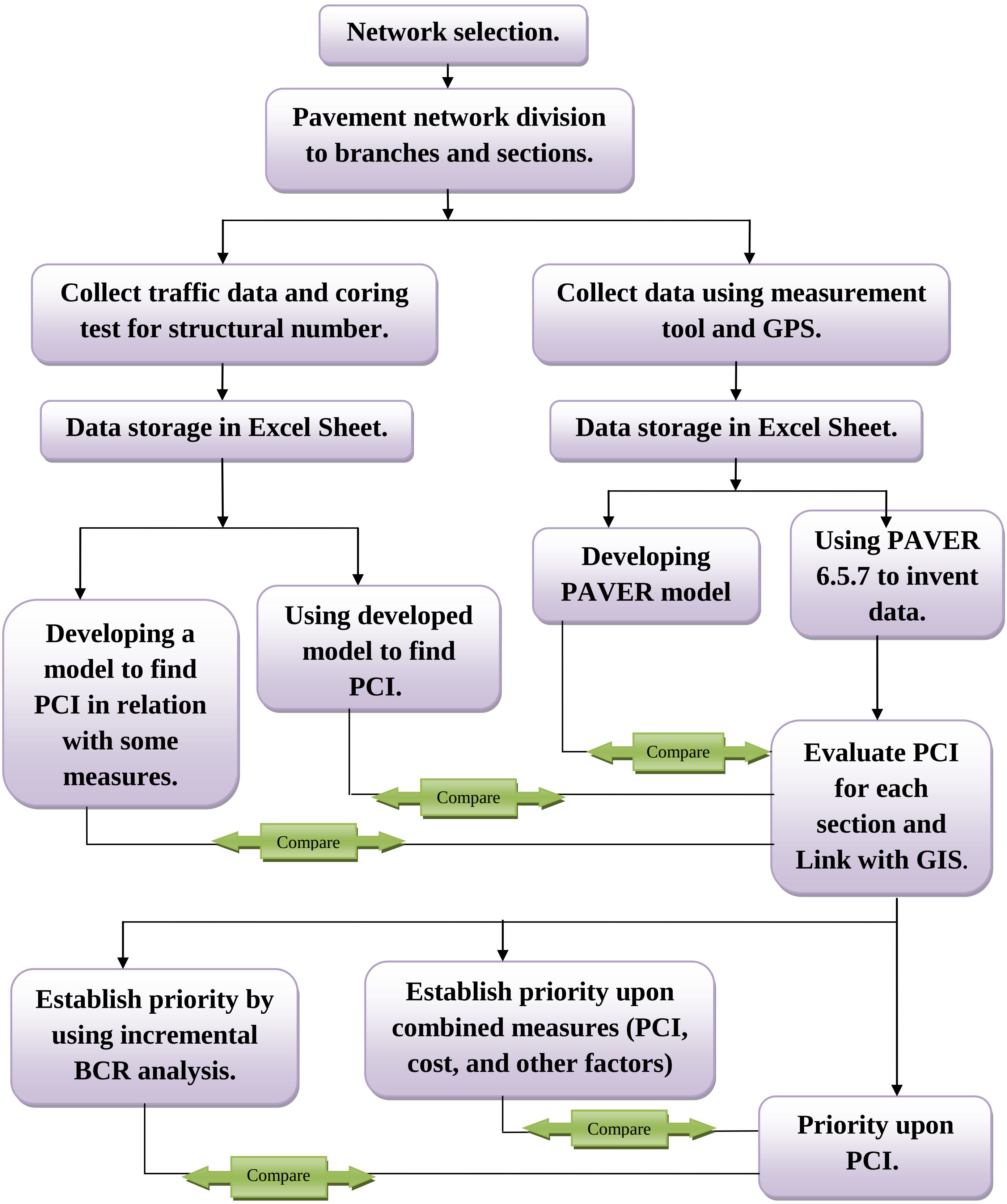


Figure (3-1) Research Methodology.

Also, the study area is affected by the millions of visitors who visit the shrines of Imam Hussein and Imam Abbas (peace be upon them).

3.4 Data Collection

The pavement condition index (PCI) is a simple, convenient and inexpensive measure to monitor the condition of the surface of roads, identify maintenance and rehabilitation needs, and ensure that road maintenance budgets are spent wisely. In order to perform an efficient estimation of PCI, the road network needs to be divided into manageable segments.

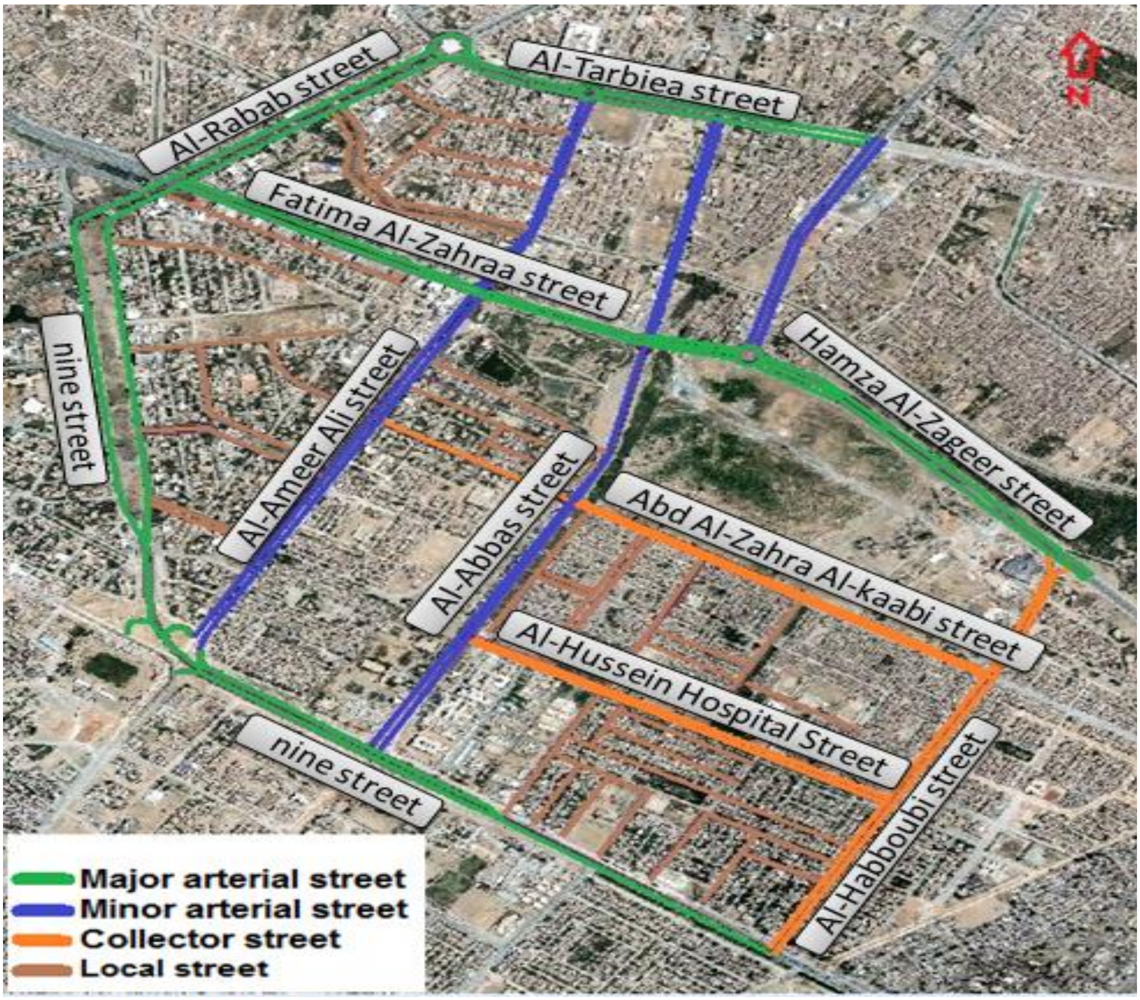


Figure (3-2) Functional Classification of the Selected Urban Street within the Study Area.

Data required for the estimation of PCI are listed and explained as follows:

- Geometric Data.
- Dividing the network into manageable units.
- Inspection data used in PAVER software.

3.4.1 Geometric Data

Geometric data have been collected by using GIS tools in map measurement depending on the available satellite images with an accuracy of 0.6m, updated to 2013 and available at Karbala municipal directorate. Right of way, lane length, lane width, and coordination of each unit in a section (start and end locations) were obtained using these tools.

3.4.2 Dividing the Network into Manageable Units

For a roadway system to be manageable, it needs to be divided down into branches that may be taken as city streets. Because a street does not always have consistent characteristics and thereby does not require the same maintenance and rehabilitation treatment at the same time throughout its entire length. Therefore, it is divided into smaller manageable segments (sections). This will also help efficiently in data collection and in making analysis(Shahin, 2005). Pavement section area having uniform construction, maintenance, usage history, and condition (ASTM D6433, 2011). Segments are defined so that the pavement within their boundaries is consistent in terms of physical and functional characteristics (Shahin, 2005).

Each road section should have a basic history attached to it:

- Class - local residential, collector, or arterial.
- Length, width, and geometry.
- Type and volume of traffic.
- Pavement type - flexible, rigid, or composite.
- Original construction date.
- Maintenance and rehabilitation history.

Pavement Management System Guidebook Review Team (1994) pointed out that one of the following factors could define the boundary between two segments:

- A change in the number of traffic lanes.
- A change in pavement type.
- An abrupt change in traffic patterns or volume.
- A change in drainage characteristics (such as curb and gutter to ditch segment).
- A change in pavement structure (thickness, material, etc.).
- A change in natural subgrade characteristics.
- Previous construction projects (different projects reflect different designs, materials, ages, and other factors).

In addition, geographic or manmade boundaries may offer or force segment boundaries, such as roadway intersections, rivers or streams, bridges, city or township limits, county lines, railroad crossings and current condition based on the last PCI.

The section of pavement should be divided into sample units. The sample unit of asphalt surfaced roads is defined as an area 2500 ±1000 ft^2 (225± 90 m^2), and the units to be inspected chosen as describe in (Shahin, 2005; ASTM D6433, 2011). A sampling plan for PAVER software is used so as a rationally accurate PCI could be estimated depended on inspecting of a limited number of the sample units in the pavement section.

3.4.3 Data Inspection

Surface distresses of road pavements are typically evaluated using the PCI. The PCI evaluation methodology was developed by ASTM D6433

(ASTM D6433, 2011). It is noteworthy that ASTM adopted the PCI as a pavement condition rating standard for road pavements.

For each manageable unit in a section of a road, the inspected data includes; type of distresses, dimension and severity for each unit in the section roads. Appendix (A) shows the details related to survey for each type of flexible pavement distress, how taken the dimensions and severity. Table (3-1) shows section sample of the distresses inspection data in the manageable pavement sample unit of section (1-A) of branch (1). Fig. (3-3) shows a sample of failure in different sections in the study area. The inspection data of all section at the study area are show in Appendix (B).

Table (3-1) The Inspection Data for Section (1-A) of AL-Rabab Street.

Pavement sample Unit 2				
Distress	Description	Severity	Quantity	Units
7	EDGE CRACKING	M	6	m
6	DEPRESSION	L	2	Sqm
Pavement sample Unit 4				
13	POTHOLE	L	4	Count
7	EDGE CRACKING	M	30	m
Pavement sample Unit 6				
7	EDGE CRACKING	H	25	m
Pavement sample Unit 8				
7	EDGE CRACKING	M	33	m
Pavement sample Unit 10				
7	EDGE CRACKING	H	32	m
Pavement sample 12	GOOD			
Pavement sample Unit 14				
6	DEPRESSION	H	1.5	Sqm
Pavement sample Unit 16				
6	DEPRESSION	M	1.5	Sqm
Pavement sample Unit 18	GOOD			
Pavement sample Unit 20	GOOD			

L: low level, M: medium level, H: high level

Data collection tools can simplify the inspection task. Coordinates of each unit (start and end locations) of a spitted started were picked for GIS. GPS units are used to pinpoint locations of each unit, but paper and pencil still work. The steps of inspection used to find PCI are as follows:

1- Surface distresses boundary in the pavement sample units were measured as area or just length or width and are evaluated based on type, frequency and severity.
2- Using GPS to pinpoint the location of distresses in the units.
3- A digital photograph of each section of roadway provides a permanent record of the pavement condition.

3.5 PAVER Software Capabilities

PAVER software for Windows is an automated PMS. It is a tool for making a decision for the development of cost-effective maintenance and repair alternatives for roads and streets, parking lots, and airfields. PAVER software tool up many important capabilities (U.S Army Corps of Engineers, 2014), including:

1. Pavement network inventory.
2. Pavement condition rating.
3. Development of pavement condition deterioration models (Family Curves).
4. Determination of present and future pavement condition (Condition Analysis).
5. Determination of maintenance and repair (M&R) needs and analyzing the consequence of different budget scenarios (Work Planning).
6. Project formulation.

A. Joint Reflection Cracking

B. Transfer Cracking

C. Alligator or Fatigue Cracking

D. Block Cracking

E. Bleeding and Raveling

F. Rutting

G. Utility Cut Patching

H. Potholes

Figure (3-3) Type of Distresses within Study Area.

3.5.1 Inventory and Editing Data Inspected by Using PAVER

PAVER software was utilized for selecting maintenance and repair (M&R) needs and priorities and determining the optimal time of repair by predicting future pavement condition (Al-Mestarehi, 2009).

Manual calculation of a PCI is not a tedious operation for a few number of sample units. However, when the volume of data generated from a survey is generally quite large, the calculations will be time-consuming. The calculations will be therefore, done automatically after distress information been entered into PAVER software and the overall PCI will be calculated for each section, as well as extrapolated quantities of distress (Shahin, 2005).

The following steps are used to compute PCI and pavement condition rating:

A. The pavement inventory is defined in terms of network, branch, and section. A pavement section is the smallest management unit for considering a major maintenance and repair (M&R) project. Key features to be considered in section definition are pavement type, structure, construction history, functional classification (or traffic), and existing condition (Shahin, 2005). Defining the pavement inventory (network, branches, and sections) is shown in Plates (3-1) to (3-3).

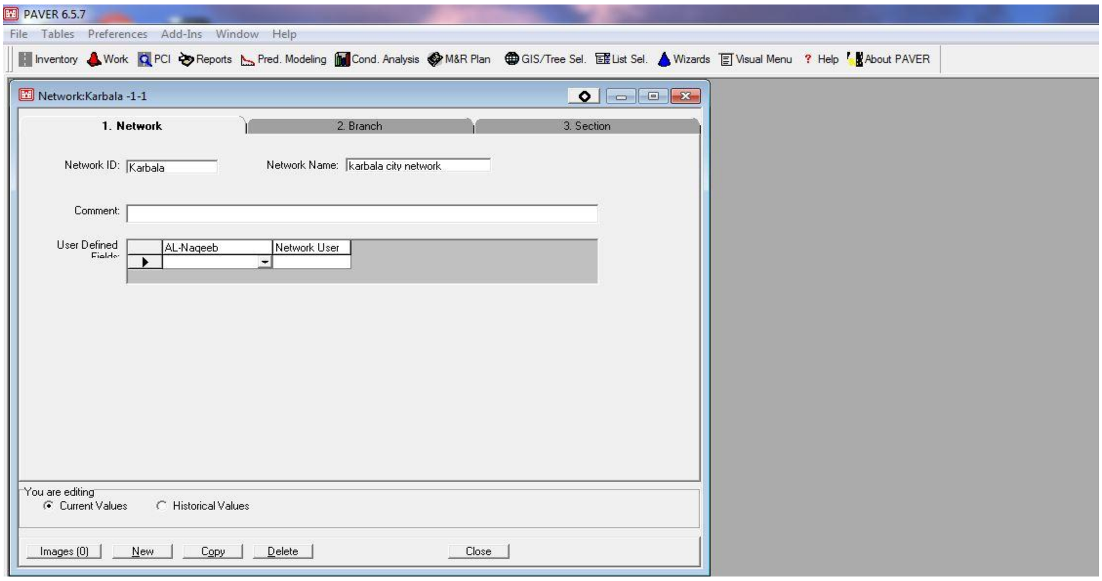


Plate (3-1) PAVER Screen for Defining Pavement Inventory (Network).

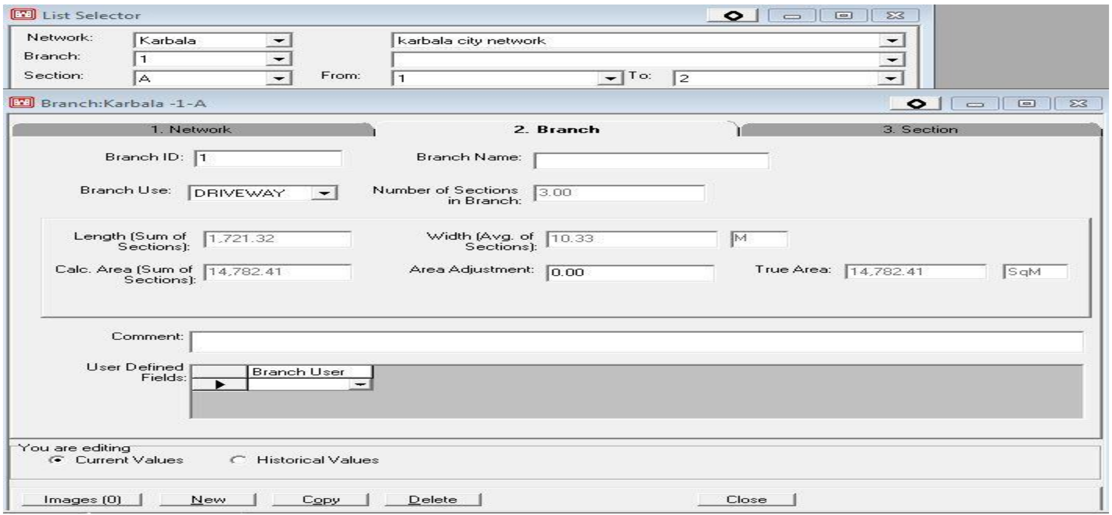


Plate (3-2) PAVER Screen for Defining Pavement Inventory (Branch).

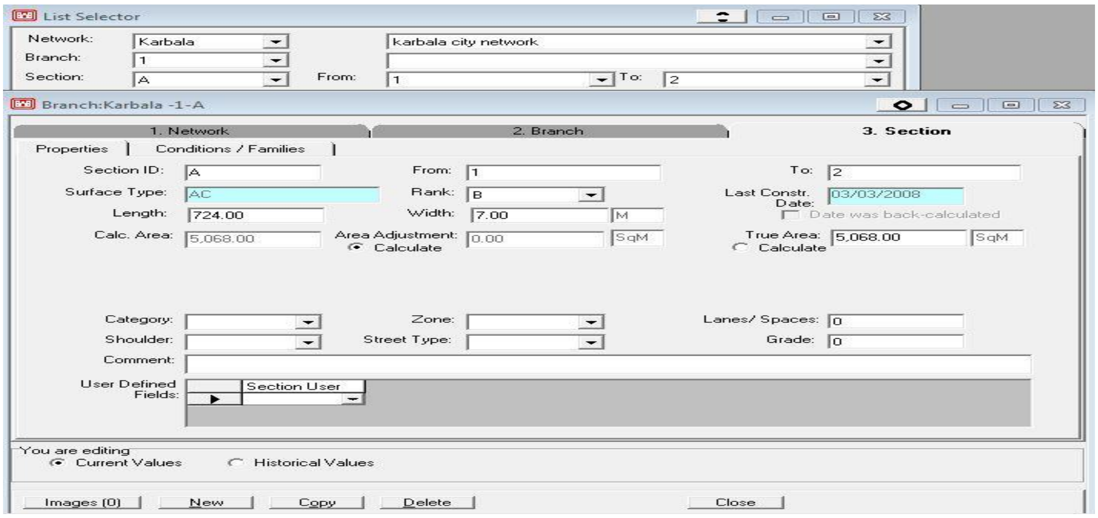


Plate (3-3) PAVER Screen for Defining Pavement Inventory (Section).

B. Entering the inspect dates and information of samples.

The inspection component of PAVER software can be launched from the PAVER software button bar via PCI, using the subsequent steps:

1- Enter inspection dates via a click on the (edit inspection) as shown in Plate (3-4).

2- Enter the survey information via a click on the (edit sample unit) as shown in Plate (3-5).

3- Enter information on distress (Type, Severity, or Quantity) as shown in Plate (3-6).

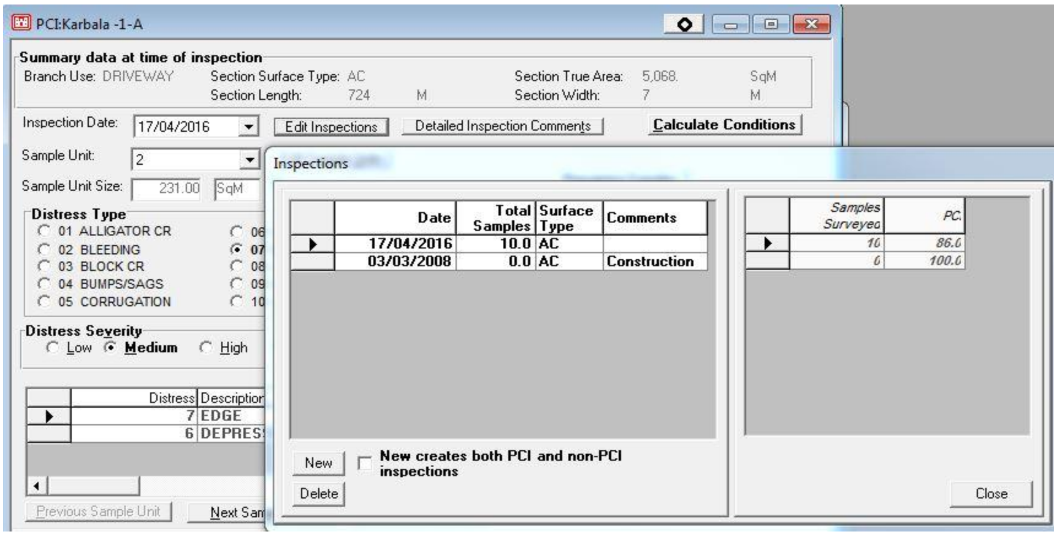


Plate (3-4) PAVER software Screen for Editing Inspection Dates.

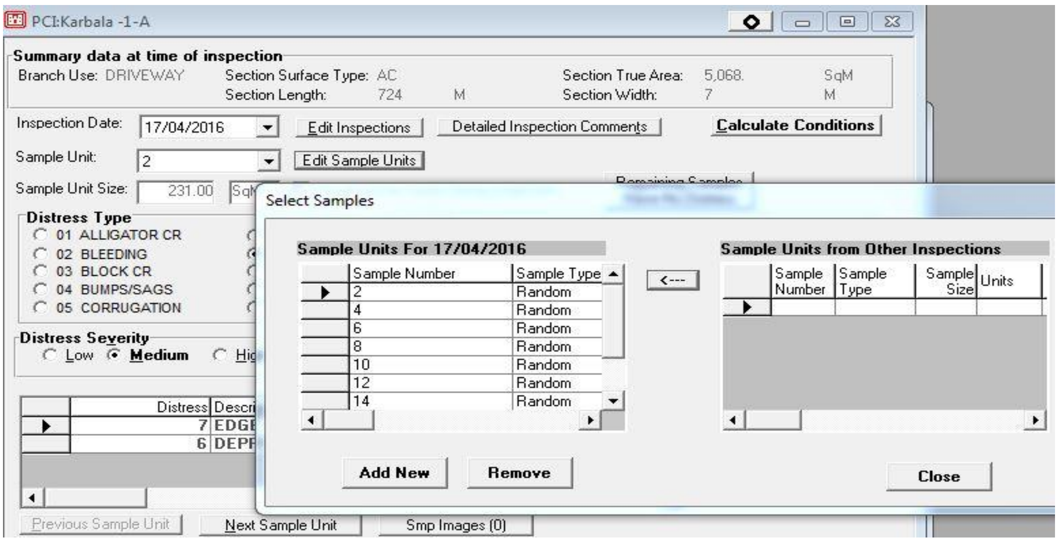


Plate (3-5) PAVER software Screen for Entering Inspection Dates.

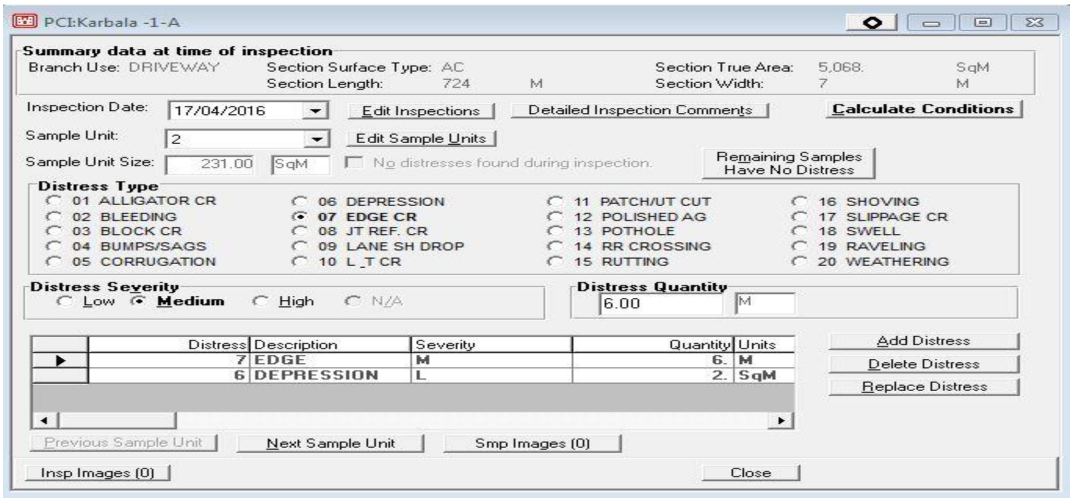


Plate (3-6) Entering Inspected Data of Section and Calculating Pavement Condition.

3.6 Data for Establishing Priority of Maintenance

The priority of maintenance was studied according to a set of selected variables that may affect priority. The priority of maintenance (as dependent variables) is related to other independent variables in addition to PCI determined from PAVER software. The independent variables include; cost, easy, and average daily traffic (ADT).

The weights of the independent variable in the equation are found during the inspection test. Experts (with at least 10 years of experience in roadway maintenance) are asked to give the suitable irrespective weight as a semantic score in relative to the questions listed in Table (3-2). The impact of cost is negative while that of PCI, easiness, and average daily traffic have positive weights.

Table (3-2) The Questionnaire Sample for Irrespective Weight of Multiple Factor Method.

No.	Definition	Irrespective Weights*	Scale reference
1	How costly would it be to implement maintenance to address a good pavement condition?	-	1. Not Costly 5. Very Costly
2	What impact has PCI measure on pavement condition?	+	1. Not Impact 5. Highly Impact
3	How easy would it be to implement the maintenance?	+	1. Not Easy 5. Very Easy
4	What impact has the functional classification of the section on priority of maintenance?	+	1. Not Impact 5. Highly Impact
5	What impact has the average daily traffic (ADT) on priority of maintenance?	+	1. Not Impact 5. Highly Impact

*Weights (from 0 to 10), Experts were asked to give the irrespective weight for each item.

3.6.1 Traffic Volume Data

The traffic flow data were recorded by using a video camera. Data recorded by video camera tapes and later copied into solid disk. The traffic data were collected and classified depending on the type of vehicles such as passenger car, light truck, heavy truck, and bus. Vehicles of different types require a different amount of road space because of variations in size and performance. To allow for this in capacity measurement for roads, traffic volumes are expressed in passenger car units (PCU) and the weighting for each class of vehicle has to be varied to suit the purpose for which they are to be used. For traffic count and design purposes, conversion factors similar to those of "Road Transport Study, Iraq, 2005" are used by SORB. These factors are shown in Table (3-3).

In this research, the conversion factors of the flat case have been used. The traffic volumes data abstracted from video recording for each section of arterial and collector roads. Table (3-4) shows the traffic data that has been collected in April, 2016.

Table (3-3) Conversion Factors of Different Type of Vehicle to PCU (Source: SORB, 2005).

SCRB- Conversion factors to PCU			
Vehicle Type	Type of Terrain		
	Flat	Hilly	Mount
Passenger cars	1.00	1.00	1.00
Buses up to 24 passengers	1.25	1.75	3.00
Buses above 24 passengers	2.00	3.00	6.00
Truck, and trailer combination	3.00	5.00	10.00

Table (3-4) Traffic Data Collected for Each Section in the Study Area of Karbala city in 2016.

Street	Passenger	Light truck	Heavy truck	Bus	Time	Day
1-1	1878	172	23	276	3:59-4:59 PM	Saturday
1-A	1389	86	10	173	3:59-4:59 PM	Saturday
1-B	1433	118	7	198	3:59-4:59 PM	Saturday
2-A	963	74	22	41	3:59-4:59 PM	Saturday
2-B	1207	93	37	73	4:05-5:05 PM	Tuesday
3-A	917	145	51	40	9:0-10:0 AM	Saturday
3-B	1083	87	62	76	9:0-10:0 AM	Saturday
3-1-A	807	133	27	152	9:0-10:0 AM	Saturday
3-1-B	615	183	29	67	9:0-10:0 AM	Saturday
4-A	1512	192	69	185	9:0-10:0 AM	Saturday
4-B	1629	195	70	190	9:0-10:0 AM	Saturday
5-A	507	74	13	18	10:0-11:0 AM	Saturday
5-B	652	62	14	29	10:0-11:0 AM	Saturday
6-A	620	52	11	28	10:0-11:0 AM	Saturday
6-B	639	59	13	33	10:0-11:0 AM	Saturday
7-A	642	50	9	21	9:35-10:35 AM	Tuesday
7-B	681	61	11	27	9:35-10:35 AM	Tuesday
8-A	1498	147	31	128	11:0-12:0 AM	Saturday
8-B	1523	140	38	252	11:0-12:0 AM	Saturday
9-A	1492	151	32	126	11:0-12:0 AM	Saturday
9-B	1581	113	26	179	11:0-12:0 AM	Saturday
9-C	1335	89	11	175	11:0-12:0 AM	Saturday
10-A	998	53	8	62	11:0-12:0 AM	Saturday
10-B	1012	62	13	79	11:0-12:0 AM	Saturday
11-A	1033	86	10	77	3:30-4:30 PM	Saturday
11-B	1128	100	14	89	3:30-4:30 PM	Saturday

Table (3-4) Traffic Data Collected for Each Section in the Study Area of Karbala city in 2016 (continued).

Street	Passenger	Light truck	Heavy truck	Bus	Time	Day
12-A	968	141	17	46	3:30-4:30 PM	Saturday
12-B	821	182	21	49	3:30-4:30 PM	Saturday
12-1-A	787	91	15	51	3:30-4:30 PM	Saturday
12-1-B	724	88	17	43	3:30-4:30 PM	Saturday
13-A	997	40	9	51	10:45-11:45 AM	Tuesday
13-B	1104	53	11	43	10:45-11:45 AM	Tuesday
15-A	1214	45	8	107	11:0-12:0 AM	Saturday
15-B	1088	32	6	81	11:0-12:0 AM	Saturday
17-A	789	29	4	17	10:0-11:0 AM	Saturday
17-B	688	25	6	23	10:0-11:0 AM	Saturday
18-A	680	28	5	26	10:35-11:35 AM	Tuesday
18-B	786	25	4	20	10:35-11:35 AM	Tuesday
19-A	1023	49	5	25	5:40-6:40 PM	Saturday
19-B	1098	37	4	32	5:40-6:40 PM	Saturday
20-A	1121	32	5	31	5:40-6:40 PM	Saturday
20-B	1153	39	4	38	5:40-6:40 PM	Saturday
21-A	1138	49	6	32	5:40-6:40 PM	Saturday
21-B	1233	40	4	41	5:40-6:40 PM	Saturday
22-A	1004	31	11	88	5:20-6:20 PM	Saturday
22-B	809	43	9	84	5:20-6:20 PM	Saturday
23-A	654	86	12	67	12:0-1:0 PM	Tuesday
23-B	677	85	9	38	12:0-1:0 PM	Tuesday
23-1-A	605	32	2	58	12:0-1:0 PM	Tuesday
23-1-B	652	55	4	66	12:0-1:0 PM	Tuesday
24-A	1246	60	9	71	12:0-1:0 PM	Tuesday
24-B	1207	59	8	73	12:0-1:0 PM	Tuesday
25-A	1936	161	20	365	6:15-7:15 PM	Tuesday
25-B	1679	157	21	207	6:15-7:15 PM	Tuesday
26-A	2184	187	22	241	5:10-6:10 PM	Tuesday
26-B	1797	198	26	219	5:10-6:10 PM	Tuesday

3.6.2 Pavement Maintenance Costs and Easiness of Performance

Maintenance costs vary with road conditions, traffic volume, geographic location, climate conditions, work methods, technical equipment, and other factors (Birmingham and Stankevich, 2005). Table (3-5) shows the maintenance cost and work easiness for each distress type in the flexible pavement from experts response. This cost includes future overlays and/or upgrading that are necessary made when the riding quality of pavement decreases to a certain minimum level of acceptability (AASHTO, 1993).

Table (3-5) The Maintenance Cost for Flexible Pavement Distress and Work Easiness.

Distress Type	Severity Levels	Description	Financial Unit Cost (ID)*	Easiness
Alligator, Block Cracking, Patching, Potholes, Depression.	Low	Surface Patching	15,000	4
	Medium	Deep Patching	30,000	3
	High	Deep Patching	40,000	2
Long., Transverse, Edge Cracking.	Low	Do Nothing	0	5
	Medium	Crack Sealing	3,000	4
	High	Slurry seal, Thin Overlay	15,000	3
Rutting, Shoving, Swelling.	Low	Do Nothing	0	5
	Medium	Milling & Repave	25,000	3
	High	Deep Patching	40,000	2
Asphalt Bleeding	Low	Do Nothing	0	5
	Medium	Do Nothing	0	5
	High	Milling & Repave	25,000	3
Weathering / Raveling	Low	Do Nothing	0	5
	Medium	Slurry Seal	15,000	4
	High	Thin Overlay	20,000	3
Bumps& Sags, Corrugations, Slippage Cracks	Low	Do Nothing	0	5
	Medium	Surface Patching	15,000	4
	High	Deep Patching	40,000	2
Reflection Cracks	Low	Do Nothing	0	5
	Medium	Refill	8,000	4
	High	Refill	10,000	4
Railroad Crossing	Low	Do Nothing	0	5
	Medium	Surface Patching	15,000	4
	High	Deep Patching	30,000	3
Lane/ Shoulder Drop	Low	Do Nothing	0	5
	Medium	Surface Patching	3,000	4
	High	Deep Patching	4,000	4

(*): Construction Cost Provided by Iraqi Contractors Union –Karbala , 2017.

Cost of maintenance (ID/M^2) determined by divided the total cost of units (ID) per the total area of inspected units. Maintenance cost for sample section (1-A) is shown in Table (3-6), and other sections are presented in Appendix (B).

Table (3-6) Maintenance Costs for Sample Section (1-A) of AL-Rabab roadway.

Section 1-A	Pavement sample section area (5068 Sqm)					
Unit 2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	M	6	M	18000	1257000
6	DEPRESSION	L	2	SqM	30000	
Unit 4						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	544.155844
13	POTHOLE	L	4	Count	60000	
7	EDGE CRACKING	M	30	M	90000	
Unit 6						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	25	M	375000	
Unit 8						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	33	M	99000	
Unit 10						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	32	M	480000	
Unit 12	GOOD					
Unit 14						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	H	1.5	SqM	60000	
Unit 16						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1.5	SqM	45000	
Unit 18	GOOD					
Unit 20	GOOD					

L: low level, M: medium level, H: height level

3.6.3 Incremental Benefit-Cost Analysis

The purpose of carrying out benefit-cost analysis is primarily to ensure that an adequate return in terms of benefits results from committing expenditure.

Any commitment of expenditure can be considered as making an investment, whether it be a capital project or an investment in maintenance. An additional purpose is to ensure that the investment option adopted gives the highest return in relation to the standards adopted, and the timing of the investment (Robinson and Wride, 1998). The incremental benefit-cost analysis is an extension of the benefit-cost ratio (BCR) method. In this study the benefit gained from pavement maintenance is assumed to equal decrease of PCI out of hundred (100 – PCI) and this compared with the cost of maintenance represent. The following steps describe the method in its simplest form (AASHTO, 2010):

1. Arrange sections with a BCR greater than 1.0 in increasing order based on their estimated cost. The section with the smallest cost is listed first.
2. Beginning at the top of the list, calculate the difference between the first and second project's benefits. Similarly, calculate the difference between the costs of the first and second sections. The differences between the benefits of the two sections and the costs of the two sections are used to compute the BCR for the incremental investment.

$$\text{Incremental BCR} = \frac{(PV_{\text{benefits } 2} - PV_{\text{benefits } 1})}{(PV_{\text{cost } 2} - PV_{\text{cost } 1})} \qquad ...(3\text{-}1)$$

where:

$PV_{\text{benefits } 1}$= Present value of benefits for lower-cost project (100-PCI).

$PV_{\text{benefits } 2}$= Present value of benefits for higher-cost project (100-PCI).

$PV_{\text{cost } 1}$= Present value of cost for lower-cost project.

$PV_{\text{cost } 2}$= Present value of cost for higher-cost project.

3. For the incremental investment, if the BCR is greater than 1.0, the section with the higher cost is compared to the next section in the list. if the incremental investment for the BCR is less than 1.0, the section with the lower cost is compared to the next section in the list.
4. Repeat this process. The section selected in the last pairing is considered the best economic investment.

To produce a ranking for sections, the entire evaluation is repeated excluding the sections previously determined to be the best economic investment until the ranking of every section is determined. In this research, a large number of trails had to be done. So, the use of a spreadsheet or special purpose software to automate the calculations is the most efficient and this purpose.

Other instances, where the resulting of an incremental difference between the cost of the two sections equal to zero. This case leads to a zero in the denominator for the BCR. If such an instance arises, the section with the greater benefit will be selected. Additional complexity is added, where appropriate, to choose one and only one section alternative for a given site. The incremental benefit-cost analysis does not explicitly impose a budget constraint.

3.7 Data for PCI Modeling

In this research, a model developed by Garber and Hoel (2009) and Hoel et al. (2011) as well as another model during this study to determine the future condition of pavement sections, depending on the same independent variables in the model developed by Garber and Hoel (2009) and Hoel et al. (2011). The information used in each model related to pavement condition including PCI, ADT, pavement age, and structural number were used as independent, while PCI expressed as dependent variable.

3.7.1 Estimation of Average Daily Traffic (ADT)

The Average Daily Traffic (ADT) value for the sections shown in Appendix (C), can be determined depending on traffic data collections, convert the data of each type vehicles to a PCU by using converting factors. In this research, the conversion factors for the flat type of terrain were used as shown in Table (3-4). By Using a Federal Highway Administration charts as shown in Fig. (3-3) to convert the traffic value from one hour to daily traffic value, and Fig. (3-5) to convert the daily traffic value to average daily traffic value.

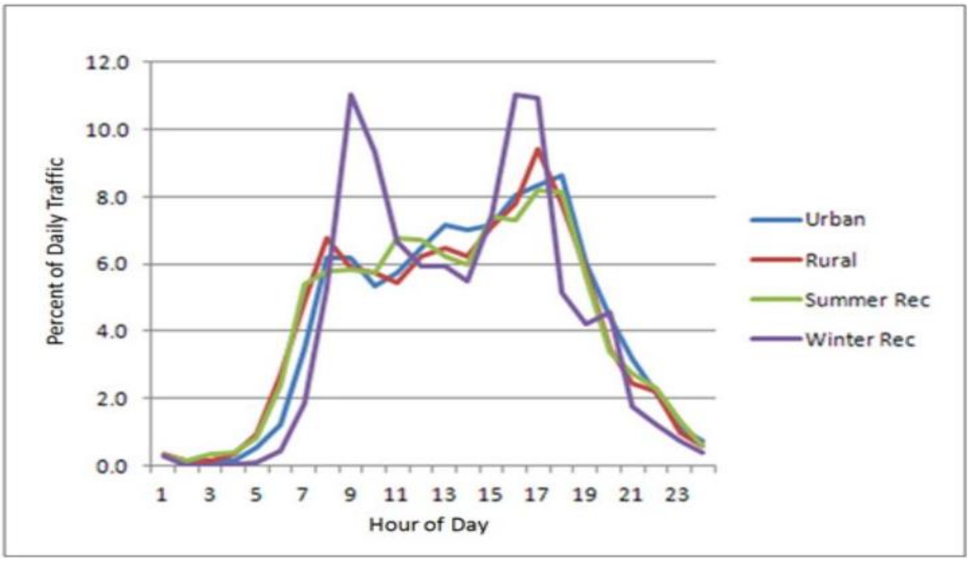


Figure (3-4) Daily Traffic Factors. (Source: Federal Highway Administration, 2016).

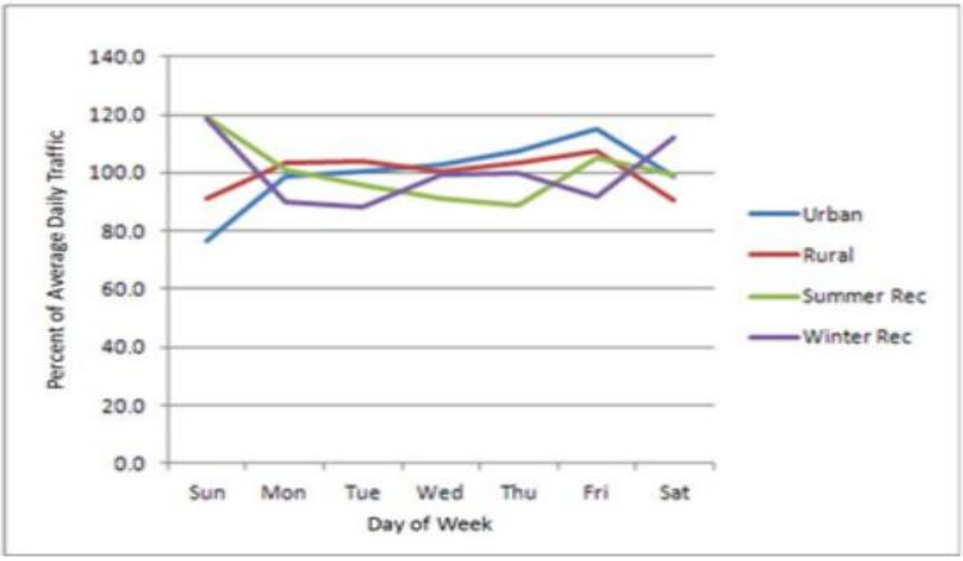


Figure (3-5) Average Daily Traffic Factors. (Source: Federal Highway Administration, 2016).

3.7.2 Estimation of Structural Number

Structural evaluation of pavement depended on nondestructive or destructive test. The data required is essential in assessing the structural capacity of pavement sections and networks (Hass et al., 2015).

3.7.2.1 Destructive Test

Destructive testing techniques include coring in bound layers, boring in soft layers, and dynamic cone penetrometer (DCP) testing in subgrade soils (Uddin, 2002). During destructive tests, each core was numbered and transferred safely to the Laboratory. However, cores serve one or more of the three general purposes in forensic investigations (i.e., for thickness, for the cause of distress, and for laboratory testing). One core can serve all of the three purposes if required, but care will need to be taken to obtain all required measurements and photographs before testing (NCHRP Report 747, 2013). The coring is conducted by using a smooth bore bit, generally 4 to 6 inches in diameter, to be drilled into the pavement. This test is usually conducted to gather information about the pavement from the pavement surface down to the subgrade. The coring provides a very detailed picture of how the roadway structure exists at the cored point (WSDOT,1994). The core samples were taken for surface and base layer for each arterial and collector section in the studied area (fifty sections). Plate (3-7) shows core test for a specific section in the study area.

The steps that are followed throughout current study:

1- Choose a places of core samples for each section, and take the coordinates of them.
2- Use core device to cut samples.
3- Cut cores at an angle of 90° to the surface in order to ensure the recovery of straight.
4- Numbering and mark the core and record number and location on the core log.
5- Photograph the core and record the photograph number on the core log.

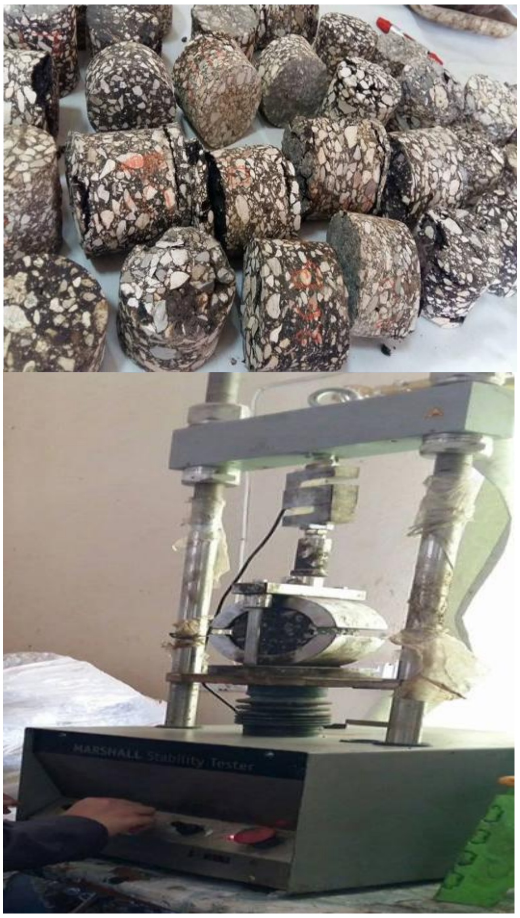
Plate (3-7) Core Test for a Section of Roadway in the Study Area.

3.7.2.2 Laboratory Testing of Samples

The Marshall Stability test procedure was used to prepare test specimens using ASTM D 6927 (2015). To determine layer coefficient and structural number for each layer (surface, binder, and base), follow these steps:

1- Separate each pavement layer (binder, surface, base)
2- Take the average height for each core. The dry weight also should be taken to determine bulk density as shown in Plate (3-8).
3- Before testing the core samples, leave them in a water bath having a temperature of 60^{o}C for half an hour and test it after that as shown in Plate. (3-9).

Plate (3-8) Dry Weight determinate.



A. Water Bath **B. Marshal Stability Apparatus.**

Plate (3-9) Marshall Stability/Flow Test Apparatus.

3.7.2.3 Structural Number of Pavement

The structural number was determined depending on data collected from Marshall test results, which shown in Appendix (C). The average thickness of core samples was used to determine stability correlation factors to correct the stability values by using ASTM D6927- 15 for Marshal Stability to correct the stability values

The corrected stability values were used to find structural layer coefficient (a) for each surface and base layer by using correlation charts. These correlation charts are used for estimating resilient modulus of asphalt concrete as shown in Fig. (3-6).

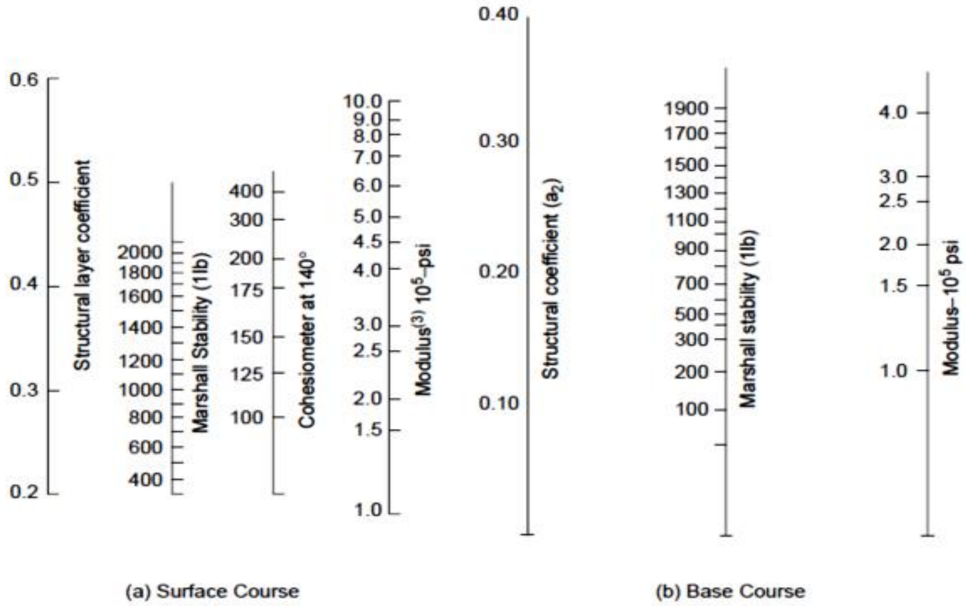


Figure (3-6) Correlation Charts for Estimating Resilient Modulus of Asphalt Concrete to Determine Structural Layer Coefficient (Source: AASHTO, 1993).

To determine the structural number for both the surface and base courses in each section, Equation (3-2) was used. Table (3-7) shows SN for 10 sections and other section are present in Appendix (C). The SN is calculated as below (Hoel et al., 2011):

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \quad \text{…. (3-2)}$$

where

SN: Structural number of the layer.

a_1 , a_2 , a_3 : Layer coefficients representative of layer 1, 2, and 3, respectively.

D_1, D_2, D_3: Actual thickness in inches of layer 1, 2, and 3, respectively.

m_2, m_3: Drainage coefficient for layer (2 & 3). In this study, it is supposed that the percent of time pavement structure exposed to moisture levels approaching saturation is greater than 25% with quality of drainage good (water remove within 1 day) for all selected roads network. So m_i equal to (1) Adapted from AASHTO guide for design of pavement Structures,(1993).

Table (3-7) Structural Number of the Different Sections in the Area Under Study.

Sample	Layer Name	Average Thickness of Layer (inches)	Stability (Ib)	Correction Factor of Thickness	Stability (Ib)	Layer Coff. (a)	SN
1	Base (1-1)	4.630	3938.645	0.659	2595.567	0.378	2.943
2	Binder (1-1)	3.976	1212.101	0.862	1044.831	0.3	
3	Base (1A)	4.429	4372.140	0.685	2994.916	0.398	3.3825
4	Binder (1A)	4.331	1656.333	0.91	1507.263	0.374	
5	Base (1B)	4.724	4409.244	0.647	2852.781	0.381	3.201
6	Binder (1B)	3.858	991.639	1.4366	1424.589	0.363	
7	Binder (2A)	1.850	1527.979	1.87125	2859.231	0.517	2.104
8	Base (2A)	3.465	3724.334	0.685	2551.169	0.371	
9	Binder (2B)	2.165	1800.294	1.4	2520.412	0.487	2.243
10	Base (2B)	3.622	4365.152	0.647	2824.253	0.386	
11	Binder(3-1A)	2.827	3187.002	0.938	2989.407	0.531	2.493
12	Base (3-1A)	2.661	2150.829	1.06	2279.879	0.359	
13	Binder(3-1B)	2.697	1688.740	1.4366	2426.045	0.475	2.694
14	Base (3-1B)	3.268	2892.464	0.775	2241.660	0.352	

Table (3-7) Structural Number of the Different Sections in the Area Under Study (continuo).

Sample	Layer Name	Average Thickness of Layer (inches)	Stability (Ib)	Correction Factor of Thickness	Stability (Ib)	Layer Coff. (a)	SN
15	Binder (4A)	2.559	3010.632	0.9875	2972.999	0.524	2.2091
16	Base (4A)	2.480	2003.120	1.0375	2078.237	0.35	
17	Binder (4B)	1.929	1688.740	1.6425	2773.756	0.503	2.0727
18	Base (4B)	3.150	2892.464	0.736	2128.854	0.35	
19	Binder (5-A)	3.008	2223.582	0.95	2112.403	0.438	2.15163
20	Base (5-A)	3.083	2234.759	0.858	1917.423	0.325	

CHAPTER FOUR

CHAPTER FOUR

EVALUATION OF PAVEMENT CONDITION USING PAVER SOFTWARE

4.1 General

A thorough explanation of PAVER software and its capabilities through identifying asphalt pavement distresses, field data collection to estimate pavement condition index, a summary of pavement inventory and condition at last inspection were presented throughout this chapter. Integrating PAVER software and GIS, critical PCI & work priorities, network condition analysis and prediction, and developing a model for PCI, all are essential factors in a successful Pavement Management System (PMS). Also, estimations of pavement condition index depending on developed models are of great importance in any PMS.

4.2 Determining the Number of Pavement Sample Units to be Inspected

The project level management needs more accurate data for the preparation of contracts and work plans. Therefore, the inspected sample units are used at the project level need to be more than that for network level management.

The minimum sample units n required for an adequate estimation of PCI value of the sections are determined at a project level by using Fig. (4.1), which shows the curves to determine the number for a project level. Using this number, lead to getting the true mean PCI of the section with an accurate estimation. There is 95% confidence that the estimate is within ± 5 points of the true mean PCI (if all the sample units were inspected, the PCI obtained). The curves in Fig.(4-1) were built using Eq. (4.1) (Shahin, 2005):

$$n = \frac{Ns^2}{((e^2/4)(N-1)+s^2)} \quad \ldots (4\text{-}1)$$

where:

n = The minimum sample units required for an adequate estimation

N = Total number of sample units in the pavement section

e = Allowable error in the estimate of the section PCI (e was set equal to 5 when constructing the curves of Fig. (4.1)).

s = Standard deviation of the PCI between sample units in the section.

The initial inspection when performing the PCI standard deviation for a pavement section is assumed to be 10 for asphalt concrete (AC) (ASTM D6433, 2011).

For section (1-A) in the selected case study area:

Area of section = 7m (width) × 724 m (length) = 5068 m^2

Sample unit area for a width of 7m (23ft) will be taken equal to 231 m^2 (approximately 2500 ft^2).

Length of each unit in the section 231/7 = 33 m (108.7 ft).

$$N= \frac{\text{Area of section}}{\text{Sample unit area}} \longrightarrow N= \frac{5068}{231} = 22$$

$$n= \frac{22*(10)^2}{((5^2/4)(22-1)+(5)^2)} = 9.51 \longrightarrow n= 10$$

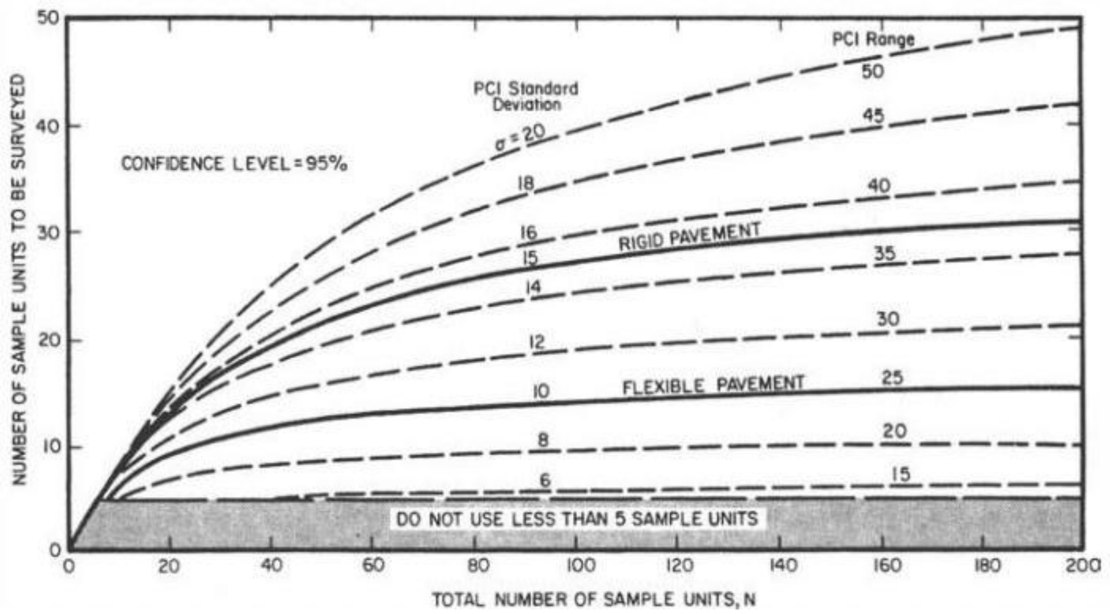


Figure (4-1) The Minimum Number of Sample Units (Source: Shahin, 2005.; UFC, 2004).

Shahin (2005) mentioned that one of the major drawbacks for each level, representative sampling at the network level and systematic random sampling at the project level is that sample units especially in bad condition may not necessarily be inclusive in the survey. Also, sample units that have a one time occurrence of distress type (such as railroad crossings) can be included unsuitably, as a random sample. Table (4-1) show the minimum sample units required for an adequate estimation of each inspected section for 12 section and other section in Appendix D.

4.2.1 Selecting Sample Units to be Inspected

It is recommended that the units of sample to be inspected be spaced uniformly throughout the section and that the first one be chosen at random. This technique, known as “systematic random,” (Shahin, 2005). The determined sampling units to be surveyed are described by the following three steps:

Table (4-1) Total Number of Sample Units and The Minimum Sample Units Required for the Section of Study Area.

Network ID	Branch ID	Section ID	Actual number of unit (N)	Minimum number of sample unit inspected (n)
Karbala	1	1	20	10
		A	22	10
		B	22	10
Karbala	2	A	46	12
		B	44	12
Karbala	3	A	2	2
		B	2	2
		A.1	2	2
		B.1	2	2
		1A	26	11
		1B	26	11
Karbala	4	A	32	11
		B	32	11
Karbala	5	1A	16	9
		1B	16	9
Karbala	6	1A	12	8
		1B	12	8
Karbala	7	1A	10	7
		1B	9	7
Karbala	8	1A	33	11
		1B	33	11
Karbala	9	A	9	6
		B	13	8
		C	13	8
Karbala	10	A	21	9
		B	21	9
Karbala	11	A	23	10
		B	23	10
Karbala	12	A	2	2
		B	2	2
		1A	4	4
		1B	4	4

A. The sampling interval (i): is established by (i = N/n), where (N) equals the whole number of obtainable sample units and (n) equals the smaller number of sample units to be surveyed. The sampling interval (i) is rounded off to the minimum total number (e.g., 3.6 is rounded to 3.0).
B. Random start (S): is/are chosen at random between sample unit 1 and the sampling interval (i). For example, if i = 3, the random starts would be a number from 1 to 3.
C. The sample units to be surveyed are identified as S, S+i, S+2i, etc. If the selected start is 3, and the sampling interval is 3 then the sample units to be surveyed are 6, 9, 12, etc. For section (1-A) in the selected case study area:

   $i=\frac{22}{10} = 2.2, i = 2$, S = 2, the sample units to be surveyed are 2, 4, 6.. etc.

4.2.2 Hand Calculation of PCI

The PCI is computed for the entire pavement section from the calculated PCI value of each inspected sample unit. Calculation of PCI depends mainly on deducting values weighing factors ranged from 0 to100 that indicate the impact of each distress has on condition of pavement. For section (1-A) in the selected case study area which has 10 sample units to be inspected with random between sample unit (i=2), so the inspecting units in this section units are: (2, 4, 6, 8, 10, 12, 14, 16, 18, and 20). The deducting value is determined based on the inspection data for each unit as shown previously in Table (3-1).

For unit 2 as example:

Density % (for Edge M) = $\frac{total\ quantity}{unit\ area} = \frac{6}{231}$ = 2.597 %.

Density % (for Depression L) = $\frac{2}{231}$ = 0.865 %.

Enter this density in the distress deduct value curves for each type of distress to find the deduct value as shown in the Fig. (4-2).

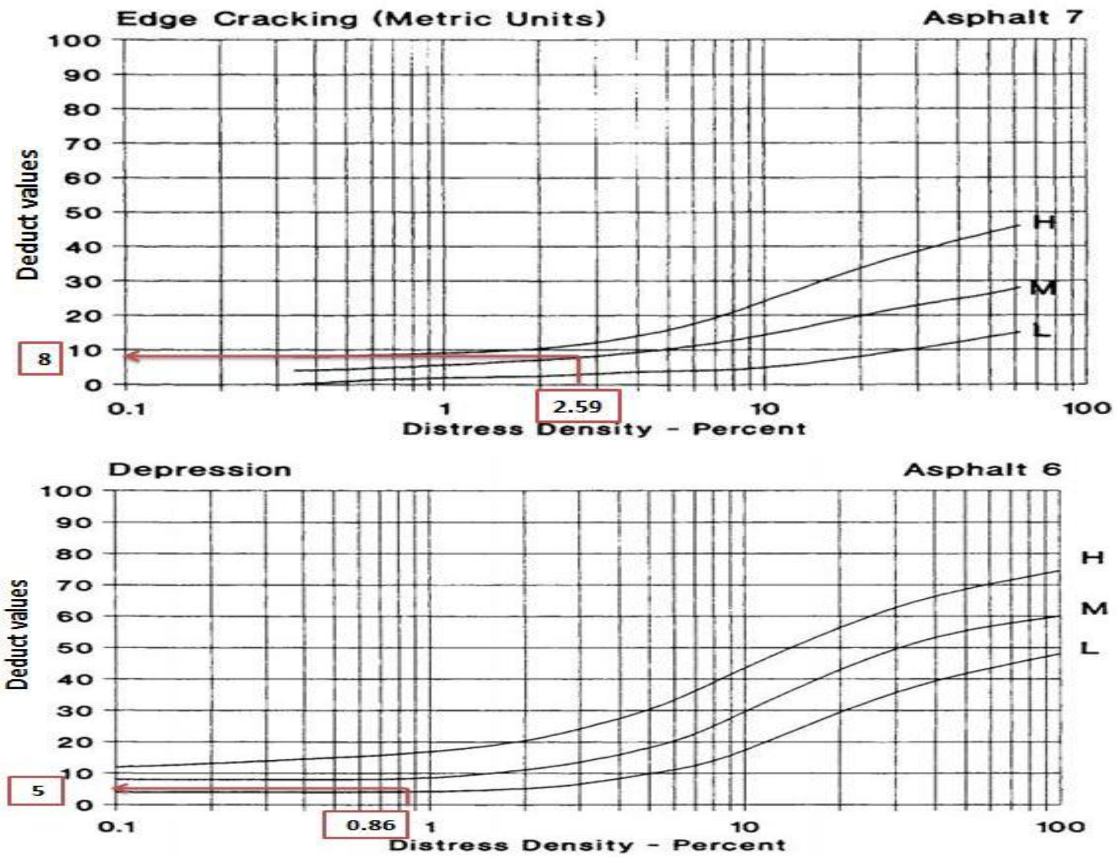


Figure (4-2) Edge Crack and Depression Distress Deduct Value Curves (Source: Shahin, 2005).

The maximum allowable number of deducts $(M_i) = 1 + \left(\frac{9}{98}\right)(100 - HDV_i)$ (for surfaced road)

where:

m_i : an allowable number of deducts, including fractions for sample unit, i.

HDV_i: highest individual deduct value for sample unit, i.

$(M_i) = 1 + \left(\frac{9}{98}\right)(100 - 8) = 9.44$

The q value for this unit is equal to 2 (take all the number of deducts with a value >2).

Total deduct value (TDV) = 8 + 5 = 13.

Determine the CDV from q and total deduct value by looking up the appropriate correction curve. Fig. (4-3) shows the correction curve for asphalt surfaced road pavements. The CDV is equal to 8.7

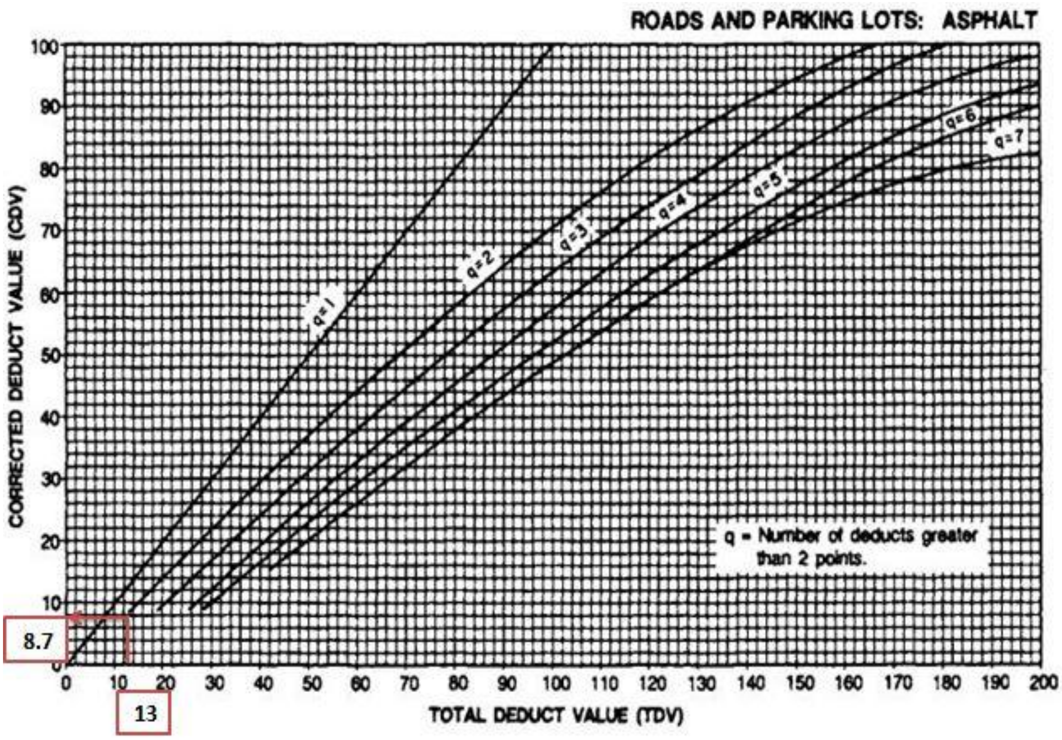


Figure (4-3) The Correction Curve for Asphalt Surfaced Road Pavements (Source: Shahin, 2005).

For surfaced roads, minimize the smallest individual deduct value that is > 2.0 to 2.0. Repeat steps until q is equivalent to1. The maximum CDV is the largest of the CDVs determined.

Total deduct value (TDV) = 8 + 3 = 11.

Determine the CDV from the same fig. when (q=1). The CDV is equal to 11, so PCI equal to:

PCI (for unit 2) = 100 – 11 = 89.

Table (4-2) gives the results of the hand calculation of PCI for other units in section (1-A). Average PCI of units in section (1-A) is equal to: {(89+60+75+83+72+100+85+92+100+100)/10} =85.6.

Table (4-2) The PCI Hand Calculation Results for each Unit in Section (1-A) of AL-Rabab Roadway.

Unit	Distress severity	Quantity	Density %	Deduct value	M_i	q	TDV	CDV	PCI
2	Edge M	6	2.597	8	9.44	2	13.0	8.7	89
	Depression L	2	0.865	5					
2	Edge M	6	2.597	8	9.44	1	11	11	
	Depression L	2	0.865	3					
4	Pothole L	4	1.731	27	7.7	2	42.4	31	60
	Edge M	30	13	15.4					
4	Pothole L	4	1.731	27	7.7	1	40.4	40	
	Edge M	30	13	13.4					
6	Edge H	25	10.822	25.5	7.84	1	25.5	25.5	75
8	Edge M	33	14.285	17.4	8.58	1	17.4	17.3	83
10	Edge H	32	13.852	29	7.52	1	29	28.5	72
12	----	----	----	----	---	-	--	--	100
14	Depression H	1.5	0.649	15.2	8.78	1	15.2	15.2	85
16	Depression M	1.5	0.649	8	9.44	1	8	8	92
18	----	----	----	----	---	-	--	--	100
20	----	----	----	----	---	-	--	--	100
Average PCI of Units									85.6

The standard deviation of the estimated PCI of each section is checked by using equation in ASTM D6433 (ASTM D6433, 2011) as shown below:

$S = (\sum_{i=1}^{n}(PCI_i - PCI_s)^2 /(n-1))^{1/2}$

Where:

PCI_i: PCI of surveyed sample units i.

PCI_s: PCI of section (mean PCI of surveyed sample units).

n: total number of sample units surveyed.

For the study area after check, it is found that, the standard deviation ranges between (12 to 14). Hence, for future study, standard deviation of 10 value may be replaced by 12 to 14.

4.3 Results of PAVER Software Application

PAVER software calculates the PCI value automatically for each sample unit in the section surveyed, determines an overall PCI for a section, and extrapolates distress quantities. PAVER software can also determine the percentage of deducting values depending on the mechanism of distress (load, climate, and other) for the section. Limiting the primary causes of pavement deterioration is a result of the percentage of deducting values attributed to each distress mechanism (Shahin, 2005).

4.3.1 Calculating PCI After Inspection

The calculations will be therefore, done automatically after distress information been entered into PAVER software and the overall PCI will be calculated for each section, as well as extrapolated quantities of distress (Shahin, 2005). Plate (4-1) shows an example of PCI calculation result from the PAVER software. Table (4-3) shows a sample of PAVER user defined reports of the last condition for 35 sections in the study area. The condition values for other sections are presented in Appendix (D).

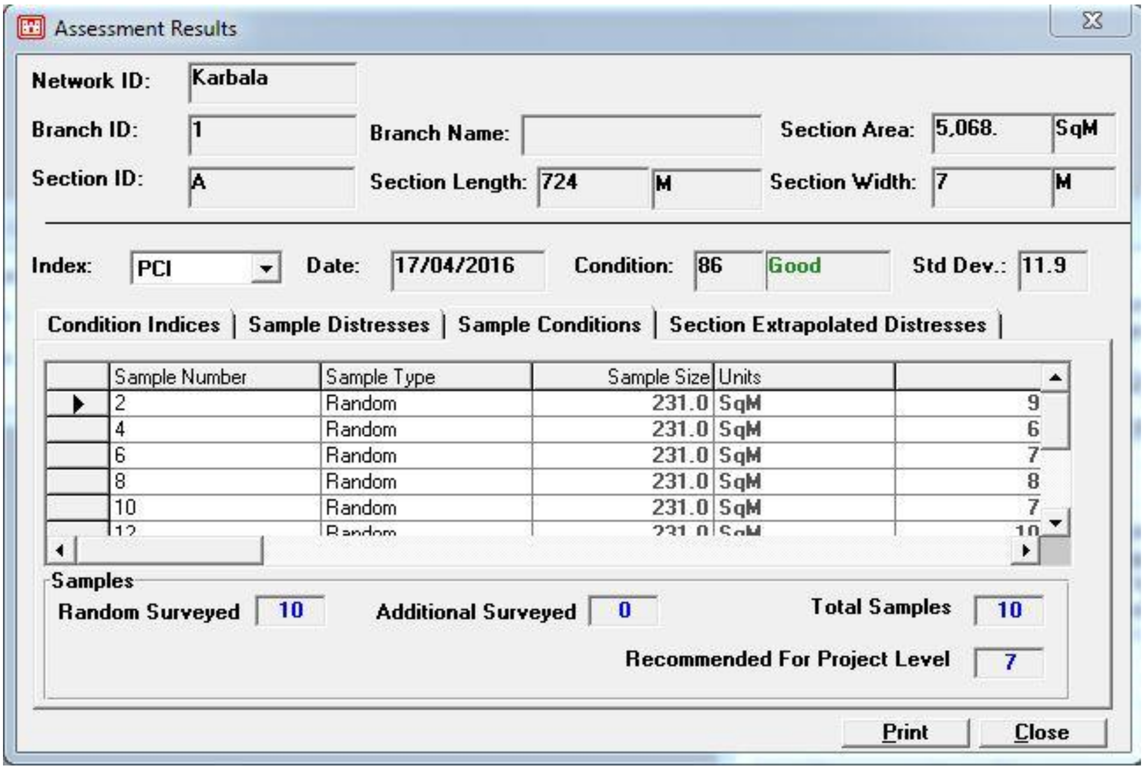


Plate (4-1) Typical List of an Automated PCI Calculation Resulted from the PAVER software.

Table (4-3) PAVER Software User Defined Reports of the Last Condition for Study Area of Karbala City.

Network ID	Branch ID	Section ID	SURFACE	PCI	PCI Category	PCI Climate	PCI Load	PCI Other
Karbala	1	1	AC	55	Poor	36	20	44
Karbala	1	A	AC	86	Good	0	49	51
Karbala	1	B	AC	85	Satisfactory	6	76	18
Karbala	2	1A	APC	51	Poor	18	64	18
Karbala	2	1B	APC	72	Satisfactory	54	23	23
Karbala	3	10A	APC	100	Good	0	0	0
Karbala	3	10B	APC	100	Good	0	0	0
Karbala	3	1A	APC	98	Good	100	0	0
Karbala	3	1B	APC	100	Good	0	0	0
Karbala	3_1	1A	AC	90	Good	39	5	56
Karbala	3_1	1B	AC	98	Good	71	29	0
Karbala	4	1A	AC	60	Fair	62	16	22
Karbala	4	1B	AC	46	Poor	29	71	0
Karbala	5	1A	AC	80	Satisfactory	41	59	0
Karbala	5	1B	AC	77	Satisfactory	36	43	21
Karbala	6	1A	AC	85	Satisfactory	45	13	42
Karbala	6	1B	AC	82	Satisfactory	50	4	46
Karbala	7	1A	AC	73	Satisfactory	34	50	16
Karbala	7	1B	AC	70	Fair	50	17	33
Karbala	8	1A	APC	86	Good	74	26	0
Karbala	8	1B	APC	90	Good	100	0	0
Karbala	9	1A	APC	90	Good	71	0	29
Karbala	9	1B	APC	85	Satisfactory	97	3	0
Karbala	9	1C	APC	85	Satisfactory	43	46	11
Karbala	10	1A	AC	97	Good	0	100	0
Karbala	10	1B	AC	91	Good	59	27	14
Karbala	11	1A	AC	93	Good	56	44	0
Karbala	11	1B	AC	87	Good	52	27	21
Karbala	12	1A	APC	94	Good	100	0	0
Karbala	12	1B	APC	95	Good	100	0	0
Karbala	12_1	1A	AC	80	Satisfactory	70	17	13
Karbala	12_1	1B	AC	80	Satisfactory	44	56	0
Karbala	13	1A	AC	76	Satisfactory	41	28	31
Karbala	13	1B	AC	68	Fair	29	53	18
Karbala	14	1A	AC	48	Poor	57	14	29

4.4 Integration PAVER Software to GIS

PAVER software has the capability to interact with GIS for displaying the results. After computing PCI through the PAVER software, PAVER output data inserted with GIS as a shape file. After that, the GIS shape file layer was selected and both software was linked, as shown in plate (4-2) for the whole area surveyed and plates (4-3) & (4-4) show zoom for each part of the study area.

Plate (4-2) PCI of PAVER Software at Last Inspection for the Whole Area Surveyed.

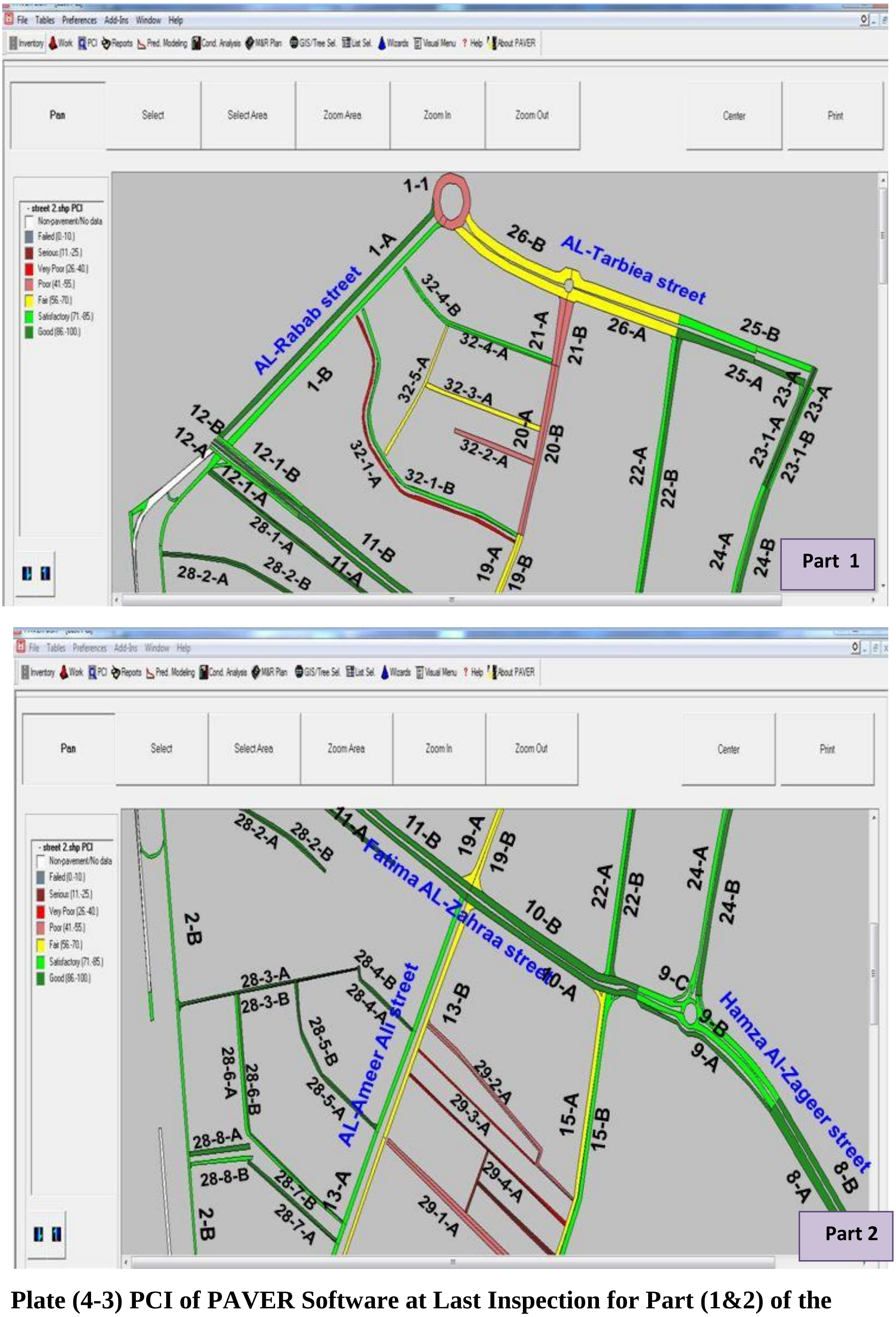


Plate (4-3) PCI of PAVER Software at Last Inspection for Part (1&2) of the Study Area.

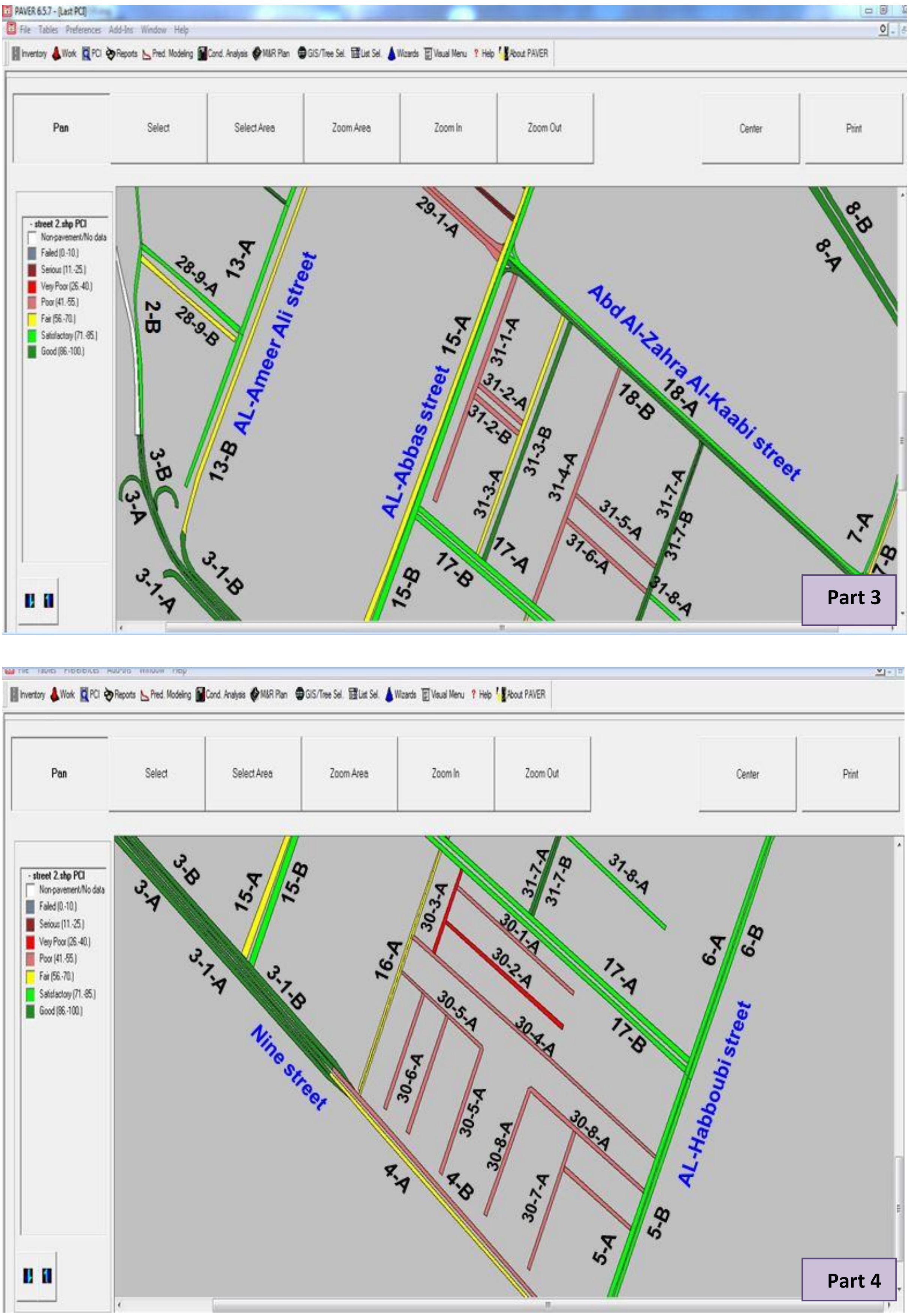


Plate (4-4) PCI of PAVER Software at Last Inspection for Part (3&4) of the Study Area.

4.5 Summary of Pavement Inventory and Condition at Last Inspection

This type of report is beneficial for quickly becoming familiar with the pavement network(s). The PAVER software "summary charts" report performs this function. In this report, the user is allowed to select a different variable for each of the x and y-axis, and the desired chart along with a summary table is automatically produced. PAVER software summary charts and table for different variables are shown in both Plate (4-5) and Table (4-4).

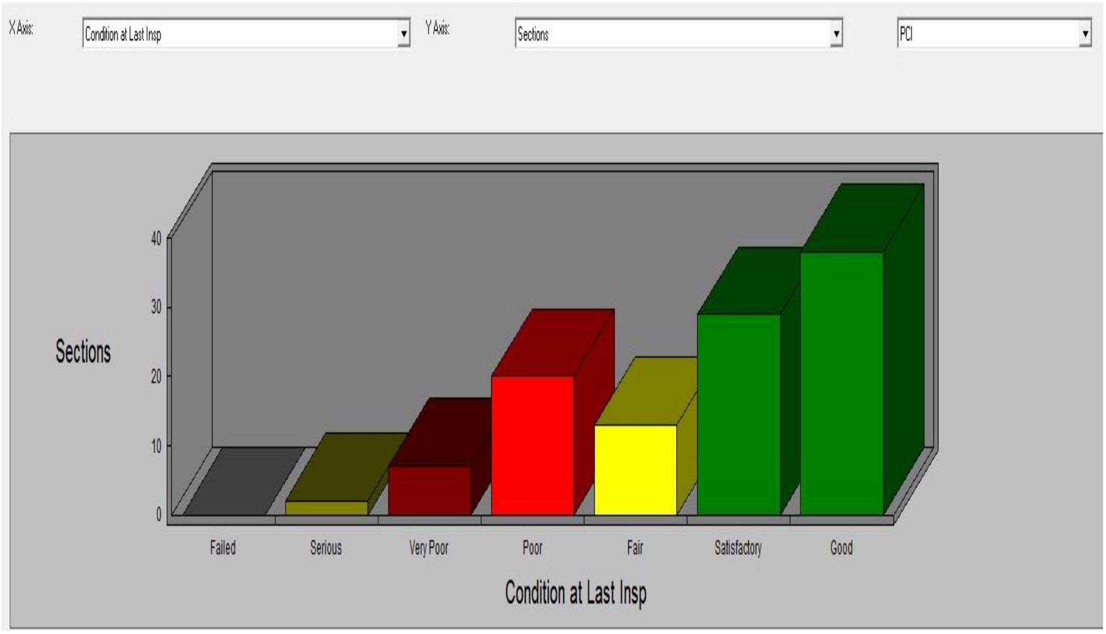


Plate (4-5) PAVER Software Summary Charts for Section vs. Condition at Last Insp.

Table (4-4) PAVER software Summary Information of PAVER software Layout Analysis.

Condition Category	Sections		Avg. Condition	Pavement Area	Unit
	Number	Percent%			
Failed	0	0			
Serious	2	2	14	1,777.00	m^2
Very Poor	7	6.5	33.14	12,287.30	m^2
Poor	20	18	48.05	56,651.46	m^2
Fair	13	12	65.15	56,701.95	m^2
Satisfactory	29	26.5	79.17	132,272.66	m^2
Good	38	35	93.53	124,344.80	m^2

4.6 Critical PCI and Work Priorities

PAVER software allows the pavement manager to maintain and rehabilitate sections roads from the set of critical PCI value, and to determine work priorities. The development of a priority allows the user to define priorities according to facility use, critical PCI value or pavement type, which is used by the (M&R) module. The priority typical scale of PCI that can be used to manage M&R operations is shown in Fig. (4-4). However, users can adapt the critical value of PCI depending on their own experience to reflect the behavior of different pavement sections. As an example, when a pavement has a high rate of deterioration, preventive maintenance (such as crack sealing) may not be cost effective, and thus the critical value of PCI can be adjusted (ATR-045, 2002). Regarding maintenance action for roads network sections of the study area, 63% need preventive maintenance (crack sealing and patching), 31% require rehabilitation (overlay.. etc.) and 6% needs reconstruction. The priority of M&R for sections of study due to PCI scale is shown in Plate (4-6).

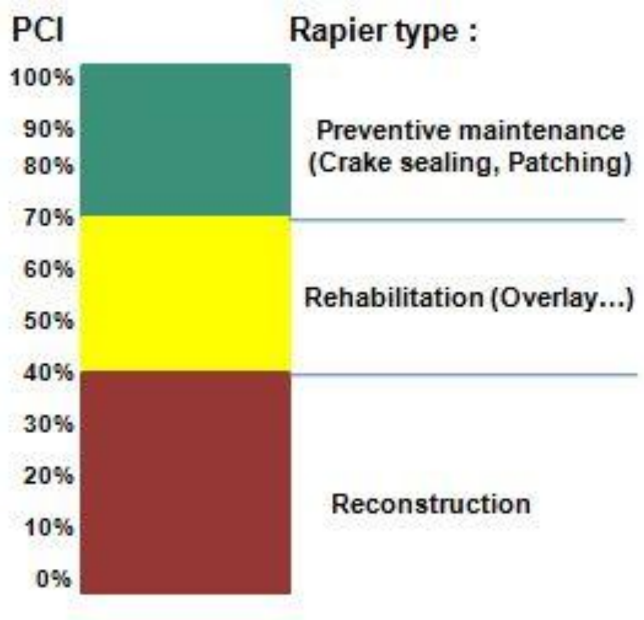


Figure (4-4) PCI Level Vs. Maintenance and Rehabilitation Type (Source: ATR-045, 2002).

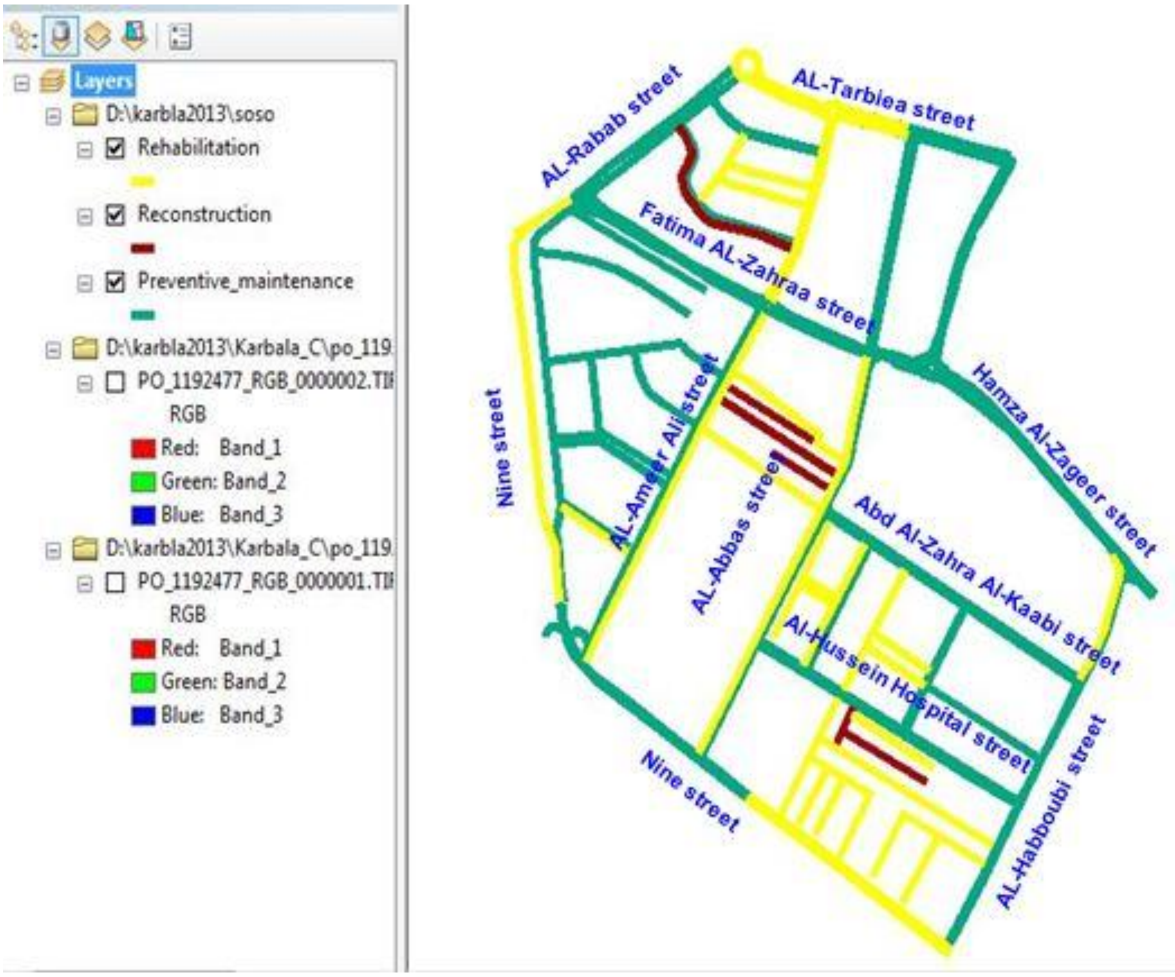


Plate (4-6) Priority of Maintenance and Rehabilitation for Selected Sections of Karbala City.

4.7 Network Condition Analysis and Prediction

The PAVER software frequency report introduces the excepted condition for each road sections. The condition analysis views the current condition performance for each road sections in the network; further analysis and prediction of the pavement condition index of sections was done through the limited period. A typical performance curve is illustrated for the latter case in Fig. (4-5) with the curve fitting for 15-year analysis and prediction period for all network sections.

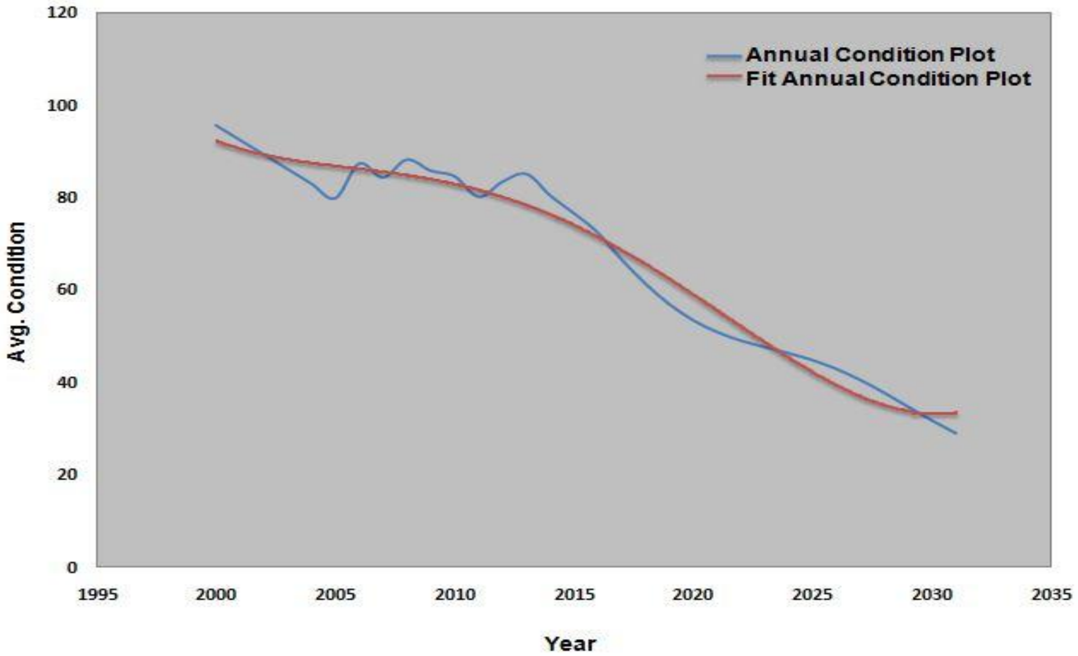


Figure (4-5) The Curve and Curve Fitting for 15-Year Analysis and Prediction Period for Network Sections.

4.8 PAVER Software PCI Model

Depending on PAVER software condition analysis and predicting model options, the predicted pavement condition index model (PCI) was developed. PAVER software prediction model grouped the pavement sections into families. These groups have the same surface type, pavement use, and pavement rank. PCI and age data for each family group were used through fiting model curve. However, many factors such as original construction, maintenance, traffic, weather, etc will greatly affect on the pavement life (ATR-045, 2002). This method of pavement condition prediction is very important in the state with limited historical data available. Depending on the data collected, PAVER PCI model was developed as shown in Plate (4-7). Outliner boundary of 95% (1.960), have eight sections out of bounds state, the review model data is presented in Appendix (D). PAVER model describes the deterioration of the pavement sections as a polynomial equation (5 degree) with age (x) as follows:

PCI = 100- 0.00003X- 2.91331X^2+ 0.5204X^3 - 0.03361 X^4+ 0.00073 X^5 ....(4-2)

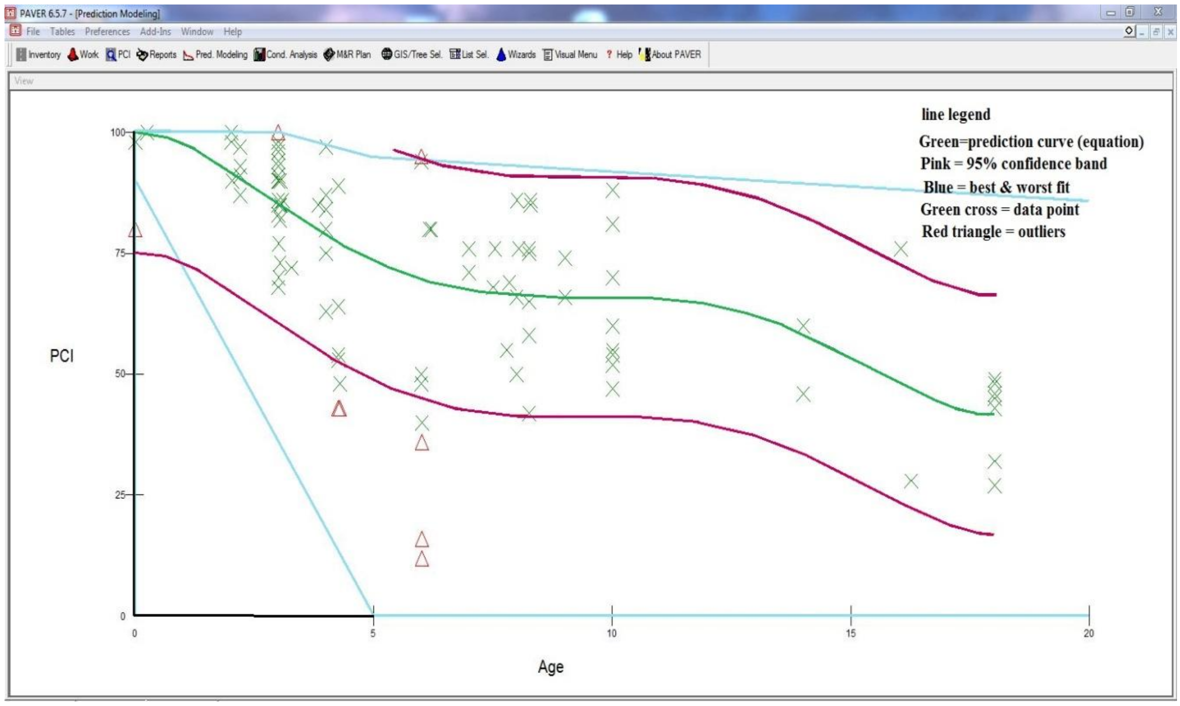


Plate (4-7) Pavement Life Prediction Curve for Study Area.

Statistical analysis output of PAVER software is shown in Table (4-5).

Table (4-5) Statistical Analysis of PAVER Software Prediction Model.

Coefficient of correlation (R)	Approximate (R^2)	Stander deviation of error	Absolute mean of error	Arithmetic mean of error
0.772	0.596	12.59	9.59	0.341

PAVER statistical test shows that 60% of the variation in the dependent variable (PCI) is explained by the independent variable (Age) in the developed model. The remaining percentage of variation (40%) is not explained due to many factors that can also affect the PCI of pavement such as traffic volume, the structure of pavement, mixing design used in paving, environment effect and human bad use.. etc.

4.9 Pavement Condition Models

First, it is intended to investigate the need for a statistical model to predict pavement condition depending on some independent variable rather than performing site inspection. Accordingly, the study demonstrates the application of developed model introduced by Hoel et al. (2011) to predict PCI in relation with some independent variables. The variables include the number of years since construction or reconstruction, average daily traffic, and the structural number (Hoel et al., 2011; Garber and Hoel, 2009).

4.9.1 Previous Model by Hoel et al. (2011)

Hoel et al. (2011), developed a model depended on a data collected by rating the condition of 20 individual pavement sections. The fitted model describes the deterioration of the pavement sections as follows:

$$CI = 98.87 - 2.18 \times AGE + 0.02 \times ADT + 0.28 \times SN \qquad \text{..... (4-3)}$$

where:

CI = condition index.

AGE = number of years since construction.

ADT = average daily traffic in 1000 veh/day.

SN = structural number.

The R^2 of this model is equal to (0.973). Typically, R^2values are within the range between 0 and 1. The developed model explains 96.7% of variation in CI as function of independent variables of AGE, ADT, and SN with 8.56E-13 degree of significance.

Pavement conditions index (CI) was calculated for 34 major and minor arterial sections and 10 collector sections from all network of Karbala city using Hoel et al., model (2011). The results are shown in Table (4-6).

Table (4-6) Pavement Condition Index of Karbala City by Using Hoel et al. Model.

Input data					Results	PCI of
Street	Type	ADT*1000	Age year	SN	CI	PAVER
1-A	Minor arterial	23.181	8	3.382	81.91	86
1-B	Minor arterial	24.728	8	3.201	81.83	85
2-B*	Major arterial	19.387	3.3	2.243	91.92	72
3-1-A	Major arterial	22.042	2	2.493	94.77	90
3-1-B	Major arterial	17.286	2	2.694	94.92	98
4-A	Major arterial	37.802	14	2.209	68.21	60
4-B*	Major arterial	39.977	14	2.073	68.13	46
5-A	Collector	11.725	4	2.152	90.52	80
5-B	Collector	14.417	4	2.074	90.44	77
6-A	Collector	13.445	4.3	2.359	89.89	85
6-B	Collector	14.209	4.3	2.399	89.88	82
7-A*	Collector	13.345	4.1	2.326	90.32	73
7-B*	Collector	14.552	4.1	2.214	90.26	70
8-A	Major arterial	34.083	3.1	2.618	92.16	86
8-B	Major arterial	38.866	3	2.682	92.30	90
9-A	Major arterial	34.049	3	2.547	92.36	90
9-B	Major arterial	36.214	3.1	2.584	92.11	85
9-C	Major arterial	30.693	3.12	2.748	92.22	85
10-A	Minor arterial	20.339	2.21	2.837	94.44	97
10-B	Minor arterial	21.598	2.21	2.875	94.43	91
11-A	Minor arterial	17.037	2.21	1.802	94.22	93
11-B	Minor arterial	18.941	2.21	1.613	94.12	87
12-1-A	Minor arterial	13.476	6	1.771	86.02	80
12-1-B	Minor arterial	12.486	6	1.881	86.07	80
13-A	Minor arterial	20.311	7.5	3.018	82.96	76
13-B*	Minor arterial	22.263	7.5	2.991	82.91	68
15-A*	Minor arterial	25.306	9	2.849	79.54	66
15-B	Minor arterial	21.950	9	2.708	79.57	74
17-A	Collector	15.129	7	2.293	83.95	71
17-B	Collector	13.601	7	2.218	83.96	76
18-A	Collector	13.241	4.2	2.320	90.10	87
18-B	Collector	15.061	4.2	2.121	90.01	84
19-A	Minor arterial	13.463	10	2.378	77.47	70
19-B*	Minor arterial	14.295	10	2.412	77.46	60
22-A	Minor arterial	14.722	9	3.543	79.95	81
22-B	Minor arterial	12.441	9	3.413	79.96	88
23-1-A	Minor arterial	11.746	3	1.883	92.62	85
23-1-B	Minor arterial	13.247	3	1.957	92.61	80

*Sections used for checking the developing model, CI: condition index of Hoel et al. model.

Table (4-6) Pavement condition index of Karbala city by using Hoel et al. Model (continued).

Input data					Results CI	PCI of PAVER
Street	Type	ADT*1000	Age year	SN		
24-A	Minor arterial	22.818	4.13	1.830	89.92	80
24-B	Minor arterial	22.221	4.1	1.871	90.01	87
25-A	Major arterial	36.270	3.5	2.036	91.08	76
25-B	Major arterial	29.145	3.5	1.999	91.22	86
26-A	Major arterial	35.692	8.5	3.154	80.51	66
26-B	Major arterial	30.818	8.5	3.019	80.57	69

*Sections used for checking the developing model, CI: condition index of Hoel et al. model.

Further, CI values obtained from the method were compared with PCI values for these sections, which represent the output of PAVER software application. SPSS tow paired test tool is used to analyze data and compared it as shown in Tables (4-7) and (4-8). The Hoel et al. (2011) model overestimated the value of CI rather than PCI estimated from PAVER software due to statistical test to a 95% degree of confidence, (R = 0.771) for 44 sections (arterial and collector). There is a significant difference between value CI and PCI for each of it (0.000 < 0.05), so the null hypothesis was rejected.

Hence, it can be calculated that there is a need to develop a new model or modeling calibration for model of Hoel et al. (2011). A new model is preformed with the same independent variable to achieve a whole calibration for each variable rather than the whole model.

Table (4-7) Paired Samples Statistics between Pavement Condition Index of PAVER and Condition Index of Hoel et al. Model.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pavement condition index (PCI)	79.5000	44	10.51798	1.58565
	Previous Garber et al. Model (CI)	87.0416	44	6.79316	1.02411

Table (4-8) Paired Samples Test between Pavement Condition Index of PAVER and Condition Index of Hoel et al. Model.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 Pavement condition index (PCI) - Previous Garber et al. Model (CI)	-7.54159	6.82875	1.02947	-9.61772	-5.46546	-7.326	43	0.000

4.9.2 Developing a Statistical Model of Pavement Condition

The data collections of study area depending on the same variables considered in the previous literature (the number of years since construction or reconstruction in the study rang between (2-14) year , average daily traffic, and the structural number). The study performs a statistical analysis to develop a predicting model of pavement condition. These statistical models were important in predicting the future condition of pavement sections in this region (Karbala city). A software program SPSS provides data analysis tool to perform same statistical analysis procedures, including regression analysis.

The first model is developed by using 37 individual pavement sections (for 29 major and minor arterial sections and 8 collector sections from all network). In order to get reliable results, it is important to check the proper sample size which determined from the equation as shown bellow:

$$N = (S\,Z/E)^2 \qquad \text{....... (4-4)}$$

Kamaludeen (1987) reported that for high accuracy and practical sample size, the maximum error should not exceed half the class width (class interval). Dependent variable (PCI) is normally distributed with sign. (0.055> 0.05), and the sample size equals to 10 (10 < 37) depended on the equation (4-4), with error (E= 5), std, deviation (8.288) with 95% degree of confidences. So, it's accept the sample size.

The SPSS statistical analysis is used for input data shown in Table (4-6) to determine the correlation between the independent variable (ADT, Age, and SN) as show in Table (4-9). The result show there is no correlation between of them. And the correlation between the dependent variable (PCI) with each of independent variable (ADT, Age, and SN), which shows respectively in Tables (4-10), (4-11), and (4-12). The correlation between PCI and ADT, Age, SN found to be 0.839, 0.693 and 0.95 respectively. Other test is percent in Appendix (E).

Table (4-9) the Correlation Between Independent Variable of the First Developed Model for the Selected Roadway in Karbala City.

Correlations

		Traffic volume(vpd *10000)	Pavement Age	Structural Number
Traffic volume(vpd *10000)	Pearson Correlation	1	.041	.228
	Sig. (2-tailed)		.809	.174
	N	37	37	37
Pavement Age	Pearson Correlation	.041	1	.386*
	Sig. (2-tailed)	.809		.018
	N	37	37	37
Structural Number	Pearson Correlation	.228	.386*	1
	Sig. (2-tailed)	.174	.018	
	N	37	37	37

*. Correlation is significant at the 0.05 level (2-tailed).

Table (4-10) Correlation Between Pavement Condition Index (PCI) and Average Daily Traffic (ADT) of the First Developed Model for the Selected Roadway in Karbala City.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.918	0.843	0.839	33.209

The independent variable is Traffic volume(vpd *1000).[a]

a. The equation was estimated without the constant term.

Table (4-10) Correlation Between Pavement Condition Index (PCI) and Average Daily Traffic (ADT) of the First Developed Model for the Selected Roadway in Karbala City(continued).

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Traffic volume(vpd *1000)	3.262	0.235	0.918	13.899	0.000

Table (4-11) Correlation between Pavement Condition Index (PCI) and Pavement Age (Age) of the First Developed Model for the Selected Roadway in Karbala city.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.838	0.701	0.693	45.782

The independent variable is Pavement Age.[a]

a. The equation was estimated without the constant term.

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Pavement Age	11.710	1. 273	0.838	9.197	0.000

(4-12) Correlation between Pavement Condition Index (PCI) and Structural Number (SN) of the First Developed Model for the Selected Roadway in Karbala City.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.975	0.951	0.95	18.524

The independent variable is Structural Number .[a]

a. The equation was estimated without the constant term.

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Structural Number	32.212	1.271	0.975	26.467	0.000

Table (4-13) shows summary of the statistical characteristics of the developed model. The others statistical analysis layout is presented in Appendix (E). According to that summary, the developed model represents 69.1 % of the variation in PCI in relation with pavement age (AGE), average daily traffic (ADT), structural number (SN) with a degree of confidence of 95%. The model that describes the deterioration of the pavement sections is stated as follows:

$$CI_1 = 82.896 - 2.607 \times AGE - 0.186 \times ADT + 6.885 \times SN \qquad ....(4\text{-}5)$$

For ADT from (11000-40000), age from (2-14), and SN from (1.5-3.6).

Table (4-13) Summary of Statistical Characteristics, and ANOVA of the First Developed Model for the Selected Roadway in Karbala City.

A- Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.847[a]	0.717	0.691	4.60372	0.717	27.891	3	33	0.000

a. Predictors: (Constant), Structural Number , Traffic volume(vpd *10000), Pavement Age
b. Dependent Variable: Pavement condition

B- ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1773.402	3	591.134	27.891	0.000[b]
	Residual	699.408	33	21.194		
	Total	2472.811	36			

a. Dependent Variable: Pavement condition
b. Predictors: (Constant), Structural Number , Traffic volume(vpd *10000), Pavement Age

C- Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	82.896	3.902		21.244	0.000
	Traffic volume(vpd *10000)	-0.186	0.090	-0.184	-2.071	0.046
	Pavement Age	-2.607	0.290	-0.902	-9.000	0.000
	Sutractural Number	6.885	1.671	0.364	4.121	0.001

In order to consider the effect of functional classification of pavement condition another model was developed. The second model developed by using just arterial section (major and minor) input data (29 individual pavement sections), as listed in Table (4-5). The sample size for the dependent variable (PCI) is checked by using the same equation. N value find equal to 12 (12< 29) with error (E= 5), std, deviation (8.9) with 95% degree of confidences.

The SPSS statistical analysis is used for input data shown in Table (4-6) to determine the correlation between the independent variable (ADT, Age, and SN) as show in Table (4-14). The result show there is no correlation between of them. And the correlation between the dependent variable (PCI) with each of independent variable (ADT, Age, and SN), which shows respectively in Tables (4-15), (4-16), and (4-17). The correlation between PCI and ADT, Age, SN found to be 0.852, 0.65 and 0.941 respectively. The others statistical analysis layout is presented in Appendix (E).

Table (4-14) the Correlation Between the Independent Variable of the Second Developed Model for the Selected Roadway in Karbala City.

Correlations

		Traffic volume(vpd *10000)	Pavement Age	Structural Number
Traffic volume(vpd *10000)	Pearson Correlation	1	.012	.148
	Sig. (2-tailed)		.949	.443
	N	29	29	29
Pavement Age	Pearson Correlation	.012	1	.391*
	Sig. (2-tailed)	.949		.036
	N	29	29	29
Structural Number	Pearson Correlation	.148	.391*	1
	Sig. (2-tailed)	.443	.036	
	N	29	29	29

*. Correlation is significant at the 0.05 level (2-tailed).

Table (4-15) Correlation Between Pavement Condition Index (PCI) and Average Daily Traffic (ADT) of the Second Developed Model for The Selected Roadway in Karbala City.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.926	0.857	0.852	32.011

The independent variable is Traffic volume(vpd *1000).[a]

a. The equation was estimated without the constant term.

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Traffic volume(vpd *1000)	3.054	0.235	0.926	12.968	0.000

Table (4-16) Correlation between Pavement Condition Index (PCI) and Pavement Age (Age) of the Second Developed Model for the Selected Roadway in Karbala city.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.814	0.662	0.650	49.268

The independent variable is Pavement Age.[a]

a. The equation was estimated without the constant term.

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Pavement Age	11.045	1.492	0.814	7.404	0.000

Table (4-17) Correlation between Pavement Condition Index (PCI) and Structural Number (SN) of the Second Developed Model for the Selected Roadway in Karbala City.

A- Model Summary[a]

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.971	0.943	0.941	20.267

The independent variable is Structural Number .[a]

a. The equation was estimated without the constant term.

Table (4-17) Correlation between Pavement Condition Index (PCI) and Structural Number (SN) of the Second Developed Model for the Selected Roadway in Karbala City (continued).

B- Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Structural Number	31.470	1.465	0.971	21.480	0.000

Also, SPSS multiple linear regression model was used to predict PCI of sections. Table (4-18) shown summaries the statistical characteristics of the developed model and the others statistical analysis layout is presented in Appendix (E).

Table (4-18) Summary of Statistical Characteristics, and ANOVA of the Second Developed Model for the Selected Roadway in Karbala City.

A- Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.876[a]	0.767	0.739	4.56130	0.767	27.439	3	25	0.000

a. Predictors: (Constant), Structural Number , Traffic volume(vpd *10000), Pavement Age

b. Dependent Variable: Pavement condition

B- ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1712.622	3	570.874	27.439	0.000[b]
	Residual	520.137	25	20.805		
	Total	2232.759	28			

a. Dependent Variable: Pavement condition

b. Predictors: (Constant), Structural Number , Traffic volume(vpd *10000), Pavement Age

Table (4-18) Summary of Statistical Characteristics, and ANOVA of the Second Developed Model for the Selected Roadway in Karbala City (continued).

C- Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	87.291	4.313		20.241	0.000
	Traffic volume(vpd *10000)	-0.280	0.099	-0.276	-2.828	0.009
	Pavement Age	-2.574	0.294	-0.919	-8.751	0.000
	Structural Number	6.266	1.683	0.395	3.723	0.001

According to that summary, the developed model that represents 73.9% of the variation in PCI in relation with pavement age (AGE), average daily traffic (ADT), structural number (SN) with a degree of confidence of 95%. The model that describes the deterioration of the pavement sections is stated as follows:

CI_2 = 88.71 – 2.719×AGE + 0.272×ADT + 5.671×SN …(4-6)

For ADT from (11000-40000), age from (2-14), and SN from (1.5-3.6).

In order to test the validity of these developed models, use data collected for other seven sections that are not being used in the developing models, and apply in the two developed models, as shown in Table (4-19).

Table (4-19) The Data Collection to Check the Models.

Input data					Results		PCI of PAVER
Street	Type	ADT*1000	Age year	SN	CI_1	CI_2	
2-B	Minor arterial	19.387	3.3	2.243	86.128	87.423	72
4-B	Minor arterial	39.977	14	2.073	53.231	53.049	46
7-A	Collector	13.345	4.1	2.326	85.740	----	73
7-B	Collector	14.552	4.1	2.214	84.741	----	70
13-B	Minor arterial	22.263	7.5	2.991	79.798	80.497	68
15-A	Minor arterial	25.306	9	2.849	74.340	74.890	66
19-B	Major arterial	22.042	2	2.412	70.772	72.662	60

(CI_1) condition index for First model (arterial & collector), (CI_2) condition index for second model (arterial), (PCI) pavement condition index from PAVER.

Statistical analysis between PCI with CI_1 and PCI with CI_2 values show that the correlations were (0.975) and (0.964) respectively. Figures (4-6) and (4-7) show the normal P-P plot for these values. The results show that each of the two models has a good relationship and the standard deviation. The error of the estimate has very low values for each of the developed models. So, these models are accepted to be used for determining PCI value for any sections in the study area and each area have the same characteristics.

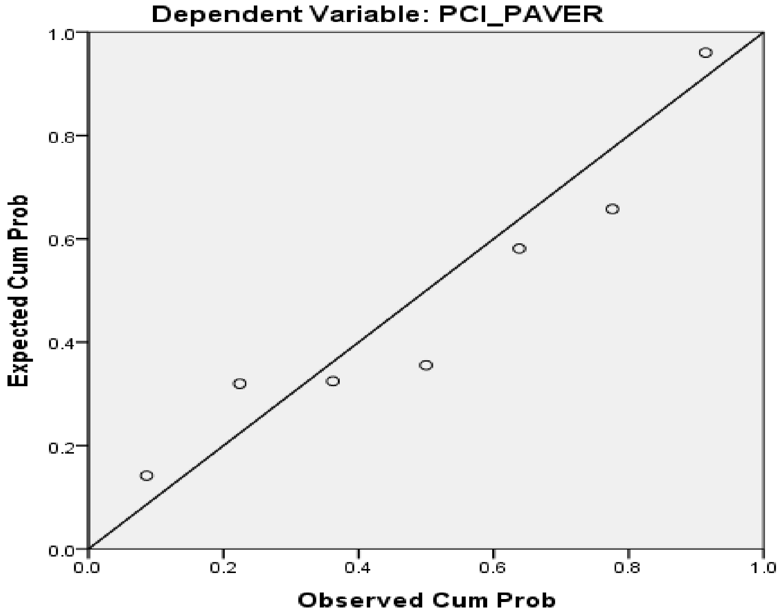


Figure (4-6) Normal P-P Plot of Regression Standardized Residual Dependent Variable of First Model.

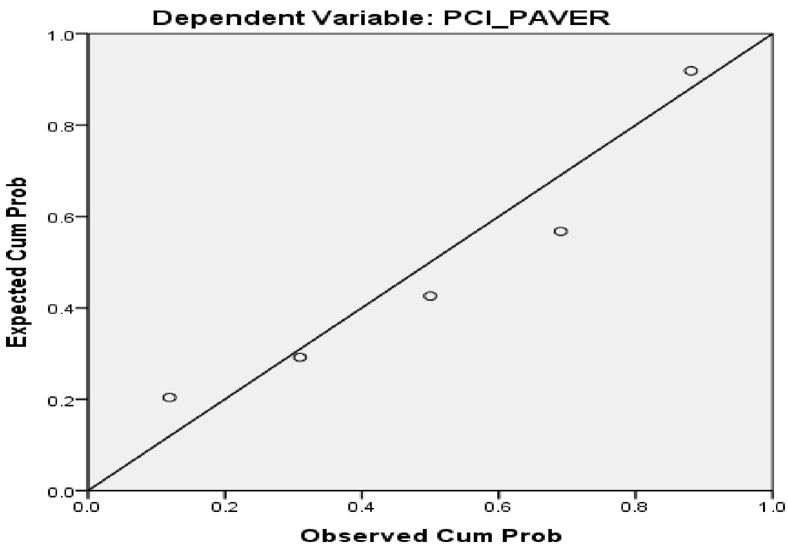


Figure (4-7) Normal P-P Plot of Regression Standardized Residual Dependent Variable Second Model.

Application of the data variables presented in Table (4-5) in combination with Eq. (4-4) used to estimate CI_1 resulted in the data and Eq. (4-5) used to estimate the CI_2 as shown in Table (4-20).

Table (4-20) Condition Index (CI) for Pavement According to Developed Models.

First model (arterial & collector)		
Section	PCI of PAVER	CI_1
1_A	86	81.02
1_B	85	79.47
3-1_A	90	90.74
3-1_B	98	93.01
4_A	60	54.57
5_A	80	85.09
5_B	77	84.06
6_A	85	85.42
6_B	82	85.55
8_A	86	86.49
8_B	90	85.31
9_A	90	86.27
9_B	85	85.86
9_C	85	87.97
10_A	97	92.88
10_B	91	92.91
11_A	93	86.37
11_B	87	84.71
12-1_A	80	76.93
12-1_B	80	77.88
13_A	76	80.34
15_B	74	73.99
17_A	71	77.62
17_B	76	77.38
18_A	87	85.45
18_B	84	83.75
19_A	70	70.69
22_A	81	81.08
22_B	88	80.61
24-A	80	80.48
24-B	87	80.95
25-A	76	81.04
25-B	86	82.1
26-A	66	75.81
26-B	69	75.78

Second model (arterial)		
Section	PCI of PAVER	CI_2
1_A	86	81.40
1_B	85	79.82
3-1_A	90	91.59
3-1_B	98	94.18
4_A	60	54.51
8_A	86	86.16
8_B	90	85.49
9_A	90	85.99
9_B	85	85.36
9_C	85	87.88
10_A	97	93.68
10_B	91	93.56
11_A	93	88.12
11_B	87	86.40
12-1_A	80	79.16
12-1_B	80	80.14
13_A	76	81.21
15_B	74	74.94
19_A	70	72.67
22_A	81	82.20
22_B	88	82.02
23-1_A	85	88.07
23-1_B	80	88.12
24_A	80	81.73
24_B	87	82.23
25_A	76	80.88
25_B	86	82.64
26_A	66	75.18
26_B	69	75.70

∗ (CI_1) condition index for First model (arterial & collector), (CI_2) condition index for second model (arterial), (PCI) pavement condition index from PAVER.

Comparing each of CI_1 and CI_2 with PCI resulted from PAVER by using SPSS (T-Test) as shown in Tables (4-21) and (4-22). The correlation of PCI with CI_1 and CI_2 with n = 37 and 29 were (0.847) and (0.876) respectively. There is no significance difference between value PCI and CI_1 (0.990 > 0.05), and for PCI with CI_2 (0.994 > 0.05). It accepts the null hypothesis.

Table (4-21) T-Test for First Developing Model

a- Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PCI_PAVER	82.2432	37	8.28789	1.36252
	CI_1_MODEL	82.2344	37	7.01865	1.15386

b-Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 PCI_PAVER - CI_1_MODEL	0.00887	4.40769	0.72462	-1.46073	1.47847	0.012	36	0.990

Table (4-22) T-Test for Second Developing Model

a- Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PCI_PAVER	82.7931	29	8.92980	1.65822
	CI_2_MODEL	82.7991	29	7.82054	1.45224

b-Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair1 PCI_PAVER - CI_2_MODEL	-0.0059	4.30993	0.80033	-1.64539	1.63343	-0.007	28	0.994

4.10 Developed Models Results and Discussion

The first model (CI_1) covered (69.1%) and the second model (CI_2) covered (73.9%) of variation in the dependent variable (PCI). Both models are explained by the independent variables (Age, ADT, and SN). The remaining percentage of variation approximately (30%) is not explained. The Dispersion in values due to many reasons, such as:

1. Deterioration of the pavement due to bad using of human.
2. Deterioration of the pavement due to vehicles passing with heavy loads at the first time of maintenance or reconstruction.
3. The weakness of pavement layers located at the bottom of surface layer gives deterioration earlier than the normal cause (have a good bottom layers).
4. Asphalt mixtures used to implement maintenance or reconstruction of the road is nonconformity with the specification standard for mixing.
5. Leveling is not set through the implementation of pavement maintenance.
6. The focus on attractive locations that can affect on many of the factors, which accelerate the pavement deterioration.

CHAPTER FIVE

CHAPTER FIVE

MAINTENANCE PRIORITY

5.1 General

The present chapter includes the proposed optimized developed priority of maintenance sections by using different methods.

5.2 The Proposed Maintenance Prioritization Methods

Three prioritization methods are proposed in this research as follows:

- Simple ranking by PCI measure.
- Ranking by multiple measures.
- Incremental benefit-cost analysis ranking.

Simple ranking by PCI measure provides a prioritized list of projects depended on a pavement condition index criterion. Other measures in addition to PCI are included in the process of ranking by multiple measures. Investigation of expert knowledge about measures that affect prioritization of sites for maintenance is achieved through a predesigned questionnaire. The irrespective scores of each measure and its importance are also investigated. Ranking by multiple measures is an improved alternative for condition index method and the matrix method developed by Washington State Department of Transportation, WSDOT (1994).

Further, incremental benefit-cost analysis ranking provides an optimized process of ranking by taking PCI measure as a benefit (when maintenance to the roadway section is achieved) and cost of maintenance (according of the suitable maintenance strategy for a specific distress in that section). Hence, this process considers the effect of budget constraints and allocated resources in developing an optimized maintenance project set. Also, this process is related to the benefit-cost ratio process and the cost-effectiveness procedure developed by Washington State Department of Transportation (WSDOT, 1994).

5.3 Application of the Proposed Prioritization Process

Site inspection was achieved for road sections in the selected zone in the study area. According to the output of PAVER and other factors affecting pavement condition, the study demonstrates the application of the prioritization process.

5.3.1 Simple Ranking by PCI Measure

Simple ranking by PCI depends mainly on the output of PAVER. PCI measure for each section of roadway represents the degree of need to maintenance. Consequently, sections of the roadway inspected, which are used in other prioritization processes in this study are ranked from lowest PCI to the highest one. Using the priority typical scale of PCI rank that can be used to manage M&R operations is shown in Plate (5-1). However, users can see the critical PCI to show the behavior of different sections of their pavement depended on their own experience. The priority of M&R for sections of study due to PCI rank scale is shown in Plate (5-1). On the other hand, and depending on PCI values from PAVER output the GIS tools was used to layout the maintenance priority for the selected sections as shown in Plate (5-2).

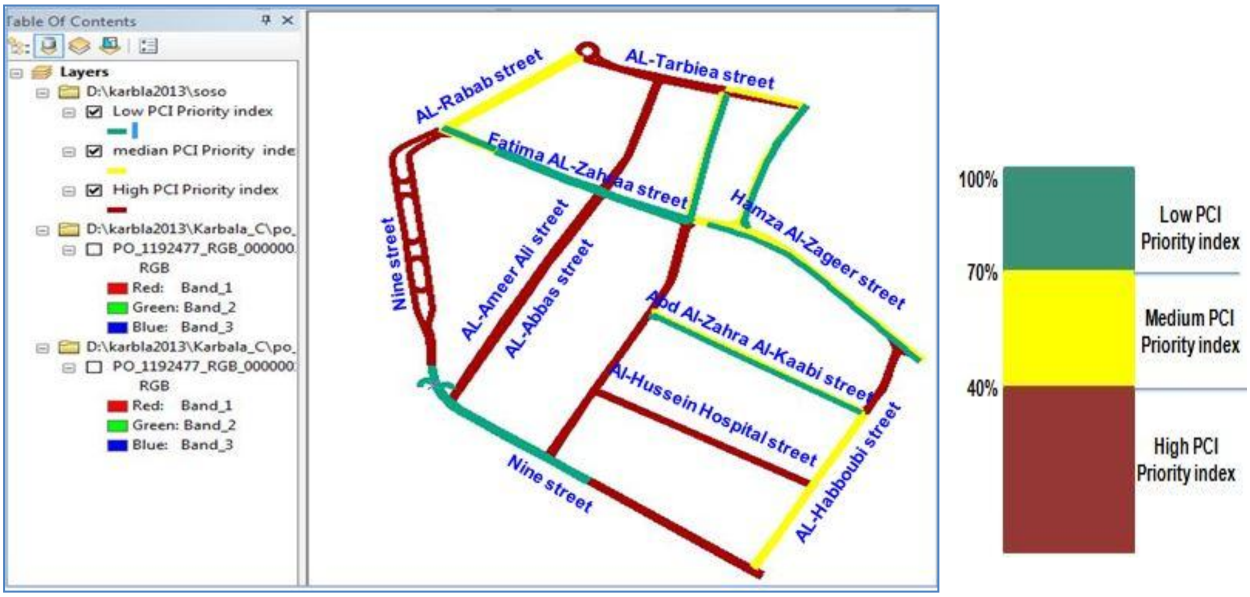


Plate (5-1) **Priority of Maintenance and Rehabilitation for Selected Roadway Zone in Karbala City.**

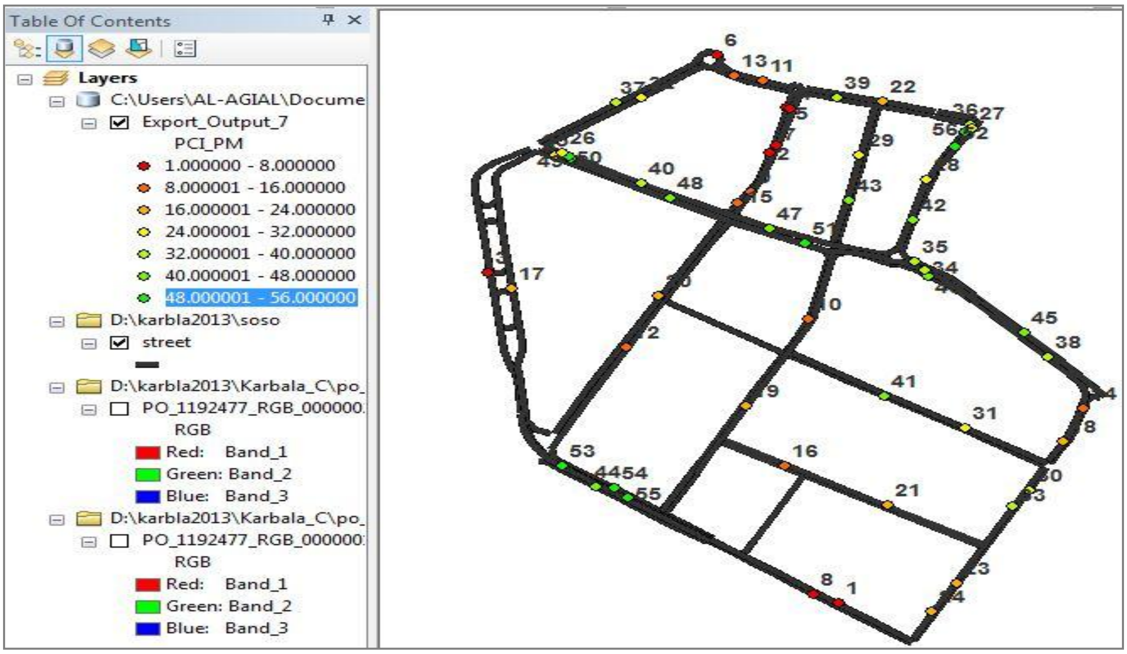


Plate (5-2) **Sectional Maintenance Priority Layouts due to PCI Values for Selected Roadway Zone in Karbala City.**

5.3.2 Ranking by Multiple Measures

The maintenance priority index (MPI) (as a dependent variable) is related to other independent variables in addition to PCI determined from PAVER system. The independent variables include; cost, easiness, average daily traffic (ADT), and function classification. Maintenance priority index equation suggested to be is equal to:

$$\text{MPI} = (a * \text{PCI}) - (b * \text{C}) + (c * \text{E}) + (d * \text{ADT}) + (e * \text{F.C.}) \qquad \dots (5\text{-}1)$$

where:

MPI: Maintenance priority index of the section.

PCI: Pavement condition index of section.

C: Maintenance cost for each section per square meter.

E: easiness of work through maintenance sections.

ADT: Average Daily Traffic for each section.

F.C.: Function Classifications of each section roads.

a,b,c,d,e: Irrespective weight value due to experts response.

The weights of the independent variable in the equation were found during the inspection test. Whereas, statistical analysis was made for 35 questionnaire samples. Assuming normal distribution for the response of the questionnaire output, the sample number is checked to be sufficient for 95% degree of confidences and acceptable error of ±1 and the standard deviation of the output scores for each items in the questionnaire. Statistical analysis for this irrespective weight and check sample size are shown in Appendix (E). Table (5-1) shows irrespective weight for remains (32 questionnaire samples).

The average factors of these irrespective weight are determined for each variable; whereas cost, PCI, easiness, ADT, and function classification equal to (-6.39), (7.61), (4.97), (8.31), and (6.88) respectively. Determining the maintenance priority of sections in the study area (using data for 46 major and minor arterial sections, and 10 collector sections) is found by using the priority Eq. (5-1).

In this research, application on an arterial and collector sections depended on collected data of ADT as shown above. The maintenance cost per square meter which estimated as shown in Appendix (B).

Table (5-1) Irrespective Weight Value (out of 30) for Each Factor of Multiple Priority Method.

Questionnaire	Cost	PCI	Easiness	ADT	F.C.
1	-9	8	2	7	7
2	-8	9	4	9	8
3	-8	9	6	9	9
4	-5	6	4	6.5	6
5	-6	7	7	7	5
6	-5	7	5	8	6
7	-8	9	5	8	7
8	-8	9	7.5	7	8
9	-8	8	7	9	9
10	-7	9	6	9	8
11	-7	9	3	8	10
12	-6	8	3	9	9
13	-2	5	6	7	5
14	-2	10	5	10	5
15	-7	8	5	10	5
16	-3	5	4	9	7
17	-5	5	4	7	4
18	-4	6	3	8	5
19	-5	6	4	8	4
20	-7	7	6	8	9
21	-7	6	5	8	8
22	-7	6	7.5	8	7
23	-5	9.5	5	9	8
24	-6	5	5	9	8
25	-2	8	5	10	10
26	-7	7.5	5	9	8
27	-7	8	5	8	8.5
28	-8.5	8.5	6	9	7
29	-8	10	5	10	3
30	-10	10	5	8	2
31	-8	5	5	7.5	7
32	-9	10	5	8	7.5

(cost): Maintenance cost for each section per square meter, (PCI): Pavement condition index of the section, (Easy): easiness of work through maintenance sections, (ADT): Average Daily Traffic for each section, (F.C.): Functional Classifications of each section roads.

The functional classification of section roads, which ranking from 1 up to 5 (1: local, 2: local distributor, 3:collector, 4:minor arterial, 5:major arterial), and the easy work values to maintain sections use dependent in Table (3-5). Table (5-2) shows the input value for each variable and the results of maintenance priority sections from equation (5-1). Plate (5-3) shows a layout of maintenance priority for the selected sections using GIS tools. Multiple priority maintenance (MPI) can be classified into three ranges corresponding to the scale. On the other hand, and depending on MPI values the GIS tools was using to layout the maintenance priority for the selected sections as shown in Plate (5-4).

Table (5-2) Maintenance Priority Depended on Many Variables.

Input Data							Maintenance Priority	
Section	Type	PCI	Cost ID/m2	Easiness	ADT vpd	F. C.	PMI	PM.
1_1	Major arterial	55	10,002	3	33589	5	215679.7	12
1_A	Minor arterial	86	545	3.5	23181	4	189850.9	15
1_B	Minor arterial	85	817	3.9	24728	4	200962.8	14
2_A	Major arterial	50	6,739	3.2	15665	5	87544.74	53
2_B	Major arterial	72	3,187	3.6	19387	5	141341.3	28
3_A	Major arterial	98	8	5	21604	5	180283.2	18
3_B	Major arterial	100	0	5	24834	5	207190.8	13
3-1_A	Major arterial	90	904	3.9	22042	5	178131.1	19
3-1_B	Major arterial	98	30	4.6	17286	5	144258	27
4_A	Major arterial	60	6,124	3.6	37802	5	275511.2	7
4_B	Major arterial	46	6,423	3	39977	5	291565.3	4
5_A	Collector	80	2,215	3.6	11725	3	83928.23	54
5_B	Collector	77	3,132	3.8	14417	3	100417.3	41
6_A	Collector	85	3,544	3.4	13445	3	89766.18	52
6_B	Collector	82	2,952	3.8	14209	3	99877.06	43
7_A	Collector	73	2,671	3.5	13345	3	94422.83	47
7_B	Collector	70	4,082	3.8	14552	3	95415.37	45
8_A	Major arterial	86	78	4.4	34083	5	283442	5
8_B	Major arterial	90	1,134	4.4	38866	5	316471.4	1
9_A	Major arterial	90	670	4.5	34049	5	279407.6	6
9_B	Major arterial	85	870	4.7	36214	5	296083.6	2
9_C	Major arterial	85	1,627	3.9	30693	5	245362.9	9
10_A	Minor arterial	97	29	3	20339	4	169612.4	24
10_B	Minor arterial	91	329	4.2	21598	4	173562.4	20

(PCI): Pavement condition index of the section, (cost): Maintenance cost for each section per square meter, (Easy): easiness of work through maintenance section, (ADT): Average Daily Traffic for each section, (F.C.): Functional Classifications of each section roads.

Table (5-2) Maintenance Priority Depended on Many Variables (continued).

Input Data							Maintenance Priority	
Section	Type	PCI	Cost ID/m2	Easiness	ADT vpd	F. C.	PMI	PM.
11_A	Minor arterial	93	294.48	4.9	17037	4	138745.9	29
11_B	Minor arterial	87	516	4.3	18941	4	151530.2	25
12_A	Minor arterial	94	195	4.7	16549	4	137042.4	30
12_B	Minor arterial	95	130	4.7	15559	4	129238.4	31
12-1_A	Minor arterial	80	999	4.3	13476	4	104011.4	37
12-1_B	Minor arterial	80	1,008	4.4	12486	4	95736.83	44
13_A	Minor arterial	76	2,461	4.4	20311	4	153686.4	26
13_B	Minor arterial	68	2,087	3.6	22263	4	172232.5	23
15_A	Minor arterial	66	3,642	4.5	25306	4	187572.6	16
15_B	Minor arterial	74	1,112	4.2	21950	4	175910.4	22
17_A	Collector	71	2,700	3.6	15129	3	109047.8	36
17_B	Collector	76	3,453	4	13601	3	91578.52	49
18_A	Collector	87	1,661	3.6	13241	3	100119.5	42
18_B	Collector	84	814	3.9	15061	3	120634.7	32
19_A	Minor arterial	70	1,647	3.8	13463	4	101932.3	40
19_B	Minor arterial	60	2,316	3.8	14295	4	104495.2	38
20_A	Minor arterial	47	10,730	3.8	14506	4	52384.24	56
20_B	Minor arterial	55	7,427	3.2	15115	4	78609.09	55
21_A	Minor arterial	54	5,251	3.4	14834	4	58338.19	51
21_B	Minor arterial	52	6,404	3.4	15946	4	54286.44	48
22_A	Minor arterial	81	1,531	3.7	14722	4	113219	35
22_B	Minor arterial	88	174	4.2	12441	4	102990.9	39
23_A	Minor arterial	100	0	5	14273	4	119422	33
23_B	Minor arterial	97	22	4.9	13568	4	113399.5	34
23-1_A	Minor arterial	85	1,222	4.3	11746	4	90496.42	50
23-1_B	Minor arterial	80	2,521	4	13247	4	94629.58	46
24_A	Minor arterial	80	2,136	4.3	22818	4	176626.2	21
24_B	Minor arterial	87	118	4.5	22221	4	184614.4	17
25_A	Major arterial	76	1,509	4.1	36270	5	292394.3	3
25_B	Major arterial	86	557	4.6	29145	5	239347.4	11
26_A	Major arterial	66	4,313	4	35692	5	269597	8
26_B	Major arterial	69	2,520	3.9	30818	5	240573.7	10

(PCI): Pavement condition index of the section, (cost): Maintenance cost for each section per square meter, (Easy): easiness of work through maintenance section, (ADT): Average Daily Traffic for each section, (F.C.): Functional Classifications of each section roads.

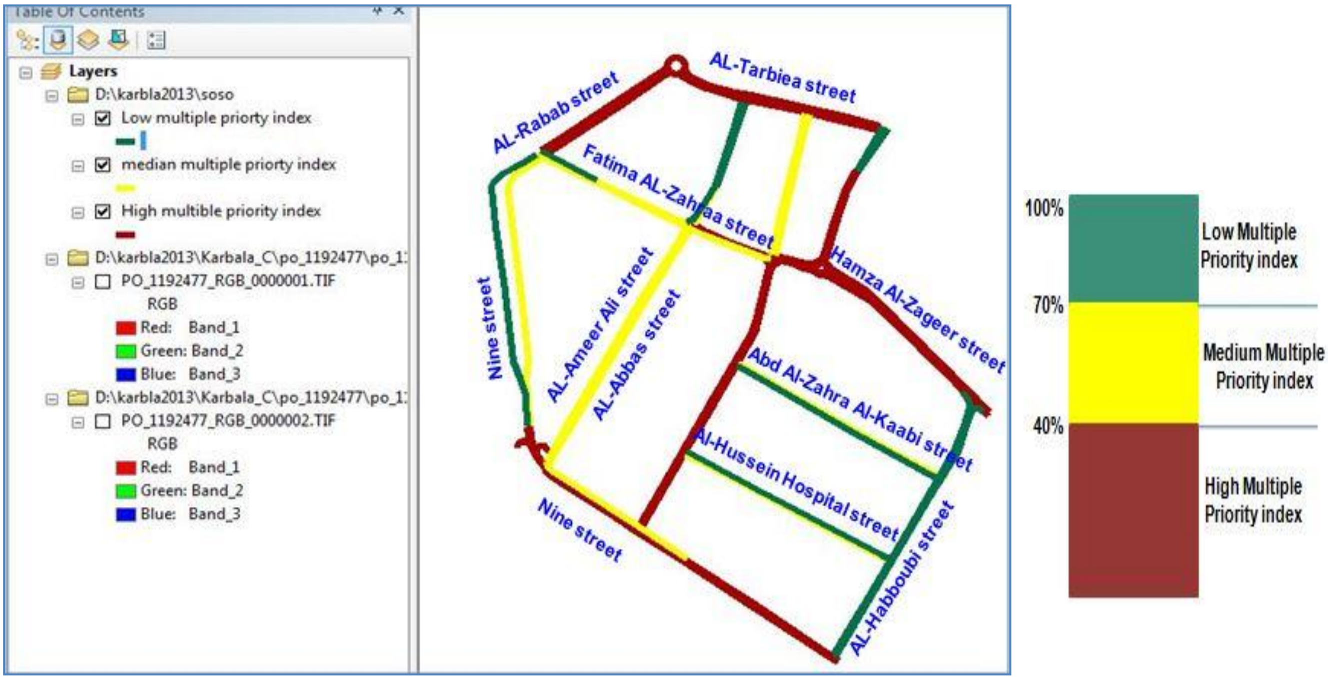


Plate (5-3) Priority of Maintenance and Rehabilitation due to Multiple Priority Index for Selected Roadway Zone in Karbala City.

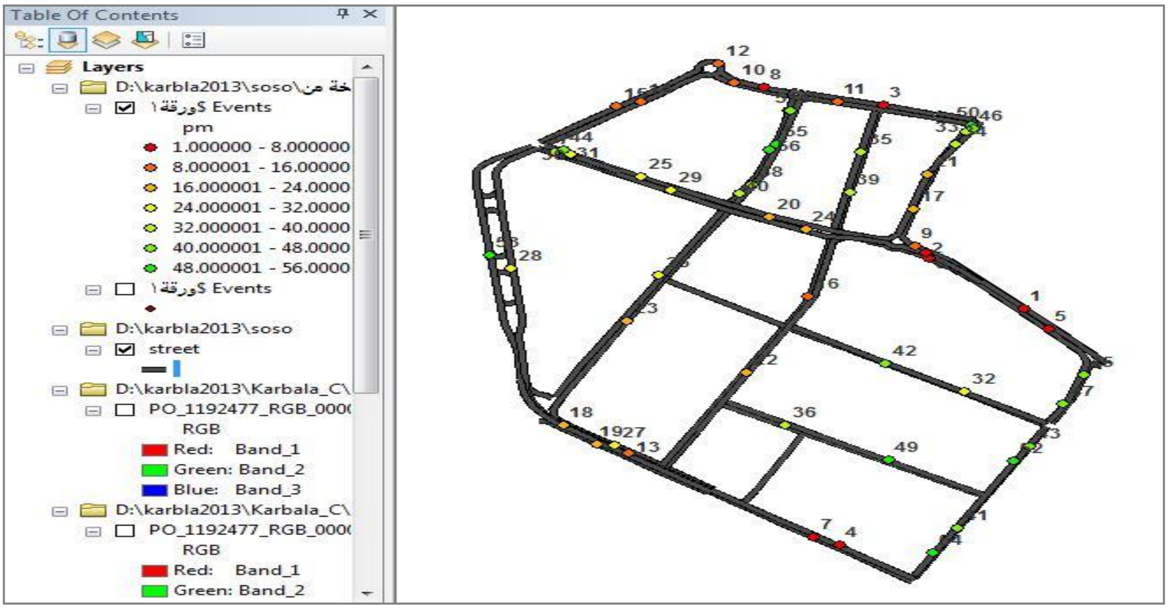


Plate (5-4) Sectional Maintenance Priority Layout due to Multiple Measures for Selected Roadway Zone in Karbala City.

5.3.3 Incremental Benefit-Cost Method

This method represents an extension of the benefit/cost ratio. The benefit gained from pavement maintenance is assumed to equal decrease of PCI out of hundred (100 – PCI). On the other hand, the ratio of benefit to cost of pavement maintenance represents (BCR) depends on two variables benefit value (100 – PCI). PCI determined from PAVER system, and maintenance cost of each section per square meter are used depended on Appendix (B).. In this research, input data (benefit and cost) are used for arterial and collector section roads (in the study area). This section data arrangement depended on cost-effectiveness (from low to high cost) and ranking results of incremental BCR analysis as shown in Table (5-3).

Table (5-3) Sections Input Data Arranged and Ranking Results of Incremental BCR Analysis of Roadways Sections in the Study Area in Karbala City.

Section	PCI	Cost ID/m2	PCI Benefit	Cost-Effectiveness Ranking			Ranking Results of Incremental BCR Analysis		
				Section	Cost ID/m2	PCI Benefit	Rank	Section	repeated
1_1	55	10,002	45	3-B	0	0	1	Sec.(19-B)	15
1_A	86	545	14	23-A	0	0	2	Sec. (13-B)	14
1-B	85	817	15	3-A	8	2	3	Sec. (8-A)	12
2-A	50	6,739	50	23-B	22	3	4	Sec. (26-B)	10
2-B	72	3,187	28	10-A	29	3	5	Sec. (19-A)	14
3-A	98	8	2	3-1-B	30	2	6	Sec. (15-B)	12
3-B	100	0	0	8-A	78	14	7	Sec. (25-A)	9
3-1-A	90	904	10	24-B	118	13	8	Sec.(12-1-A)	10
3-1-B	98	30	2	12-B	130	5	9	Sec.(12-1-B)	9
4-A	60	6,124	40	22-B	174	12	10	Sec.(24-B)	8
4-B	46	6,423	54	12-A	195	6	11	Sec.(18-B)	7
5_A	80	2,215	20	11-A	294.48	7	12	Sec. (17-A)	7
5_B	77	3,132	23	10-B	329	9	13	Sec.(1-B)	6
6_A	85	3,544	15	11-B	516	13	14	Sec.(4-B)	6
6_B	82	2,952	18	1-A	545	14	15	Sec. (22-B)	5
7-A	73	2,671	27	25-B	557	14	16	Sec. (9-B)	5
7-B	70	4,082	30	9-A	670	10	17	Sec. (1-A)	6
8-A	86	78	14	18-B	814	16	18	Sec. (25-B)	5
8-B	90	1,134	10	1-B	817	15	19	Sec. (11-B)	5
9-A	90	670	10	9-B	870	15	20	Sec.(23-B)	4
9-B	85	870	15	3-1-A	904	10	21	Sec.(9-A)	4
9-C	85	1,627	15	12-1-A	999	20	22	Sec. (22-A)	4
10-A	97	29	3	12-1-B	1,008	20	23	Sec.(23-1-A)	4
10-B	91	329	9	15-B	1,112	26	24	Sec.(7-A)	4
11-A	93	294.48	7	8-B	1,134	10	25	Sec. (13-A)	5
11-B	87	516	13	23-1-A	1,222	15	26	Sec. (24-A)	5
12-A	94	195	6	25-A	1,509	24	27	Sec. (5-A)	4
12-B	95	130	5	22-A	1,531	19	28	Sec.(2-B)	4

Table (5-3) Sections Input Data Arranged and Ranking Results of Incremental BCR Analysis of Roadways Sections in the Study Area in Karbala City(Continued).

Section	PCI	Cost ID/m2	PCI Benefit	Cost-Effectiveness Ranking			Ranking Results of Incremental BCR Analysis		
				Section	Cost ID/m2	PCI Benefit	Rank	Section	repeated
12-1-A	80	999	20	9-C	1,627	15	29	Sec.(15-A)	4
12-1-B	80	1,008	20	19-A	1,647	30	30	Sec.(2-A)	4
13-A	76	2,461	24	18-A	1,661	13	31	Sec. (21-B)	4
13-B	68	2,087	32	13-B	2,087	32	32	Sec.(21-A)	5
15-A	66	3,642	34	24-A	2,136	20	33	Sec. (10-A)	3
15-B	74	1,112	26	5-A	2,215	20	34	Sec. (3-A)	3
17-A	71	2,700	29	19-B	2,316	40	35	Sec. (3-1-A)	3
17-B	76	3,453	24	13-A	2,461	24	36	Sec. (9-C)	3
18-A	87	1,661	13	26-B	2,520	31	37	Sec. (23-1-B)	3
18-B	84	814	16	23-1-B	2,521	20	38	Sec. (17-B)	3
19-A	70	1,647	30	7-A	2,671	27	39	Sec.(5_B)	3
19-B	60	2,316	40	17-A	2,700	29	40	Sec.(6-B)	3
20-A	47	10,730	53	6-B	2,952	18	41	Sec. (20-B)	3
20-B	55	7,427	45	5-B	3,132	23	42	Sec. (3-B)	2
21-A	54	5,251	46	2-B	3,187	28	43	Sec. (3-1-B)	2
21-B	52	6,404	48	17-B	3,453	24	44	Sec. (12-B)	2
22-A	81	1,531	19	6-A	3,544	15	45	Sec. (12-A)	2
22-B	88	174	12	15-A	3,642	34	46	Sec. (11-A)	2
23-A	100	0	0	7-B	4,082	30	47	Sec. (10-B)	2
23-B	97	22	3	26-A	4,313	34	48	Sec. (8-B)	2
23-1-A	85	1,222	15	21-A	5,251	46	49	Sec. (18-A)	2
23-1-B	80	2,521	20	4-A	6,124	40	50	Sec. (6-A)	2
24-A	80	2,136	20	21-B	6,404	48	51	Sec. (7-B)	2
24-B	87	118	13	4-B	6,423	54	52	Sec. (26-A)	2
25-A	76	1,509	24	2-A	6,739	50	53	Sec. (4-A)	2
25-B	86	557	14	20-B	7,427	45	54	Sec. (1-1)	2
26-A	66	4,313	34	1-1	10,002	45	55	Sec. (20-A)	1
26-B	69	2,520	31	20-A	10,730	53	56	Sec. (23-A)	1

Developing a special program to accomplish the calculations, which is the most efficient and effective application for this way. MATLAB R2015a software is developed to determine the priority of section roads as shown in Appendix (F). Furthermore, GIS Geostatic Analyses Tools is used to layout the priority result of this method as shown in Plate (5-5). On the other hand, and depending on ranking values through incremental BCR priority index the GIS tools was used to layout the maintenance priority for the selected sections as shown in Plate (5-6).

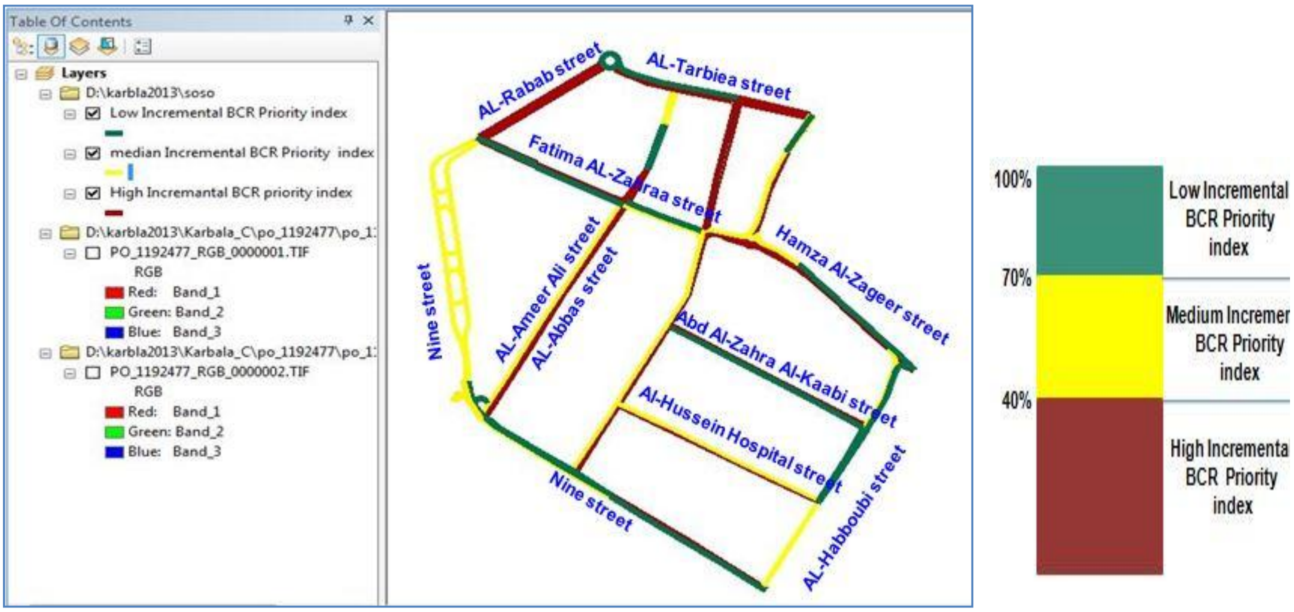


Plate (5-5) Priority of Maintenance and Rehabilitation due to Incremental BCR Index for Sections of Karbala City.

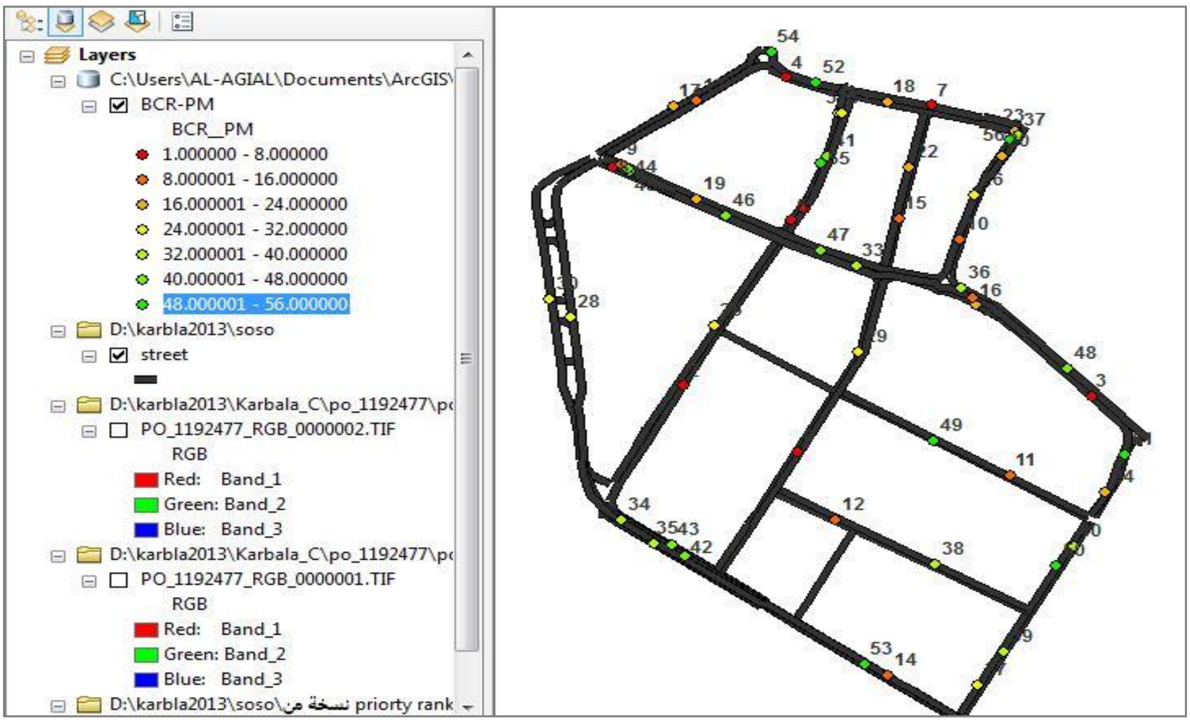


Plate (5-6) Sectional Maintenance Priority Layout due to Incremental BCR Index for Sections of Karbala City.

5.4 Maintenance Priority Result Analysis

Maintenance priority rank result from simple ranking by PCI measure, ranking by multiple measures, and incremental benefit-cost analysis ranking are analyzed by using Wilcoxon signed-rank test (Matched Pairs Test) in SPSS software.

The testing equality of means of two continuous distributions that are obviously non-normal, and samples are independent (i.e., there is no pairing of observations), the Wilcoxon rank-sum test or Wilcoxon two-sample test is an appropriate alternative to the two-sample. We shall test the null hypothesis (Walpole et al., 2012). Assume the cases are a null hypothesis, which means that the median difference between two pairs of observations is zero. If the significant value is less than (0.05), then reject the null hypothesis. The two developed method listed depended on the section rank of simple ranking by PCI measure as shown in Table (5-4). Each of the three priority methods used is checked as shown in Table (5-5).

From test, the significance of ranks for each method and with each other is more than (0.05) with a 95% degree of confidences, so will agree null hypothesis. As there is no evidence to reject the null hypothesis, it can be concluded that there is no significant difference in the output of these priority methods. This shows the convergence of priority values, and in this study area and other cities, which have a fix funds, it is suggested to use the incremental BCR method.

Table (5-4) Input Data Used in Wilcoxon Matched Pairs Test.

Section	PCI	MPI	BCR	Section	PCI	MPI	BCR
4_B	1	4	14	22_A	29	35	22
20_A	2	56	55	6_B	30	43	40
2_A	3	53	30	18_B	31	32	11
21_B	4	48	31	1_B	32	14	13
21_A	5	51	32	6_A	33	52	50
1_1	6	12	54	9_B	34	2	16
20_B	7	55	41	9_C	35	9	36
4_A	8	7	53	23-1_A	36	50	23
19_B	9	38	1	1_A	37	15	17
15_A	10	16	29	8_A	38	5	3
26_A	11	8	52	25_B	39	11	18
13_B	12	16	2	11_B	40	25	19
26_B	13	10	4	18_A	41	42	49
7_B	14	45	51	24_B	42	17	10
19_A	15	40	5	22_B	43	39	15
17_A	16	36	12	3-1_A	44	19	35
2_B	17	28	28	8_B	45	1	48
7_A	18	47	24	9_A	46	6	21
15_B	19	22	6	10_B	47	20	47
13_A	20	23	25	11_A	48	29	46
17_B	21	49	38	12_A	49	30	45
25_A	22	3	7	12_B	50	31	44
5_B	23	41	39	10_A	51	24	33
5_A	24	54	27	23_B	52	34	20
12-1_A	25	37	8	3_A	53	18	34
12-1_B	26	44	9	3-1_B	54	27	43
23-1_B	27	46	37	3_B	55	13	42
24_A	28	21	26	23_A	56	33	56

Table (5-5) Wilcoxon Matched Pairs Test of Ranking Results for Each Method.

A-Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Simple-priority	56	28.5000	16.310	1.00	56.00
Multiple-priority	56	28.5000	16.392	1.00	56.00
BCR-priority	56	28.5000	16.295	1.00	56.00

Table (5-5) Wilcoxon Matched Pairs Test of Ranking Results for Each Method (continued).

B- Wilcoxon Signed Ranks Test

		N	Mean Rank	Sum of Ranks
Multiple-priority - Simple-priority	Negative Ranks	27[a]	30.31	818.50
	Positive Ranks	29[b]	26.81	777.50
	Ties	0[c]		
	Total	56		
BCR-priority – Simple-priority	Negative Ranks	31[d]	26.06	808.00
	Positive Ranks	23[e]	29.43	677.00
	Ties	2[f]		
	Total	56		
BCR-priority – Multiple-priority	Negative Ranks	29[g]	27.16	787.50
	Positive Ranks	26[h]	28.94	752.50
	Ties	1[i]		
	Total	56		

a. Multiple-priority < Simple-priority b. Multiple-priority > Simple-priority c. Multiple-priority = Simple-priority

d. BCR-priority < Simple-priority e. BCR-priority > Simple-priority f. BCR-priority = Simple-priority

g. BCR-priority < Multiple-priority h. BCR-priority > Multiple-priority i. BCR-priority = Multiple-priority

C- Test Statistics[a]

	Multiple-priority - Simple-priority	BCR-priority - Simple-priority	BCR-priority - Multiple-priority
Z	-.167-[b]	-.564-[b]	-.147-[b]
Asymp. Sig. (2-tailed)	0.867	0.573	0.883

a. Wilcoxon Signed Ranks Test b. Based on positive ranks.

CHAPTER SIX

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

On the basis of the research findings, the following conclusions can be drawn:

1. Pavement condition evaluation by PAVER software showed that the current status for the selected zone of roads network in Karbala city, in general have a satisfactory condition. Where 63% of the selected roads network need to preventive maintenance, 31% require rehabilitation, and 6% needs reconstruction.
2. Priority of maintenance can be estimated according to the layout of integrity PAVER software with GIS. This will give easiness to assign the location of best and worst sections which help decision makers and assure efficient maintenance management.
3. According to the developed models in this study, pavement condition represented by PCI, decreases with age of pavement for all studied sections in a trend agree with other studies.
4. PAVER model describes the deterioration of the pavement sections as a polynomial. PAVER statistical test shows that 60% of the variation in the dependent variable (PCI) is explained by the independent variable (Age).
5. The significant difference between value CI from Hoel et al. developed model and PCI from PAVER for the sections is ($0.000 < 0.05$), so the null hypothesis was rejected and cannot be used to predict PCI value for the study area.
6. Pavement age is the most significant element in PCI developed predicting model, followed by the structural number (SN) and average daily traffic (ADT).

7. Statistical developed models for PCI introduce a correlation with independent variables of; ADT, age and structure number as R^2 (0.73, 0.69), and reasonably can be used to predict the pavement condition of roadways.
8. The study introduces efficient display of layout and ranking for the selected zone of roadway system based developed maintenance priority method. From this layout, show that Al-Tarbiea street, Al-Rabab street, Al-Abbas street, and nine street have the first priority in maintenance after that Al-Ameer Ali street, Al-Hussein hospital street, and Al-Habboubi street.
9. A statistical test (Wilcoxon Signed Ranks) shows that there is no significant difference between the simple ranking method due to PCI of PAVER and the two developed prioritization of maintenance (multiple ranking and BCR ranking). So, the two developed optimized methods of prioritization developed in the study can be used successfully in addition to the simple ranking of PAVER.
10. The convergence between of priority values, and in this study area and other cities, which have a fix funds, it is suggested to use the incremental BCR method.

6.2 Recommendations

The following recommendations could be suggested:

1. Extending the work application of software's (PAVER and GIS) over all the network roads system of municipalities to get up accurate data. The comprehensive database of pavement condition given the ability to finding the maintenance needs and assign maintenance priorities activities and the required funding which need.

2. Use the modeling of pavement condition of maintenance alternatives in Iraq to predict optimum maintenance. These models may assist decision makers and local engineers of Pavement maintenance management system agencies (SORB, Karbala Mayoralty, and directors of roads and bridges in Karbala) to make the right decision in selecting optimum pavement maintenance.
3. Karbala city (KC) staff of maintenance department would be trained and learnt to recognize the best ways of performing the PMMS tasks.

6.3 Future Works

1. Applying the methodology in this study for rigid pavement roadways and develop a statistical model to predict pavement condition of rigid and airfield pavement roadways.
2. Developing model for the study area by using another variable such as weight of estimation single axel load (ESAL) and environmental measures.

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APPENDIX

APPENDIX A

Inspected Data Method for Each Distress Type

A. Ride Quality Assessment

Ride quality must be assessed in order to establish a severity level for the following distress types:

•Bumps
•Shoving
•Corrugation
•Swells
•Railroad Crossings

To assess ride quality for these distresses, the inspector should use the following severity level definitions:

Low (L): Vehicle vibrations (e.g., from corrugation) are noticeable, but no reduction in speed is necessary for comfort or safety; and/ or individual bumps or settlements cause the vehicle to bounce slightly, but create little discomfort.

Medium (M): Vehicle vibrations are significant and some reduction in speed is necessary for safety and comfort; and/ or individual bumps or settlements cause the vehicle to bounce significantly, creating some discomfort.

High (H): Vehicle vibrations are so excessive that speed must be reduced considerably for safety and comfort; and/ or individual bumps or settlements cause the vehicle to bounce excessively, creating substantial discomfort, safety hazard, or high potential vehicle damage.

The inspector should drive at the posted speed in a sedan that is representative of cars typically seen in local traffic. Pavement sections near stop signs should be rated at a deceleration speed appropriate for the intersection.

B. The distress definitions and measurement methods for asphalt surfaced roads

The five major categories of common asphalt pavement surface distresses are:

A. Cracking
B. Surface deformation

C. **Disintegration**
D. **Surface defects**
E. **Others**

A. Cracking:

The most common types of cracking are:

1. Alligator Cracking (Fatigue cracking)
2. Longitudinal and Transverse Cracking
3. Block cracking
4. Slippage cracking
5. Joint Reflective cracking
6. Edge cracking

1. Alligator Cracking (Fatigue cracking)

Description

Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. Cracking begins at the bottom of the asphalt surface (or stabilized base) where tensile stress and strain are highest under a wheel load .The cracks propagate to the surface initially as a series of parallel longitudinal cracks .After repeated traffic loading, the cracks connect, forming many sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator .The pieces are generally less than 2ft (0.6m) on the longest side.

Severity Levels:

L-Fine, longitudinal hairline cracks running parallel to each other with no, or only a few interconnecting cracks. The cracks are not spoiled.

M— Further development of light alligator cracks into a pattern or network of cracks that may be lightly speckled.

H—Network or pattern cracking has progressed so that the pieces are well defined and spelled at the edges. Some of the pieces may rock under traffic.

Figure (A-1) Alligator Cracking

2. Longitudinal and Transverse Cracking

Description

Longitudinal cracks are parallel to the pavement's center line or lay down direction .They may be caused by:

1. A poorly constructed paving lane joint.
2. Shrinkage of the AC surface due to low temperatures or hardening of the asphalt and/or daily temperature cycling.
3. A reflective crack caused by cracking beneath the surface course , including Cracks in PCC slabs(but not PCC joints).

Transverse cracks extend a cross the pavement at approximately right angles to the pavement centerline or direction of lay down .These types of cracks are not usually load-associated.

Severity Levels

L— One of the following conditions exists:

1 .Non-filled crack width is less than 3/8 in. (10mm).

2 . Filled crack of any width (filler in satisfactory condition).

M— One of the following conditions exists:

1 .Non-filled crack width is 3/8 to 3in. (10 to 76mm).

2 .Non-filled crack is up to 3in. (76mm) surrounded by light and random cracking.

3 .Filled crack is of any width surrounded by light random cracking.

H— One of the following conditions exists:

1 .Any crack filled or non-filled surrounded by medium or high severity random cracking.

2. Non-filled crack over 3in. (76mm).

3. A crack of any width where a few inches of pavement around the crack is Severely broken.

a. Low severity b. Medium severity c. High severity

Figure (A-2) Longitudinal and Transverse

3. Block cracking

Description

Block cracks are interconnected cracks that divide the pavement in to approximately rectangular pieces .The blocks may range in size from approximately 1 by 1ft(0.3 by 0.3m) to 10 by10 ft (3by3m) .Block cracking is caused mainly by shrinkage of the asphalt Concrete and daily temperature cycling (which results in daily stress/strain cycling).It is not load associated. Block cracking usually indicates that the asphalt has hardened significantly. Block cracking normally occurs over a large portion of the pavement area, but sometimes will occur only in non traffic areas.

Severity Levels

L—Blocks are defined by low severity 4 cracks.

M—Blocks are defined by medium severity 3cracks.

H—Blocks are defined by high severity cracks.

a. Low severity b. Medium severity c. High severity

Figure (A-3) Block cracking

4. Slippage cracking

Description

Slippage cracks are crescent or half moon shaped cracks. They are produced when Braking or turning wheels cause the pavement surface to slide or deform. This distress usually occurs when there is a low-strength surface mix or poor bond between the surface and then explainer of the pavement structure.

Severity Level

L—Average crack width is <3/8 in.(10mm).

M— One of the following conditions exists:

1 .Average crack width between 3/8 in. and 1-1/ 2in.(10mm and 38mm).

2. The area around the crack is broken in to tight-fitting pieces.

H— One of the following conditions exists:

1 .The average crack width is greater than 1-1/ 2in.(38mm).

2. The area around the crack is broken in to easily removed pieces.

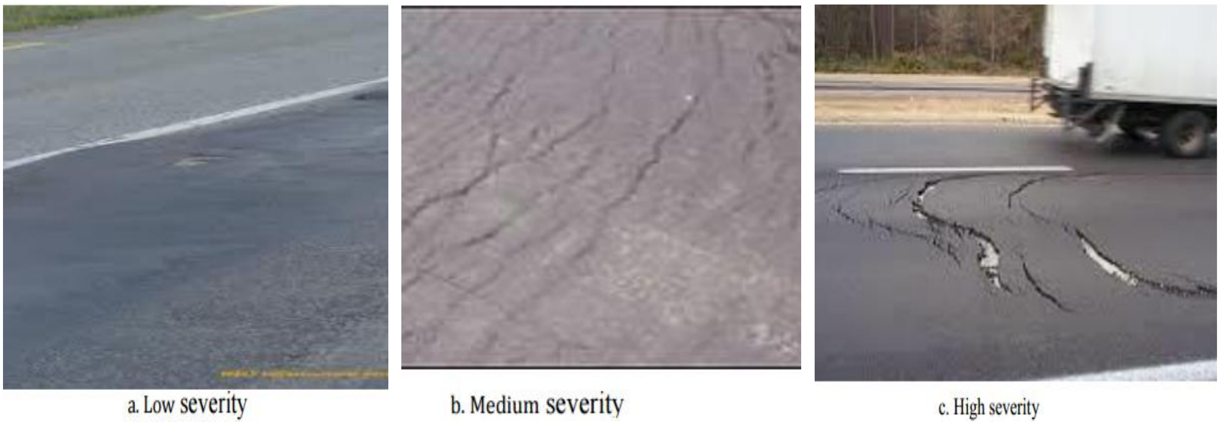


Figure (A-4) Slippage cracking

5. Joint Reflective cracking

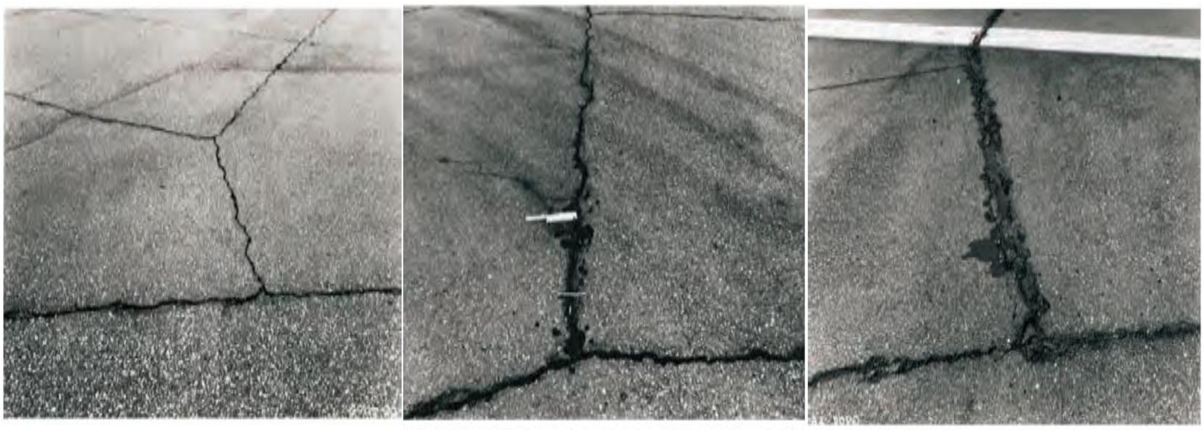
Description

This distress occurs only on asphalt surfaced pavements that have been laid over a PCC slab. It does not include deflection cracks from any other type of base (i.e., cement or lime stabilized); these cracks are caused mainly by thermal or moisture induced movement of the PCC slab beneath the AC surface .This distress is not load related; however, Traffic loading may cause a breakdown of the AC surface near the crack .If the pavement is fragmented along a crack, the crack is said to be spelled. A knowledge of slab dimension beneath the AC surface will help to identify these distresses.

Severity Levels

L— One of the following conditions exists:
1 .Non-filled crack width is less than 3/8in.(10mm).
2. Filled crack of any width (filler in satisfactory condition).
M— One of the following conditions exists:
1 .Non-filled crack width is 3/8 to 3in.(10to76mm).
2. Non-filled crack of any width up to 3in. (76mm) Surrounded by light random cracking.
3. Filled crack of any width surrounded by light random cracking.
H— One of the following conditions exists:
1 .Any crack filled or non Filled surrounded by medium or high severity random cracking;
2. Non-filled cracks over3in. (76mm).

3. A crack of any width where a few inches of pavement around the crack are Severely broken (Crack is severely broken)



a. Low severity b. Medium severity c. High severity

Figure (A-5) Joint Reflective cracking

6. Edge cracking

Description

Edge cracks are parallel to and usually within 1 to 2ft (0.3to 0.6m) of the outer edge of the pavement .This distress is accelerated by traffic loading and can be caused by frost weakened base or subgrade near the edge of the pavement. The area between the crack and pavement edge is classified as raveled if it is broken up (sometimes to the extent that pieces are removed)**.**

Severity Levels

L— Low or medium cracking with no break up or raveling.

M—Medium cracks with some break up and raveling.

H—Considerable break up or raveling along the edge medium**.**

Low, medium, high

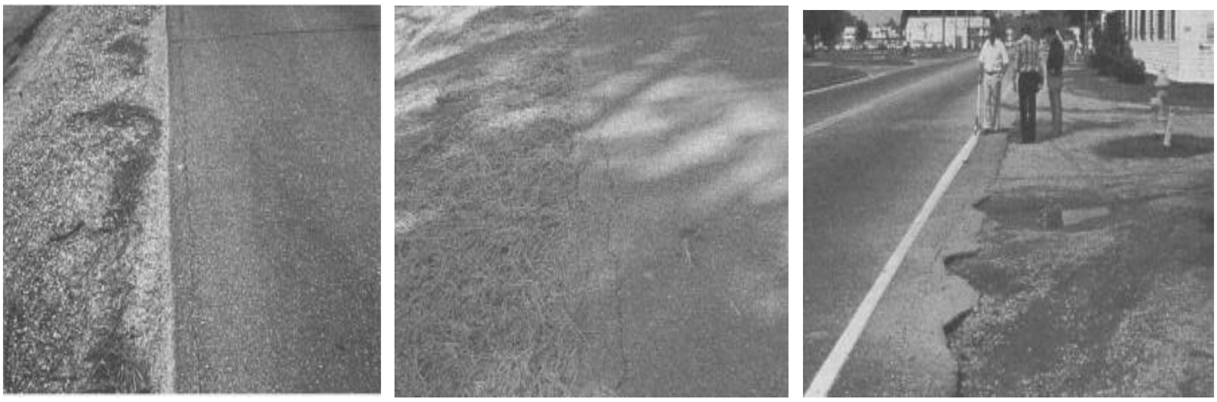


Figure (A-6) Edge cracking

B. Surface deformation:

Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard.

The basic types of surface deformation are:
1. Rutting
2. Corrugations
3. Shoving
4. Depressions
5. Swell
6. Bumps and Sags

1. Rutting

Description A rut is a surface depression in the wheel paths .Pavement up lift may occur along the sides of the rut, but, in many instances, ruts are notice able only after a rainfall when the Paths are filled with water .Rutting stems from a permanent deformation in any of the Pavement layers or subgrades, usually caused by consolidated or lateral movement of the materials due to traffic load. Significant rutting can lead to major structural failure of the pavement.

Severity Levels

Mean Rut Depth

L— 1/4to1/ 2in.

M— Greater than1/ 2in. upto1in.

H— Greater than 1in.

a. Low severity b. Medium severity c. High severity

Figure (A-7) Rutting

2. Corrugations

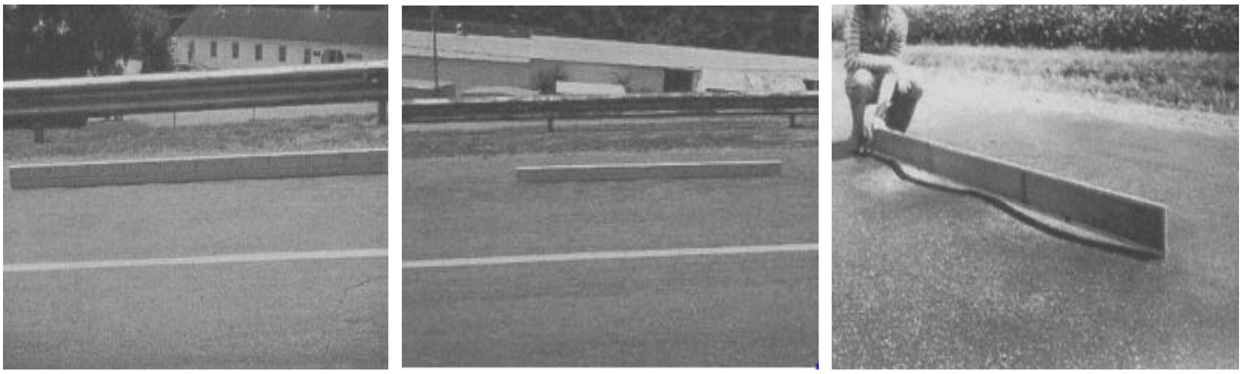
Description

Corrugation (also known as "wash boarding") is a series of closely spaced ridges and valleys (ripples) occurring at fairly regular intervals, usually < 10 ft (3m) Pavement .The ridges are perpendicular to the traffic direction .This type of distress is Usually caused by traffic action combined with an unstable pavement surface or base. If Bumps occur in a series of < 10 ft (3m), due to any cause, the distress is considered corrugation.

Severity Levels

L—Corrugation produces low severity ride quality.

M—Corrugation produces medium-severity ride quality.
H—Corrugation produces high-severity ride quality



Low, medium, high

Figure (A-8) Rutting

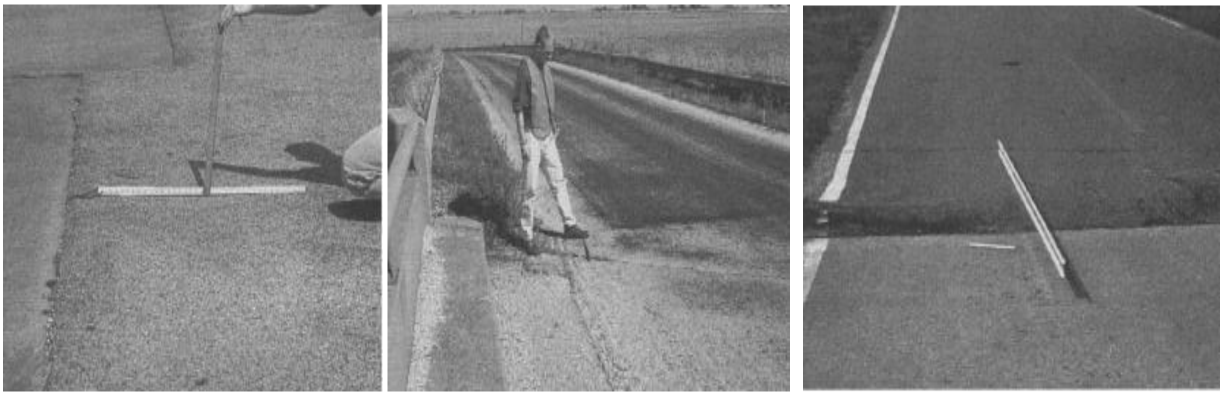
3. Shoving

Description

Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading .When traffic pushes against the pavement, it produces a short, abrupt wave in the pavement surface. This distress normally occurs only in unstable liquid asphalt mix (cut back or emulsion) pavements. Shoves also occur where asphalt pavements abut PCC pavement; the PCC pavements increase in length and push the asphalt pavement, causing the shoving.

Severity Levels

L—Shove causes low severity ride quality.
M—Shove causes medium severity ride quality.
H—Shove causes high severity ride quality.



Low, medium, high

Figure (A-9) Shoving

4. Depressions

Description

Depressions are localized pavement surface areas with elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not Notice able until after a rain, when pounding water creates a "bird bath" area; on dry pavement, depressions can be spotted by looking for stains caused by pounding water. Depressions are created by settlement of the foundation soil or are a result of improper Construction. Depressions cause some roughness, and when deep enough or filled with water, can cause hydroplaning. Sags, unlike depressions, are abrupt drops in elevation.

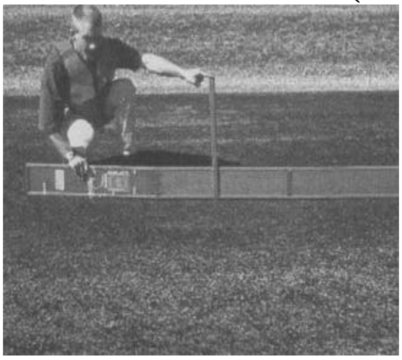
Severity Levels

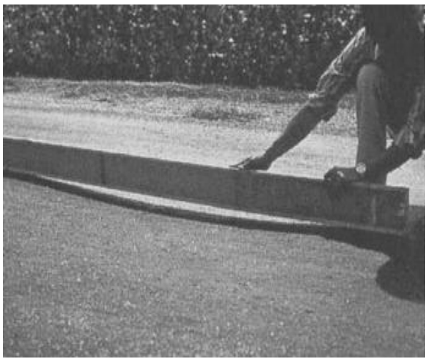
Maximum Depth of Depression

L—13 to 25 mm (1/2 to1in.).

M—25 to 50mm (1to 2in.).

H— more than 50 mm (2in.)





Low, medium, high

Figure (A-10) Depressions

5. Swell

Description

Swell is characterized by an upward bulge in the pavement's surface along, gradual wave greater than 10ft (3m) long. Swelling can be accompanied by surface cracking. This distress is usually caused by frost action in the subgrade or by swelling soils.

Severity Level

L—Swell causes low severity ride quality .Low-severity swells are not always easy to see, but can be detected by driving at the speed limit over the pavement section .An upward motion will occur at the swell if it is present.

M—Swell causes medium severity ride quality.

H—Swell causes high severity ride quality.

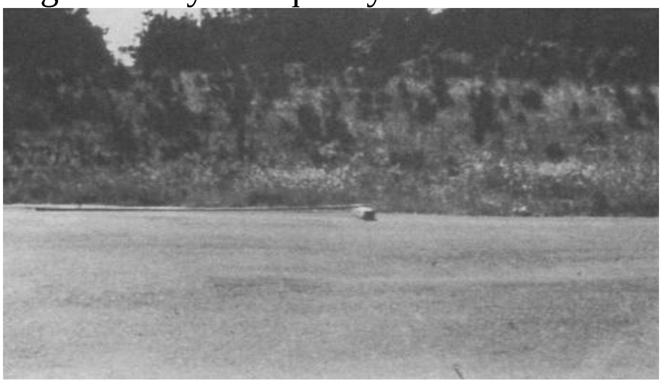


Figure (A-11) Swell

6. Bumps and Sags

Description

Bumps are small ,localized ,upward displacements of the pavement surface. They are different from shoves in that shoves are caused by unstable pavement .Bumps, on the other hand, can be caused by several factors, including:

1 .Buckling or bulging of underlying PCC slabs in an AC overlay over PCC pavement.

2. Frost heaves (ice, lens growth).

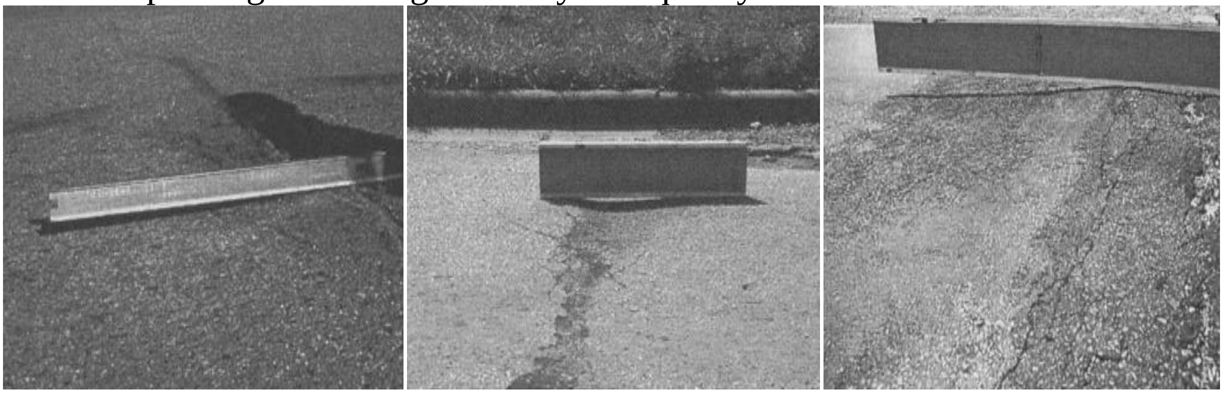
3. Infiltration and build up of material in a crack in combination with traffic loading (sometimes called "tenting"). Sags are small, abrupt, downward displacements of the pavement surface .Distortion and displacement that occur over large areas of the pavement surface, causing large and/or long dips in the pavement should be recorded as "swelling."

Severity Levels

L—Bump or sag causes low severity ride quality.

M—Bump or sag causes medium severity ride quality.

H—Bump or sag causes high severity ride quality.



Low, medium, high

Figure (A-12) Bump or sag

C. Disintegration

The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the integration is not repaired in its early stages, complete reconstruction of the pavement may be needed.

The two most common types of disintegration are:

1. Potholes
2. Patching and Utility Cut Patching

1. Potholes

Description

Potholes are small usually less than 3ft (0.9m) in diameter bowl shaped depressions in the pavement surface. They generally have sharp edge sand vertical sides near the top of the hole. Their growth is accelerated by free moisture collection inside the hole. Potholes are produced when traffic abrades small pieces of the pavement surface .The Pavement continues to disintegrate because of poor surface mixtures, weak spots in the Base or subgrade, or because it has reached a condition of high severity alligator cracking. Potholes most often are structurally related distresses and should not be confused with raveling and weathering. When holes are created by high severity alligator cracking, they should be identified as potholes, not as weathering.

Severity Levels

The levels of severity for potholes less than 30in. (762mm) in diameter are based on both the diameter and the depth of the pothole, according to Table (l).

If the pothole is more than 30 in. (76mm) in diameter, the area should be determined in Square feet and divided by 5 sqft ($0.47m^2$) to find the equivalent number of holes. If the Dept his 1in .(25mm) or less, the holes are considered medium severity .If the depth is more than 1in. (25mm) ,they are considered high severity.

	Average Diameter, in. (mm)		
Maximum Depth to Pothole	4 to 8 in. (102 to 203 mm)	8 to 18 in. (203 to 457 mm)	18 to 30 in. (457 to 762 mm)
1/2 to 1in. (12.7 to 25.4 mm)	L	L	M
>1 to 2 in. (25.4 to 50.8 mm)	L	M	H
>2 in. (50.8 mm)	M	M	H

a. Low severity b. Medium severity c. High severity

Figure (A-13) pothole

2. Patching and Utility Cut Patching

Description

A patch is an area of pavement that has been replaced with new material to repair the Existing pavement .A patch is considered a defect no matter how it is performing (a patched area or adjacent are a usually does not perform as well as an original pavement section). Generally, some roughness is associated with this distress.

Severity Levels

L—Patch is in good condition and satisfactory .Ride quality is rated as low severity or better.

M—Patch is moderately deteriorated and/or ride quality is rated as medium severity.

H—Patch is badly deteriorated and/or ride quality is rated as high severity. Need replacement soon.

a. Low severity b. Medium severity c. High severity

Figure (A-14) patching and Utility Cut Patching

D. Surface defects:

Surface defects are related to problems in the surface layer. The most common types of surface distress are:

1. Weathering and Raveling
2. Bleeding
3. Polishing

1. Weathering and Raveling

Description

Weathering and raveling are the wearing away of the pavement surface due to a loss of Asphalt or tar binder and dislodged aggregate particles. These distresses indicate that either the asphalt binder has hardened appreciably or that a poor quality mixture is present. In addition, raveling may be caused by certain types of traffic, for example, tracked vehicles. Softening of the surface and dislodging of the aggregates due to oil spillage are also included under raveling.

Severity Levels

L—Aggregate or binder has started to wear away .In some areas, the surface is starting top it. In the case of oil spillage, the oil stain can be seen, but the surface is hard and cannot be penetrated with a coin.

M__ Aggregate or binder has worn away. The surface texture is moderately rough and pitted .In the case of oil spillage, the surface is soft and can be penetrated with a coin.
H__ Aggregate or binder has been worn away considerably .The surface texture is very rough and severely pitted. The pitted areas are less than 4in. (10mm) in diameter and less than 1/ 2in .(13mm) deep; pitted areas larger than this are counted as potholes .In The case of oil spillage, the asphalt binder has lost its binding effect and the aggregate has become loose.

low, medium , high

Figure (A-15) Weathering and raveling

2. Bleeding

Description

Bleeding is a film of bituminous material on the pavement surface that creates a shiny, Glass like, reflecting surface that usually becomes quite sticky. Bleeding is caused by excessive amounts of asphaltic cement or tars in the mix, excess application of a bituminous sealant, and/or low air void content .It occurs when asphalt fills the voids of the Mix during hot weather and then expands onto the pavement surface .Since the bleeding Process in not reversible during cold weather, asphalt or tar will accumulate on the surface.

Severity Levels

L—Bleeding has only occurred to a very slight degree and is noticeable only during a few days of the year. Asphalt does not stick to shoes or vehicles.
M—Bleeding has occurred to the extent that asphalt sticks to shoes and vehicles during only a few weeks of the year.
H—Bleeding has occurred extensively and considerable asphalt sticks to shoes and vehicles during at least several weeks of the yea

a.Low severity b. Medium severity c. High severity

Figure (A-16) Bleeding

3. Polished Aggregate

Description

This distress is caused by repeated traffic applications. When the aggregate in the Surface becomes smooth to the touch, adhesion with vehicle tires is considerably reduced. When the portion of aggregate extending ,the pavement texture does not significantly contribute to reducing vehicle speed .Polished Aggregate should be counted when close examination reveals that the aggregate extending above the asphalt is negligible, and the surface aggregate is smooth to the touch. This type of distress is indicated when the number on a skid resistance test is Low or has dropped significantly from a previous rating.

Severity Levels

No degrees of severity are defined. However, the degree of polishing should be clearly evident in the sample unit in that the aggregate surface should be smooth to the touch.

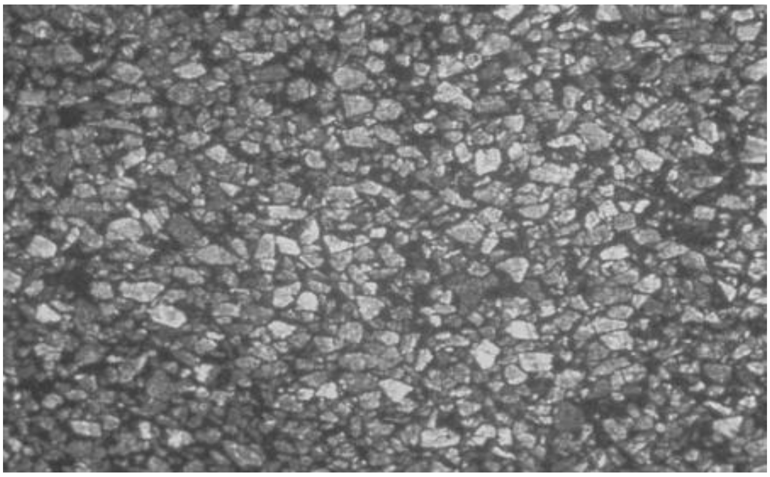


Figure (A-17) Polished Aggregate

E. other

1. Lane /Shoulder Drop Off
2. Railroad Crossing

1. Lane /Shoulder Drop Off

Description

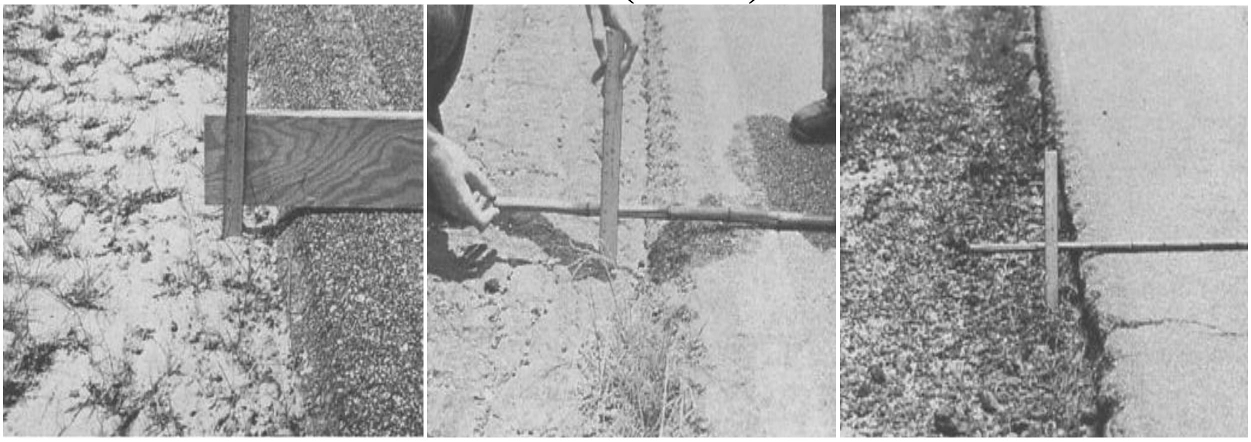
Lane /shoulder drop off is a difference in elevation between the pavement edge and the shoulder. This distress is caused by shoulder erosion ,shoulder settlement, or by building up the road way without adjusting the shoulder level.

Severity Levels

L— The difference in elevation between the pavement edge and shoulder is 1to2in. (25 To 51mm).

M—The difference in elevation is > 2 to4in.(51to102mm).

H—The difference in elevation is > 4in.(102mm).



low, medium , high

Figure (A-18) Lane /shoulder drop

2 .Railroad Crossing

Description

Railroad crossing defects are depressions or bumps around and/ or between tracks.

Severity Levels

L—Rail road crossing causes low severity ride quality.

M— Rail road crossing cause's medium severity ride quality.

H—Rail road crossing causes high severity ride quality.

low, medium , high

Figure (A-19) Railroad crossing

APPENDIX B

Data Collection for Study Area

Table (B.1) The inspection data of all section at the study area and Maintenance costs.

sec(1-1)						
1						
Distress	Description	Severity	Quantity	Units	cost	total ID
11	PATCH/UTILITY CUT	H	25	SqM	1000000	
19	RAVELING	M	231	SqM	3465000	23104000
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
3						cost ID/M2
Distress	Description	Severity	Quantity	Units	cost	10001.7316
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
19	RAVELING	H	9	SqM	180000	
18	SWELL	H	6	SqM	240000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
19	RAVELING	M	231	SqM	3465000	
5						
Distress	Description	Severity	Quantity	Units	cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
6	DEPRESSION	H	1.5	SqM	60000	
11	PATCH/UTILITY CUT	L	5	SqM	75000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	17	M	51000	
7	EDGE CRACKING	M	12	M	36000	
7						
Distress	Description	Severity	Quantity	Units	cost	
11	PATCH/UTILITY CUT	M	4.5	SqM	135000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
13	POTHOLE	H	1	Count	40000	
9						
Distress	Description	Severity	Quantity	Units	cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	15	M	45000	
19	RAVELING	M	231	SqM	3465000	
11						
Distress	Description	Severity	Quantity	Units	cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
11	PATCH/UTILITY CUT	H	1	SqM	40000	
11	PATCH/UTILITY CUT	M	1.5	SqM	45000	
19	RAVELING	M	231	SqM	3465000	
13						
Distress	Description	Severity	Quantity	Units	cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
19	RAVELING	M	231	SqM	3465000	
13	POTHOLE	H	1	Count	40000	
7	EDGE CRACKING	L	11	M	0	

*Note: L: low level, M: medium level, H: height level

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (continue)

sec(1-1) con.						
15						
Distress	Description	Severity	Quantity	Units	cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
13	POTHOLE	M	1	Count	30000	
17						
Distress	Description	Severity	Quantity	Units	cost	
7	EDGE CRACKING	M	10	M	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	12	M	36000	
19						
Distress	Description	Severity	Quantity	Units	cost	
19	RAVELING	M	231	SqM	3465000	
7	EDGE CRACKING	M	11	M	33000	
sec(1-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	H	25	M	375000	1888000
4	good					
7						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	817.316
7	EDGE CRACKING	H	8	M	120000	
9						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	8	M	120000	
6	DEPRESSION	M	0.4	SqM	12000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
7	EDGE CRACKING	L	24	M	0	
6	DEPRESSION	L	1	SqM	15000	
13						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
15						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	2	M	6000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
7	EDGE CRACKING	M	8	M	24000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	21000	
15	RUTTING	M	12	SqM	300000	
15	RUTTING	M	10	SqM	250000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
1	ALLIGATOR CRACKING	M	18	SqM	540000	
20	good					
22	good					
sec(2-A)						
3	good					
7						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	M	8	M	24000	18255000
11	PATCH/UTILITY CUT	H	8	SqM	320000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

sec(2-A)						
7	EDGE CRACKING	M	4	M	12000	cost ID/M2
11						6738.649
11						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	19	M	57000	
7	EDGE CRACKING	H	13	M	195000	
1	ALLIGATOR CRACKING	H	56	SqM	2240000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	H	45	SqM	1800000	
3	BLOCK CRACKING	M	5	SqM	150000	
7	EDGE CRACKING	M	24	M	72000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	4	M	60000	
19	RAVELING	M	66	SqM	990000	
19						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	65	SqM	975000	
1	ALLIGATOR CRACKING	M	77	SqM	2310000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	5	M	75000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	H	2	Count	80000	
11	PATCH/UTILITY CUT	H	5	SqM	200000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3.5	M	0	
26						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	M	77	SqM	2310000	
19	RAVELING	M	76	SqM	1140000	
7	EDGE CRACKING	M	23	M	69000	
11	PATCH/UTILITY CUT	H	6	SqM	240000	
30						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	25	M	75000	
7	EDGE CRACKING	H	8	M	120000	
13	POTHOLE	H	1	Count	40000	
7	EDGE CRACKING	H	23	M	345000	
34						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	67	SqM	1005000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	12	M	180000	
6	DEPRESSION	H	2	SqM	80000	
6	DEPRESSION	M	3	SqM	90000	
38						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	87	SqM	1305000	
15	RUTTING	L	21	SqM	0	
13	POTHOLE	H	1	Count	40000	
42						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	108	SqM	1620000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
46						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
sec(2-B)						
3	good					
7						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

7						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	H	98	SqM	1960000	8923000
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
11						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	3186.786
sec(2-B)						
11						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	87	SqM	1305000	
7	EDGE CRACKING	L	4	M	0	
17	SLIPPAGE CRACKING	L	0.7	SqM	0	
1	ALLIGATOR CRACKING	H	2	SqM	80000	
13	POTHOLE	L	1	Count	15000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	5	SqM	150000	
19	RAVELING	M	76	SqM	1140000	
19						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	64	SqM	960000	
11	PATCH/UTILITY CUT	L	7	SqM	105000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	4	SqM	60000	
11	PATCH/UTILITY CUT	L	7	SqM	105000	
11	PATCH/UTILITY CUT	M	5	SqM	150000	
26						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	16	SqM	480000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	6	M	18000	
11	PATCH/UTILITY CUT	L	1	SqM	15000	
30						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	7	SqM	210000	
34						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	18	SqM	270000	
38						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
15	RUTTING	M	4	SqM	100000	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	M	80	SqM	1200000	
42						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1	SqM	30000	
11	PATCH/UTILITY CUT	M	2	SqM	60000	
3	BLOCK CRACKING	L	20	SqM	300000	
44						
Distress	Description	Severity	Quantity	Units	Comments	
19	RAVELING	M	12	SqM	180000	
sec(3-A)						
2						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1	M	0	3750
10	LONGITUDINAL/TRANSVERSE CRACKING	L	0.6	M	0	cost ID/M2
6						8.116883
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	0.25	SqM	3750	
sec(3-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	L	0.55	M	0	0
4						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	0
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1	M	0	
sec(3-0A)						total ID
2						0
Distress	Description	Severity	Quantity	Units	Cost	cost ID/M2
10	LONGITUDINAL/TRANSVERSE CRACKING	L	0.8	M	0	0
sec(3-0B)						total ID
1						0
Distress	Description	Severity	Quantity	Units	Cost	cost ID/M2
10	LONGITUDINAL/TRANSVERSE CRACKING	L	0.8	M	0	0
sec(3-1-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
6	DEPRESSION	H	1.5	SqM	60000	2298000
6	DEPRESSION	M	0.7	SqM	21000	
4	good					cost ID/M2
6	good					904.3684
9	good					
11	good					
13	good					
15						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	L	6.8	SqM	102000	
19	RAVELING	M	23	SqM	345000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	45	SqM	675000	
20						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	31	SqM	465000	
13	POTHOLE	L	1	Count	15000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	8	M	0	
19	RAVELING	M	41	SqM	615000	
25						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	8	M	0	
sec(3-1-B)						
2	good					
4	good					
6						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	L	5.6	M	0	75000
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
13	POTHOLE	L	1	Count	15000	cost ID/M2
9	good					29.51594
11	good					
13						
sec(3-1-B)						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	4	SqM	60000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
15	good					
17	good					
20	good					
23	good					
sec(4-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	15562000
5						
Distress	Description	Severity	Quantity	Units	Cost	cost ID/M2
11	PATCH/UTILITY CUT	H	8	SqM	320000	6124.3605
18	SWELL	M	2	SqM	50000	
19	RAVELING	M	128	SqM	1920000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	86	SqM	1290000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
13	POTHOLE	M	2	Count	60000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	192	SqM	2880000	
14						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	23	M	69000	
19	RAVELING	H	35	SqM	700000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	67	SqM	1005000	
20						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	165	SqM	2475000	
23						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	23	M	345000	
26						
29	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	70	SqM	1400000	
29						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	M	2	Count	60000	
19	RAVELING	M	87	SqM	1305000	
sec(3-1-B) con.						
32						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	98	SqM	1470000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	8	M	120000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

sec(4-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	25	M	75000	16319500
5						
Distress	Description	Severity	Quantity	Units	Cost	cost ID/M2
1	ALLIGATOR CRACKING	L	12	SqM	180000	6422.471
13	POTHOLE	M	1	Count	30000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	M	44	SqM	1320000	
7	EDGE CRACKING	M	21	M	63000	
11	good					
14						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	H	12.6	SqM	504000	
19	RAVELING	M	89	SqM	1335000	
13	POTHOLE	M	1	Count	30000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	107	SqM	1605000	
1	ALLIGATOR CRACKING	L	64	SqM	960000	
20						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	H	55	SqM	2200000	
23						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	H	55	SqM	2200000	
19	RAVELING	M	85	SqM	1275000	
26						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	H	20	SqM	800000	
19	RAVELING	H	23	SqM	460000	
13	POTHOLE	M	2	Count	60000	
29						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	M	23	M	184000	
19	RAVELING	M	88	SqM	1320000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	7	M	105000	
1	ALLIGATOR CRACKING	H	20	SqM	800000	
32						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	16	SqM	320000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4.5	M	13500	
1	ALLIGATOR CRACKING	H	12	SqM	480000	
sec(4-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	67	SqM	1005000	4605000

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

2						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	2215.007
19	RAVELING	M	67	SqM	1005000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	56	SqM	840000	
13	POTHOLE	H	1	Count		
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	31	SqM	465000	
8	good					
sec(5-A) 1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	67	SqM	1005000	4605000
2						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	2215.007
19	RAVELING	M	67	SqM	1005000	
sec(5-A)						
8	good					
10	good					
12	good					
13	good					
15						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	78	SqM	1170000	
13	POTHOLE	M	4	Count	120000	
sec(5-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
16	SHOVING	L	4	SqM	0	6510500
6	DEPRESSION	M	4.5	SqM	135000	cost ID/M2
5	CORRUGATION	M	2.5	SqM	37500	3131.554
3	good					
4	good					
6	good					
8						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	56	SqM	840000	
10						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	16	M	48000	
19	RAVELING	M	95	SqM	285000	
12						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	M	22	SqM	330000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

14						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	195	SqM	2925000	
16						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	104	SqM	1560000	
5	CORRUGATION	L	8	SqM	120000	
13	POTHOLE	H	1	Count	40000	
15	RUTTING	M	7	SqM	175000	
sec(6-A)						
1	good					
3	good					
6	good					
7	good					
9	good					
10						
Distress	Description	Severity	Quantity	Units	Cost	total ID
6	DEPRESSION	M	0.24	SqM	7200	6549400
19	RAVELING	M	102	SqM	1530000	cost ID/M2
11						3544.048
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	124	SqM	1860000	
13						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1	SqM	30000	
19	RAVELING	M	188	SqM	2820000	
11	PATCH/UTILITY CUT	M	3.24	SqM	97200	
7	EDGE CRACKING	H	7	M	105000	
18	SWELL	M	4	SqM	100000	
sec(6-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
6	DEPRESSION	L	1	SqM	15000	5455500
3						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	2952.11
19	RAVELING	M	79	SqM	1185000	
5	good					
6	good					
7						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	0.7	SqM	10500	
9						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	88	SqM	1320000	
11						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	M	76	SqM	1140000	
13						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	98	SqM	1470000	
16	SHOVING	M	4	SqM	100000	
6	DEPRESSION	H	5	SqM	200000	
sec(7-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
16	SHOVING	M	5	SqM	125000	4319000
7	EDGE CRACKING	M	11	M	33000	cost ID/M2
19	RAVELING	M	14	SqM	210000	2670.996
10	LONGITUDINAL/TRANSVERSE CRACKING	M	3	M	9000	
13	POTHOLE	M	2	Count	60000	
13	POTHOLE	L	1	Count	15000	
11	PATCH/UTILITY CUT	L	5	SqM	75000	
3						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	99	SqM	1485000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	5	SqM	150000	
19	RAVELING	M	96	SqM	1440000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	29	SqM	435000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	17	SqM	255000	
9	good					
10						
Distress	Description	Severity	Quantity	Units	Comments	
13	POTHOLE	H	1	Count	15000	
sec(7-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
13	POTHOLE	M	3	Count	90000	6600000
19	RAVELING	M	92	SqM	1380000	cost ID/M2
3						4081.633
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	86	SqM	1290000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	100	SqM	1500000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	89	SqM	1335000	
6	DEPRESSION	M	1	SqM	30000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
5	CORRUGATION	L	4	SqM	0	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

19	RAVELING	M	54	SqM	810000	
9						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1.5	SqM	45000	
5	CORRUGATION	M	6	SqM	90000	
10						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1	SqM	30000	
sec(8-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	198000
5						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	77.92208
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
13	POTHOLE	M	3	Count	90000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
11	good					
14						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
17						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	
20						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
23						
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
19	RAVELING	M	18	SqM	270000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	11	M	33000	
29						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	26	SqM	390000	
sec(8-A)						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
26						

Distress	Description	Severity	Quantity	Units	Cost	
32						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	23	SqM	345000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	8	M	0	
sec(8-B)						
2	good					
5						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	2880000
11	good					cost ID/M2
14	good					1133.412
sec(8-B) con.						
17						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	8	M	0	
20						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
19	RAVELING	M	88	SqM	1320000	
23						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	12	M	0	
26						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	
29						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	20	M	0	
32						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	99	SqM	1485000	
sec(8-B)						
sec(9-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	966000
3						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	696.9697
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
5	good					
6						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	2	SqM	60000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	17	M	51000	
19	RAVELING	M	53	SqM	795000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

sec(9-A)						
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
9						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	8	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	16	M	48000	
sec(9-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	1522000
2						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	869.7143
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	36	SqM	540000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	21	SqM	315000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	23	SqM	345000	
10						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	14	SqM	280000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
11						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	1.2	SqM	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
13						
Distress	Description	Severity	Quantity	Units	Comments	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2	M	0	
sec(9-C)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
16	SHOVING	L	3	SqM	0	2847400
19	RAVELING	M	4	SqM	60000	cost ID/M2
3						1627.086
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	109	SqM	1635000	
13	POTHOLE	H	1	Count	40000	
6	DEPRESSION	L	0.76	SqM	11400	
4						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue).

Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	36	SqM	540000	
6	good					
sec(9-C)						
8	good					
10						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	12	SqM	180000	
11	good					
13						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	24	SqM	360000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
sec(10-A)						
2	good					
4	good					
6						
Distress	Description	Severity	Quantity	Units	Cost	total ID
13	POTHOLE	M	2	Count	60000	60000
8	good					cost ID/M2
10	good					28.86003
12	good					
14	good					
16	good					
18	good					
sec(10-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
13	POTHOLE	L	1	Count	0	685000
19	RAVELING	M	10	SqM	150000	cost ID/M2
15	RUTTING	L	7	SqM	0	329.4853
4						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	3	SqM	45000	
19	RAVELING	H	2	SqM	40000	
15	RUTTING	L	3	SqM	0	
6						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	5	M	0	
19	RAVELING	M	28	SqM	420000	
13	POTHOLE	L	1	Count	15000	
8	good					
10						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
12	good					
14	good					
16	good					
18	good					
sec(11-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2.5	M	0	680250
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	cost ID/M2
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	294.480519
10	LONGITUDINAL/TRANSVERSE CRACKING	M	2	M	6000	
19	RAVELING	M	34	SqM	510000	
4						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	M	3	M	9000	
6	good					
8						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	8	M	24000	
13	POTHOLE	L	1	Count	15000	
13	POTHOLE	L	1	Count	15000	
11, 15,17	good					
sec(11-A) con.						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	3	M	0	
19	RAVELING	M	6	SqM	90000	
20	good					
22						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	8	M	0	
13	POTHOLE	L	0.35	Count	5250	
13	POTHOLE	L	0.4	Count	6000	
sec(11-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
13	POTHOLE	L	2	Count	30000	1191000
4						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	515.584416
19	RAVELING	M	7.5	SqM	112500	
13	POTHOLE	L	1	Count	15000	
4	BUMPS/SAGS	L	4.5	M	0	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	6	SqM	90000	
13	POTHOLE	L	1	Count	15000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	M	13.5	SqM	202500	
11						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	17	SqM	255000	
13						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	11.6	SqM	174000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	7.8	SqM	117000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	10	SqM	150000	
7	EDGE CRACKING	L	8	M	0	
20						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	1	SqM	15000	
22	good					
sec(12-B)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2.3	M	0	60000
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1	M	0	cost ID/M2
6						129.87013
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

19	RAVELING	M	4	SqM	60000	
sec(12-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	6	SqM	90000	90000
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2	M	0	cost ID/M2
5						194.80519
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2.3	M	0	
sec(12-1-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	12	SqM	180000	982500
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	cost ID/M2
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	998.4756098
6	DEPRESSION	L	1.5	SqM	22500	
3						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	21	SqM	315000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	2	M	6000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
19	RAVELING	M	15	SqM	225000	
5						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	2	Count	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
19	RAVELING	M	9	SqM	135000	
sec(12-1-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	496500
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	cost ID/M2
1	ALLIGATOR CRACKING	L	1.5	SqM	22500	1007.450216
2						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	6	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	13	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
13	POTHOLE	L	2	Count	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
3						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1.5	M	0	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	H	6	SqM	120000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
13	POTHOLE	L	2	Count		
4						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
19	RAVELING	M	17	SqM	255000	
13	POTHOLE	L	1	Count	15000	
7	EDGE CRACKING	M	3	M	9000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
sec(13-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	L	13	M	0	7389000
7	EDGE CRACKING	L	8	M	0	cost ID/M2
19	RAVELING	M	6	SqM	90000	2460.53946
19	RAVELING	M	34	SqM	510000	
sec(13-A)						
7						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	L	12	SqM	180000	
11	PATCH/UTILITY CUT	L	6	SqM	90000	
19	RAVELING	M	26	SqM	390000	
19	RAVELING	M	7	SqM	105000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
4	BUMPS/SAGS	L	9	M	0	
7	EDGE CRACKING	M	9	M	27000	
7	EDGE CRACKING	M	10	M	30000	
19	RAVELING	M	31	SqM	465000	
11	PATCH/UTILITY CUT	L	12	SqM	180000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	42	SqM	630000	
19	RAVELING	M	27	SqM	405000	
7	EDGE CRACKING	L	16	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	10	M	30000	
8	JOINT REFLECTION CRACKING	L	25	M	0	
19						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	18	M	54000	
9	LANE/SHOULDER DROP	L	6	M	0	
19	RAVELING	M	12	SqM	180000	
11	PATCH/UTILITY CUT	L	9	SqM	135000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	14	M	42000	
8	JOINT REFLECTION CRACKING	L	24	M	0	
11	PATCH/UTILITY CUT	L	12	SqM	180000	
23						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	25	M	0	
19	RAVELING	M	48	SqM	144000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
7	EDGE CRACKING	M	5	M	15000	
9	LANE/SHOULDER DROP	L	20	M	0	
27						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
7	EDGE CRACKING	H	5	M	75000	
19	RAVELING	M	30	SqM	450000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
6	DEPRESSION	L	2.5	SqM	37500	
31						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	25	M	0	
19	RAVELING	M	80	SqM	1200000	
11	PATCH/UTILITY CUT	L	1.5	SqM	22500	
7	EDGE CRACKING	M	4	M	12000	
6	DEPRESSION	L	4	SqM	60000	
35						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	13	SqM	390000	
19	RAVELING	M	24	SqM	360000	
8	JOINT REFLECTION CRACKING	L	11	M	0	
4	BUMPS/SAGS	L	12	M	0	
19	RAVELING	M	12	SqM	180000	
39						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	17.5	M	0	
11	PATCH/UTILITY CUT	L	17	SqM	255000	
19	RAVELING	M	30	SqM	450000	
9	LANE/SHOULDER DROP	L	6	M	0	
sec(13-A) con.						
43	good					
47	good					
51	good					
sec(13-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	M	7	M	21000	6266600
19	RAVELING	M	18	SqM	270000	cost ID/M2
7	EDGE CRACKING	L	8.5	M	0	2086.779887
6						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	6.7	M	20100	
19	RAVELING	M	21	SqM	315000	
14						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	43	SqM	645000	
7	EDGE CRACKING	L	23	M	0	
18						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	20	M	60000	
7	EDGE CRACKING	M	15	M	45000	
19	RAVELING	M	54	SqM	810000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	M	2	Count	60000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
6	DEPRESSION	M	1.5	SqM	45000	
19	RAVELING	M	26.9	SqM	403500	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	24	M	0	
3	BLOCK CRACKING	L	17	SqM	255000	
26						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	27	SqM	405000	
7	EDGE CRACKING	L	18	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	25	M	0	
1	ALLIGATOR CRACKING	M	7	SqM	210000	
30						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	11	M	0	
19	RAVELING	M	23.7	SqM	355500	
7	EDGE CRACKING	M	7	M	21000	
7	EDGE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2	M	0	
34						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	12	SqM	180000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	14	M	42000	
9	LANE/SHOULDER DROP	L	25	M	0	
7	EDGE CRACKING	L	3	M	0	
15	RUTTING	H	3	SqM	120000	
1	ALLIGATOR CRACKING	L	18	SqM	270000	
38						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	71	SqM	1065000	
7	EDGE CRACKING	L	8	M	0	
13	POTHOLE	L	2	Count	30000	
15	RUTTING	L	20	SqM	0	
43						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	3	M	45000	
15	RUTTING	L	15	SqM	0	
6	DEPRESSION	L	2	SqM	30000	
6	DEPRESSION	L	1.5	SqM	22500	
19	RAVELING	M	6	SqM	90000	
sec(13-B) con.						
46						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	25	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
13	POTHOLE	M	2	Count	60000	
15	RUTTING	L	5	SqM	0	
48						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	12	SqM	240000	
11	PATCH/UTILITY CUT	H	2	SqM	80000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2.5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1	M	0	
50	good					
sec(14-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
13	POTHOLE	M	1	Count	30000	20021000
6	DEPRESSION	L	3	SqM	45000	cost ID/M2
7	EDGE CRACKING	H	4	M	60000	12089.9758
6	DEPRESSION	L	2.5	SqM	37500	
13	POTHOLE	L	1	Count	15000	
3						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	220	SqM	3300000	
6	DEPRESSION	L	1	SqM	15000	
6	DEPRESSION	L	2	SqM	30000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	160	SqM	2400000	
19	RAVELING	H	13	SqM	260000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

6	DEPRESSION	H	2	SqM	80000	
6	DEPRESSION	M	1	SqM	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
7	EDGE CRACKING	L	6	M	0	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	6	SqM	120000	
19	RAVELING	H	12	SqM	240000	
19	RAVELING	M	110	SqM	1650000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	200	SqM	4000000	
6	DEPRESSION	M	1.5	SqM	45000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	4	M	60000	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	3	M	45000	
11	PATCH/UTILITY CUT	H	18	SqM	720000	
13	POTHOLE	M	1	Count	30000	
7	EDGE CRACKING	M	8	M	24000	
10						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	12	SqM	240000	
6	DEPRESSION	L	0.5	SqM	7500	
19	RAVELING	M	200	SqM	3000000	
7	EDGE CRACKING	M	11	M	33000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	230	SqM	3450000	
6	DEPRESSION	H	0.75	SqM	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
sec(15-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	36	SqM	540000	10936000
13	POTHOLE	H	1	Count	40000	cost ID/M2
16	SHOVING	L	7	SqM	0	3641.6916
7						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	12	SqM	180000	
16	SHOVING	L	3	SqM	0	
12						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	80	SqM	1200000	
2	BLEEDING	H	75	SqM	1875000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	120	SqM	1800000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	2	Count	30000	
15	RUTTING	L	4	SqM	0	
19	RAVELING	M	28	SqM	420000	
27						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	21.2	M	0	
19	RAVELING	M	23	SqM	345000	
11	PATCH/UTILITY CUT	L	5	SqM	75000	
13	POTHOLE	H	1	Count	40000	
31						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
19	RAVELING	M	44	SqM	660000	
36						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	12	SqM	0	
15	RUTTING	L	12	SqM	0	
19	RAVELING	M	55	SqM	825000	
13	POTHOLE	H	1	Count	40000	
41						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	24	M	72000	
19	RAVELING	M	65	SqM	975000	
46						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
51						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	12	M	36000	
56						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	32	SqM	640000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
61						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	8	M	24000	
15	RUTTING	L	3	SqM	0	
19	RAVELING	M	72	SqM	1080000	
sec(15-B)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
5	CORRUGATION	M	5	SqM	75000	3338500
18	SWELL	L	4	SqM	0	cost ID/M2
18	SWELL	M	1.5	SqM	37500	1111.7216
sec(15-B)						
7						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	25.7	SqM	0	
13	POTHOLE	H	1	Count	40000	
12						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	26	SqM	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	H	9	M	135000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	11	SqM	0	
16	SHOVING	L	12	SqM	0	
22						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
18	SWELL	M	12	SqM	300000	
16	SHOVING	L	10.5	SqM	0	
15	RUTTING	L	11	SqM	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	9	M	27000	
27						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

9	LANE/SHOULDER DROP	M	20	M	60000	
19	RAVELING	M	67	SqM	1005000	
31						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	12.5	SqM	0	
13	POTHOLE	M	1	Count	30000	
41						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	51	SqM	765000	
19	RAVELING	M	33	SqM	495000	
36						
46						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	23	M	69000	
15	RUTTING	L	9	SqM	0	
51						
Distress	Description	Severity	Quantity	Units	Cost	
18	SWELL	M	6	SqM	150000	
56						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	4	SqM	120000	
61						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	3	M	9000	
sec(16-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
7	EDGE CRACKING	H	8	M	120000	6605500
16	SHOVING	L	3	SqM	0	cost ID/M2
15	RUTTING	L	4	SqM	0	3443.95203
3	BLOCK CRACKING	M	15	SqM	450000	
3						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	M	12	SqM	300000	
19	RAVELING	M	23.7	SqM	355500	
11	PATCH/UTILITY CUT	M	16	SqM	240000	
5						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	45	SqM	675000	
15	RUTTING	L	4	SqM	0	
11	PATCH/UTILITY CUT	M	3	SqM	90000	
1	ALLIGATOR CRACKING	M	10	SqM		

sec(16-A)					
6					
Distress	Description	Severity	Quantity	Units	Cost
15	RUTTING	M	2	SqM	50000
1	ALLIGATOR CRACKING	M	19	SqM	570000
8					
Distress	Description	Severity	Quantity	Units	Cost
3	BLOCK CRACKING	L	78	SqM	1170000
19	RAVELING	M	33	SqM	495000
10					
Distress	Description	Severity	Quantity	Units	Cost
18	SWELL	M	2	SqM	50000
11	PATCH/UTILITY CUT	L	11	SqM	165000
15	RUTTING	L	2	SqM	0
19	RAVELING	M	34	SqM	510000
19	RAVELING	M	13	SqM	195000
7	EDGE CRACKING	L	7	M	0
sec(16-A) con.					

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

12						
Distress	Description	Severity	Quantity	Units	Cost	
1	ALLIGATOR CRACKING	M	4.5	SqM	135000	
11	PATCH/UTILITY CUT	H	4.5	SqM	180000	
19	RAVELING	M	12	SqM	180000	
14						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	45	SqM	675000	
18	SWELL	L	16	SqM	0	
sec(17-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	56.8	SqM	852000	6861000
6						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	2700.11806
19	RAVELING	M	77	SqM	1155000	
9						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	67	SqM	1005000	
5	CORRUGATION	M	4	SqM	60000	
12						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	22	SqM	440000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	23	SqM	345000	
18						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	46	SqM	690000	
13	POTHOLE	L	3	Count	45000	
21	good					
24	good					
27						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	87	SqM	1305000	
30						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	61.6	SqM	924000	
13	POTHOLE	H	1	Count	40000	
33						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	H	1	Count	40000	
19	RAVELING	M	90	SqM	1350000	
sec(17-B)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	32	SqM	480000	8774500
6						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	3453.16804
19	RAVELING	M	89	SqM	1335000	
9						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	97	SqM	1455000	
12						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	M	67	SqM	1005000	
18						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

19	RAVELING	M	79	SqM	1185000	
18	SWELL	L	2.5	SqM	62500	
21						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	54	SqM	810000	
24						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	36.8	SqM	552000	
30						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	23	SqM	345000	
33	good					
sec(18-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	32	SqM	480000	4220000
4	good					cost ID/M2
7						1660.76348
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	25	SqM	375000	
10						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	75	SqM	1125000	
13	good					
16	good					
19						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	H	9.5	SqM	380000	
19	RAVELING	M	98	SqM	1470000	
13	POTHOLE	M	1	Count	30000	
22	good					
25	good					
27						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	12	SqM	360000	
31	good					
sec(18-B)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
11	PATCH/UTILITY CUT	M	1.5	SqM	45000	2067000
6						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	813.45927
19	RAVELING	H	12	SqM	240000	
sec(18-B) con.						
9						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	4	M	0	
12	good					
13						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	32	SqM	480000	
18						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	23.8	SqM	357000	
21						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	18	SqM	270000	
24						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

19	RAVELING	M	45	SqM	675000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
27	good					
30						
Distress	Description	Severity	Quantity	Units	Comments	
19	RAVELING	M	68	SqM	1020000	
11	PATCH/UTILITY CUT	L	0.75	SqM	11250	
33						
Distress	Description	Severity	Quantity	Units	Comments	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5.7	M	0	
19	RAVELING	M	38	SqM	570000	
sec(19-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	10	SqM	150000	2017500
13	POTHOLE	L	1	Count	15000	cost ID/M2
11	PATCH/UTILITY CUT	M	10	SqM	300000	1646.9388
2						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	5	SqM	0	
19	RAVELING	M	13	SqM	195000	
11	PATCH/UTILITY CUT	L	10	SqM	150000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	13	SqM	di14*d20	
7	EDGE CRACKING	L	11	M	0	
15	RUTTING	L	3	SqM	0	
11	PATCH/UTILITY CUT	L	10	SqM	150000	
5						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	10	SqM	200000	
7	EDGE CRACKING	H	6.5	M	97500	
13	POTHOLE	M	1	Count	30000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	12	SqM	180000	
7	EDGE CRACKING	M	10	M	30000	
11	PATCH/UTILITY CUT	M	12	SqM	360000	
11	PATCH/UTILITY CUT	H	4	SqM	160000	
sec(19-B)						
1						
sec(19-A) con.						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	H	14	SqM	280000	2837500
15	RUTTING	L	4.5	SqM	0	cost ID/M2
9	LANE/SHOULDER DROP	M	13	M	39000	2316.327
19	RAVELING	M	8	SqM	120000	
2						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	7	SqM	0	
19	RAVELING	M	71	SqM	1065000	
13	POTHOLE	L	3	Count	45000	
3						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	32	SqM	480000	
15	RUTTING	L	8	SqM	0	
5						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

15	RUTTING	L	5.7	SqM	0	
9	LANE/SHOULDER DROP	M	11	M	33000	
15	RUTTING	L	8	SqM	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	13.5	M	40500	
13	POTHOLE	M	1	Count	30000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	11.4	SqM	0	
19	RAVELING	M	22	SqM	330000	
15	RUTTING	M	7	SqM	175000	
16	SHOVING	H	5	SqM	200000	
sec(20-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
11	PATCH/UTILITY CUT	L	55	SqM	825000	13712300
19	RAVELING	M	66	SqM	990000	cost ID/M2
18	SWELL	M	4	SqM	100000	10729.5
8	JOINT REFLECTION CRACKING	L	27	M	0	
6	DEPRESSION	M	1.5	SqM	45000	
6	DEPRESSION	L	1.5	SqM	22500	
3						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	L	69	SqM	1035000	
19	RAVELING	M	64	SqM	960000	
11	PATCH/UTILITY CUT	L	6	SqM	90000	
15	RUTTING	L	5	SqM	0	
4						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	8.6	M	25800	
6	DEPRESSION	L	4.4	SqM	66000	
11	PATCH/UTILITY CUT	L	69	SqM	1035000	
8	JOINT REFLECTION CRACKING	M	26	M	208000	
11	PATCH/UTILITY CUT	L	56	SqM	840000	
13	POTHOLE	H	1	Count	40000	
13	POTHOLE	H	1	Count	40000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	H	12	M	180000	
11	PATCH/UTILITY CUT	M	3	SqM	90000	
6	DEPRESSION	M	6	SqM	180000	
18	SWELL	M	17.6	SqM	440000	
11	PATCH/UTILITY CUT	L	68	SqM	1020000	
sec(20-A) con.						
7						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	110	SqM	1650000	
16	SHOVING	L	4	SqM	0	
11	PATCH/UTILITY CUT	L	90	SqM	1350000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
18	SWELL	M	8	SqM	200000	
11	PATCH/UTILITY CUT	L	6	SqM	90000	
11	PATCH/UTILITY CUT	L	44	SqM	660000	
19	RAVELING	M	102	SqM	1530000	
sec(20-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
11	PATCH/UTILITY CUT	H	1.5	SqM	60000	9492000
11	PATCH/UTILITY CUT	M	88	SqM	2640000	cost ID/M2
11	PATCH/UTILITY CUT	M	5	SqM	150000	7427.23
3						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	M	22	SqM	550000	
11	PATCH/UTILITY CUT	L	43	SqM	645000	
11	PATCH/UTILITY CUT	H	2	SqM	80000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	33	SqM	990000	
19	RAVELING	M	132	SqM	1980000	
11	PATCH/UTILITY CUT	M	12	SqM	360000	
13	POTHOLE	H	3	Count	120000	
5						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1	SqM	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	2.5	SqM	75000	
16	SHOVING	L	2	SqM	0	
8	JOINT REFLECTION CRACKING	L	23	M	0	
8						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	56	SqM	1680000	
11	PATCH/UTILITY CUT	H	3	SqM	120000	
sec(21-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
11	PATCH/UTILITY CUT	L	2	SqM	30000	4851500
11	PATCH/UTILITY CUT	M	2	SqM	60000	cost ID/M2
18	SWELL	M	2	SqM	50000	5250.541126
11	PATCH/UTILITY CUT	L	2	SqM	0	
6	DEPRESSION	L	1.2	SqM	0	
11	PATCH/UTILITY CUT	M	2.5	SqM	75000	
2						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	23	SqM	690000	
11	PATCH/UTILITY CUT	L	12.5	SqM	187500	
11	PATCH/UTILITY CUT	M	3.5	SqM	105000	
7	EDGE CRACKING	M	11	M	162000	
19	RAVELING	M	54	SqM	810000	
15	RUTTING	L	4.5	SqM	0	
11	PATCH/UTILITY CUT	M	6	SqM	180000	
19	RAVELING	H	5	SqM	100000	
15	RUTTING	L	3	SqM	0	
sec(21-A) con.						
3						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	32	SqM	480000	
13	POTHOLE	M	2	Count	60000	
11	PATCH/UTILITY CUT	H	7	SqM	280000	
16	SHOVING	H	3	SqM	120000	
13	POTHOLE	H	1	Count	40000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	0.9	SqM	27000	
11	PATCH/UTILITY CUT	M	33	SqM	990000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	15	M	0	
19	RAVELING	M	22	SqM	330000	
11	PATCH/UTILITY CUT	L	5	SqM	75000	
sec(21-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

11	PATCH/UTILITY CUT	H	2.5	SqM	100000	5917000
11	PATCH/UTILITY CUT	L	20	SqM	300000	cost ID/M2
11	PATCH/UTILITY CUT	H	5	SqM	200000	6403.68
19	RAVELING	M	41	SqM	1230000	
2						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	4	SqM	0	
11	PATCH/UTILITY CUT	M	25	SqM	750000	
19	RAVELING	M	32	SqM	480000	
3						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	33	SqM	990000	
19	RAVELING	M	25	SqM	375000	
11	PATCH/UTILITY CUT	H	1.5	SqM	60000	
11	PATCH/UTILITY CUT	H	2	SqM	80000	
13	POTHOLE	H	2	Count	80000	
4						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	1	SqM	30000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
11	PATCH/UTILITY CUT	H	2.5	SqM	100000	
16	SHOVING	L	3	SqM	0	
8	JOINT REFLECTION CRACKING	L	17	M	680000	
11	PATCH/UTILITY CUT	M	15	SqM	450000	
sec(22-A)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	67	SqM	1005000	3535500
4	good					cost ID/M2
6	good					1530.519
8						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	M	2	Count	60000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
6	DEPRESSION	M	0.75	SqM	22500	
11	PATCH/UTILITY CUT	M	18	SqM	540000	
11	PATCH/UTILITY CUT	M	5	SqM	150000	
18	SWELL	M	6	SqM	150000	
8	JOINT REFLECTION CRACKING	L	22	M	0	
18						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	81	SqM	1215000	
sec(22-A) con.						
20						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	M	6	M	18000	
6	DEPRESSION	M	6	SqM	180000	
21						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	6	SqM	0	
19	RAVELING	M	12	SqM	180000	
sec(22-B)						
1						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

Distress	Description	Severity	Quantity	Units	Cost	total ID
4	BUMPS/SAGS	M	7	M	105000	402000
4						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	174.026
15	RUTTING	L	23	SqM	0	
6						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	3.5	SqM	105000	
8						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	1.5	SqM	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
11						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	7	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
13	Good					
15						
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	M	3.5	SqM	105000	
6	DEPRESSION	M	1.5	SqM	45000	
18						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
20						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	33	M	0	
22						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	33	M	0	
sec(23-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1.5	M	0	0
5						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	0
10	LONGITUDINAL/TRANSVERSE CRACKING	L	0.76	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1.2	M	0	
sec(23-B)						
2						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1.5	M	0	15000
10	LONGITUDINAL/TRANSVERSE CRACKING	L	1.5	M	0	cost ID/M2
4						21.64502
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3	M	0	
7						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	1	SqM	15000	
sec(23-1-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
6	DEPRESSION	L	0.3	SqM	4500	1518750
2						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	1221.842
10	LONGITUDINAL/TRANSVERSE CRACKING	M	3	M	9000	
6	DEPRESSION	L	0.2	SqM	3000	
4						
Distress	Description	Severity	Quantity	Units	Cost	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	2	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	3.2	M	0	
11	PATCH/UTILITY CUT	L	0.25	SqM	3750	
6						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	0.25	SqM	7500	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
19	RAVELING	M	18	SqM	270000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	77	SqM	1155000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	5	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	7	M	21000	
sec(23-1-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	M	79	SqM	1185000	3133500
2						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	2520.917
19	RAVELING	M	52.9	SqM	793500	
4						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	53	SqM	795000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	24	SqM	360000	
7	good					
sec(24-A)						
1	good					
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
8	JOINT REFLECTION CRACKING	L	30	M	0	3453750
13	POTHOLE	L	3	Count	45000	cost ID/M2
19	RAVELING	M	55	SqM	825000	2135.9
5						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	33	M	0	
19	RAVELING	M	23	SqM	345000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	26	M	0	
8						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	76	SqM	1140000	
10						
sec(24-A) con.						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	69	SqM	1035000	
6	DEPRESSION	L	0.75	SqM	11250	
13	POTHOLE	L	1	Count	15000	
15	RUTTING	M	1.5	SqM	37500	
8	JOINT REFLECTION CRACKING	L	33	M	0	
12						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	28	M	0	
sec(24-B)						
1						

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	190750
5						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	117.9654
10	LONGITUDINAL/TRANSVERSE CRACKING	M	4	M	12000	
8	JOINT REFLECTION CRACKING	L	33	M	0	
13	POTHOLE	H	1	Count	40000	
6						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	33	M	0	
8						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	0.45	SqM	6750	
4	BUMPS/SAGS	L	7	M	0	
6	DEPRESSION	M	2	SqM	60000	
8	JOINT REFLECTION CRACKING	L	33	M	0	
10						
sec(24-B)						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	33	M	0	
6	DEPRESSION	L	2	SqM	30000	
12						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	2	SqM	30000	
8	JOINT REFLECTION CRACKING	L	27	M	0	
sec(25-A)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
15	RUTTING	L	14	SqM	0	4182500
19	RAVELING	M	67	SqM	gu5*d20	cost ID/M2
7						1508.838
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	H	1	Count	40000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	11	M	0	
15						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	M	4.5	SqM	112500	
19	RAVELING	M	69	SqM	1035000	
8	JOINT REFLECTION CRACKING	L	12	M	0	
19						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	M	4	SqM	100000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	14	M	0	
13	POTHOLE	M	3	Count	90000	
26						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	32	SqM	480000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	9	M	0	
sec(25-A) con.						
30						
Distress	Description	Severity	Quantity	Units	Comments	
19	RAVELING	M	54	SqM	810000	
34						
Distress	Description	Severity	Quantity	Units	Comments	
19	RAVELING	M	45	SqM	675000	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

10	LONGITUDINAL/TRANSVERSE CRACKING	L	4	M	0	
38						
Distress	Description	Severity	Quantity	Units	Comments	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	16	M	0	
42						
Distress	Description	Severity	Quantity	Units	Comments	
19	RAVELING	M	56	SqM	840000	
46	good					
sec(25-B)						
3						
Distress	Description	Severity	Quantity	Units	Cost	total ID
8	JOINT REFLECTION CRACKING	L	14	M	0	1543000
7						cost ID/M2
Distress	Description	Severity	Quantity	Units	Cost	556.6378
8	JOINT REFLECTION CRACKING	L	14	M	0	
15	RUTTING	L	6	SqM	0	
15	RUTTING	L	6	SqM	0	
11						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	14	M	0	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	16	M	48000	
15	RUTTING	L	6	SqM	0	
15						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	M	4.6	SqM	115000	
15	RUTTING	L	2	SqM	0	
13	POTHOLE	M	1	Count	30000	
7	EDGE CRACKING	L	6	M	0	
19						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	13	M	0	
7	EDGE CRACKING	H	3	M	45000	
22						
Distress	Description	Severity	Quantity	Units	Cost	
15	RUTTING	L	12	SqM	0	
8	JOINT REFLECTION CRACKING	L	14	M	0	
26						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	87	SqM	1305000	
15	RUTTING	L	12	SqM	0	
30						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	11	M	0	
34	good					
38	good					
42	good					
46						
Distress	Description	Severity	Quantity	Units	Cost	
7	EDGE CRACKING	L	11	M	0	
sec(26-A)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
19	RAVELING	H	1	SqM	20000	8966250
19	RAVELING	M	33	SqM	495000	cost ID/M2
3						4312.771
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	L	0.75	SqM	11250	
8	JOINT REFLECTION CRACKING	L	14	M	0	
sec(26-A) con.						
19	RAVELING	M	70	SqM	1050000	
5						

Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	13	M	0	
19	RAVELING	M	143	SqM	2145000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	H	1.5	SqM	60000	
8	JOINT REFLECTION CRACKING	L	11	M	0	
19	RAVELING	M	11	SqM	165000	
15	RUTTING	L	3	SqM	0	
9						
Distress	Description	Severity	Quantity	Units	Cost	
6	DEPRESSION	M	2	SqM	60000	
8	JOINT REFLECTION CRACKING	L	12	M	0	
11	PATCH/UTILITY CUT	H	1.5	SqM	60000	
11						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	13	M	0	
19	RAVELING	M	74	SqM	1110000	
10	LONGITUDINAL/TRANSVERSE CRACKING	L	6	M	0	
13						
Distress	Description	Severity	Quantity	Units	Cost	
13	POTHOLE	L	1	Count	15000	
19	RAVELING	H	8	SqM	160000	
8	JOINT REFLECTION CRACKING	L	13	M	0	
19	RAVELING	M	75	SqM	1125000	
15						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	M	56	SqM	840000	
11	PATCH/UTILITY CUT	H	1.5	SqM	60000	
8	JOINT REFLECTION CRACKING	L	10	M	0	
13	POTHOLE	L	1	Count	15000	
13	POTHOLE	M	2	Count	60000	
17						
Distress	Description	Severity	Quantity	Units	Cost	
8	JOINT REFLECTION CRACKING	L	5	M	0	
19	RAVELING	M	101	SqM	1515000	
sec(26-B)						
1						
Distress	Description	Severity	Quantity	Units	Cost	total ID
8	JOINT REFLECTION CRACKING	L	13.5	M	0	5238500
19	RAVELING	M	14	SqM	210000	cost ID/M2
3						2519.72102
Distress	Description	Severity	Quantity	Units	Cost	
11	PATCH/UTILITY CUT	L	6	SqM	90000	
6	DEPRESSION	M	1.5	SqM	45000	
15	RUTTING	M	6	SqM	150000	
7	EDGE CRACKING	L	13	M	0	
5						
Distress	Description	Severity	Quantity	Units	Cost	
19	RAVELING	H	18	SqM	360000	
13	POTHOLE	M	3	Count	90000	
6	DEPRESSION	M	1.5	SqM	45000	
1	ALLIGATOR CRACKING	L	14	SqM	210000	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
7						
Distress	Description	Severity	Quantity	Units	Cost	
10	LONGITUDINAL/TRANSVERSE CRACKING	M	5	M	15000	
11	PATCH/UTILITY CUT	M	1.5	SqM	45000	
6	DEPRESSION	M	1.5	SqM	45000	
15	RUTTING	M	4.7	SqM	117500	

Table (B.1) The inspection data of all section at the study area and Maintenance costs. (Continue)

sec(26-B) con.					
9					
Distress	Description	Severity	Quantity	Units	Cost
6	DEPRESSION	M	2	SqM	60000
10	LONGITUDINAL/TRANSVERSE CRACKING	M	12	M	36000
8	JOINT REFLECTION CRACKING	L	11	M	0
11					
Distress	Description	Severity	Quantity	Units	Cost
8	JOINT REFLECTION CRACKING	L	11	M	0
19	RAVELING	M	78	SqM	1170000
13					
Distress	Description	Severity	Quantity	Units	Cost
19	RAVELING	M	67	SqM	1005000
8	JOINT REFLECTION CRACKING	L	13	M	0
15					
Distress	Description	Severity	Quantity	Units	Cost
8	JOINT REFLECTION CRACKING	L	13	M	0
19	RAVELING	M	46	SqM	690000
17					
Distress	Description	Severity	Quantity	Units	Cost
19	RAVELING	M	56	SqM	840000

APPENDIX C

Data Collection of Marshal Test and ADT

Table (C-1) the Average Daily Traffic (ADT) Value.

Section	Hourly Volume (HV) veh/h	C(hr)	C(day)	ADT veh/day
1-1	2714	0.08	1.01	33589
1-A	1873	0.08	1.01	23181
1-B	1998	0.08	1.01	24728
2-A	1204	0.0761	1.01	15665
2-B	1580	0.0815	1	19387
3-A	1331	0.061	1.01	21604
3-B	1530	0.061	1.01	24834
3-1-A	1358	0.061	1.01	22042
3-1-B	1065	0.061	1.01	17286
4-A	2329	0.061	1.01	37802
4-B	2463	0.061	1.01	39977
5-A	675	0.057	1.01	11725
5-B	830	0.057	1.01	14417
6-A	774	0.057	1.01	13445
6-B	818	0.057	1.01	14209
7-A	774	0.058	1	13345
7-B	844	0.058	1	14552
8-A	2031	0.059	1.01	34083
8-B	2316	0.059	1.01	38866
9-A	2029	0.059	1.01	34049
9-B	2158	0.059	1.01	36214
9-C	1829	0.059	1.01	30693
10-A	1212	0.059	1.01	20339
10-B	1287	0.059	1.01	21598
11-A	1325	0.077	1.01	17037
11-B	1473	0.077	1.01	18941
12-A	1287	0.077	1.01	16549
12-B	1210	0.077	1.01	15559
12-1-A	1048	0.077	1.01	13476
12-1-B	971	0.077	1.01	12486
13-A	1176	0.0579	1	20311
13-B	1289	0.0579	1	22263
15-A	1508	0.059	1.01	25306
15-B	1308	0.059	1.01	21950
17-A	871	0.057	1.01	15129
17-B	783	0.057	1.01	13601
18-A	764	0.0577	1	13241
18-B	869	0.0577	1	15061
19-A	1149	0.0845	1.01	13463

Table (C-1). The Average Daily Traffic (ADT) value (Continued)

Section	Hourly Volume (HV) veh/h	C(hr)	C(day)	ADT veh/day
19-B	1220	0.0845	1.01	14295
20-A	1238	0.0845	1.01	14506
20-B	1290	0.0845	1.01	15115
21-A	1281	0.0855	1.01	14834
21-B	1377	0.0855	1.01	15946
22-A	1252	0.0842	1.01	14722
22-B	1058	0.0842	1.01	12441
23-A	932	0.0653	1	14273
23-B	886	0.0653	1	13568
23-1-A	767	0.0653	1	11746
23-1-B	865	0.0653	1	13247
24-A	1490	0.0653	1	22818
24-B	1451	0.0653	1	22221
25-A	2927	0.0807	1	36270
25-B	2352	0.0807	1	29145
26-A	2966	0.0831	1	35692
26-B	2561	0.0831	1	30818

Table (C.2) The structural number of sections in study area determined depending on data collection by marshal test.

sample	layer name	Average thickness of layer (inches)	stability Ib	Corr.facter of H	stability Ib	layer coff. A	SN
21	binder (5-B)	2.913	2010.615	0.8768	1762.907	0.403	2.0741
22	Base (5-B)	3.150	2252.550	0.8544	1924.579	0.327	
23	binder (6-A)	2.953	2044.566	0.871	1780.817	0.406	2.3588
24	Base (6-A)	3.402	3405.678	0.685	2332.889	0.364	
25	binder (6-B)	2.992	2175.301	0.849	1846.830	0.415	2.3988
26	Base (6-B)	3.287	3713.730	0.7544	2801.638	0.384	
27	binder (7-A)	2.984	2044.566	0.8768	1792.676	0.409	2.32627
28	Base (7-A)	3.335	3405.678	0.775	2639.400	0.377	
29	binder (7-B)	2.902	2230.416	0.85	1895.854	0.42	2.2138
30	Base (7-B)	3.228	3713.730	0.673	2499.340	0.373	
31	binder (8A)	2.638	3327.656	0.938	3121.342	0.53	2.6175
32	Base (8A)	3.465	3141.586	0.685	2151.987	0.352	
33	binder (8B)	2.165	2214.322	1.36375	3019.782	0.528	2.6822
34	Base (8B)	3.976	5070.631	0.58	2940.966	0.387	
35	binder (9A)	2.559	2610.890	0.938	2449.015	0.478	2.5467
36	Base (9A)	3.465	4001.830	0.694	2777.270	0.382	
37	binder (9B)	2.087	1938.833	1.652	3202.952	0.536	2.5839
38	Base (9B)	3.898	3958.002	0.651	2576.659	0.376	
39	binder (9C)	2.244	2442.942	1.36375	3331.562	0.544	2.7483
40	Base (9C)	3.819	4793.510	0.647	3101.401	0.4	

Table (C.2) The structural number of sections in study area determined depending on data collection by marshal test. (Continue)

sample	layer name	Average thickness of layer (inches)	stability Ib	Corr.facter of H	stability Ib	layer coff. A	SN
41	binder (10A)	2.756	3968.320	0.95	3769.904	0.575	2.8379
42	Base (10A)	3.209	3745.873	0.728	2726.996	0.38	
43	binder (10B)	2.677	3758.881	1.148	4315.195	0.592	2.8748
44	Base (10B)	3.386	4091.338	0.675	2761.653	0.381	
45	binder (11A)	2.362	1003.544	1.258	1262.458	0.334	1.80238
46	Base (11A)	3.189	2154.357	0.785	1691.170	0.29	
47	binder (11B)	1.693	818.797	2.0693	1694.336	0.402	1.6125
48	Base (11B)	2.835	2028.693	0.8544	1733.315	0.308	
49	binder (12-1A)	2.244	1092.831	1.258	1374.782	0.353	1.77
50	Base (12-1A)	2.795	2331.829	0.91	2121.964	0.35	
51	binder (12-1B)	2.165	1264.571	1.652	2089.072	0.43	1.8815
52	Base (12-1B)	2.677	2245.187	0.95	2132.928	0.355	
53	binder (13A)	2.795	4645.139	0.862	4004.109	0.577	3.0182
54	Base (13A)	3.622	4629.706	0.647	2995.420	0.388	
55	surface (13B)	2.756	3155.255	0.862	2719.830	0.5	2.9915
56	binder (13B)	1.969	1281.326	1.87125	2397.682	0.47	
57	Base (13B)	1.850	1427.272	1.79	2554.817	0.372	
58	surface (15A)	1.870	1186.968	1.89	2243.370	0.45	2.8489
59	binder (15A)	2.047	1118.405	1.6425	1836.980	0.411	
60	Base (15A)	2.937	3190.308	0.95	3030.793	0.397	
61	surface (15B)	1.969	1302.932	1.6	2084.691	0.429	2.7077
62	binder (15B)	2.165	901.249	1.6425	1480.302	0.372	
63	Base (15B)	2.657	3224.480	0.95	3063.256	0.398	
64	binder (17-A)	3.008	2243.093	0.8768	1966.744	0.428	2.2933
65	Base (17-A)	2.874	2475.791	0.858	2124.228	0.35	
66	binder (17-B)	2.795	1857.526	0.892	1656.913	0.397	2.2177
67	Base (17-B)	3.484	2136.058	0.862	1841.282	0.318	
68	binder (18-A)	2.976	2014.010	0.8788	1769.912	0.403	2.3197
69	Base (18-A)	3.228	2660.979	0.775	2062.259	0.347	
70	binder (18-B)	2.717	1759.950	0.8768	1543.124	0.374	2.1215
71	Base (18-B)	3.543	2646.296	0.674	1783.603	0.312	
72	binder (19A)	2.638	1664.247	1.12	1863.957	0.418	2.3775
73	Base (19A)	3.465	3482.200	0.685	2385.307	0.368	
74	binder (19B)	2.638	2170.098	0.95	2061.593	0.435	2.412
75	Base (19B)	3.465	3532.929	0.665	2349.398	0.365	
76	binder (20A)	2.717	1515.457	1.278	1936.754	0.424	2.5455
77	Base (20A)	3.583	4122.643	0.69	2844.624	0.389	
78	binder (20B)	3.031	3800.327	0.775	2945.254	0.52	2.5572
79	base (20B)	2.835	2429.934	0.8544	2076.136	0.346	

Table (C.2) The structural number of sections in study area determined depending on data collection by marshal test. (Continue)

sample	layer name	Average thickness of layer (inches)	stability Ib	Corr.facter of H	stability Ib	layer coff. A	SN
80	binder (21A)	2.677	1769.209	1.185	2096.513	0.439	2.5228
81	Base (21A)	3.386	4091.338	0.747	3056.229	0.398	
82	binder (21B)	2.677	2811.576	1.027	2887.489	0.513	2.6938
83	Base (21B)	3.386	4113.384	0.689	2834.121	0.39	
84	surface (22A)	2.441	2110.705	1.258	2655.267	0.43	3.5428
85	binder (22A)	2.283	1028.015	1.298	1334.364	0.34	
86	Base (22A)	2.598	2655.467	0.95	2522.694	0.368	
87	Base (22A)	2.717	1529.853	0.99	1514.555	0.28	
88	surface (22B)	2.559	2049.858	0.97	1988.362	0.428	3.4134
89	binder (22B)	2.087	752.658	1.465	1102.644	0.31	
90	Base (22B)	2.913	3556.055	0.862	3065.320	0.4	
91	Base (22B)	1.969	702.833	1.87125	1315.177	0.257	
92	binder (23-1A)	2.559	878.542	0.989	868.878	0.277	1.8827
93	Base (23-1A)	2.835	2886.798	0.756	2182.419	0.352	
94	binder (23-1B)	2.480	987.935	1.12	1106.487	0.312	1.9572
95	Base (23-1B)	2.992	2662.081	0.8768	2334.113	0.361	
96	binder (24A)	2.756	1077.619	0.91	980.634	0.288	1.8303
97	Base (24A)	2.323	2302.507	1.258	2896.554	0.383	
98	binder (24B)	2.480	909.473	1.0375	943.578	0.283	1.8712
99	Base (24B)	2.756	2741.932	0.928	2544.513	0.373	
100	binder (25A)	2.992	2641.137	0.655	1729.945	0.405	2.0357
101	Base (25A)	2.520	2009.072	0.95	1908.618	0.327	
102	binder (25B)	3.465	1985.483	0.655	1300.491	0.349	1.9989
103	Base (25B)	2.323	1800.294	1.148	2066.738	0.34	
104	surface (26A)	2.795	2280.042	0.8768	1999.141	0.43	3.1543
105	binder (26A)	3.110	3647.106	0.775	2826.507	0.51	
106	Base (26A)	2.638	829.202	1.133	939.486	0.215	
107	surface (26B)	2.913	2548.984	0.8768	2234.949	0.45	3.0109
108	binder (26B)	3.031	3800.327	0.775	2945.254	0.52	
109	Base (26B)	2.480	682.551	1.06	723.504	0.185	

APPENDIX D

Review PAVER PCI and Model Data

Table (D.1) Total number of sample units and The minimum sample units required for the section of study area.

Network ID	Branch ID	Section ID	Actual number of unit (N)	Minimum number of sample unit inspected (n)
Karbala	13	A	54	13
		B	54	13
Karbala	14	A	11	7
Karbala	15	A	63	13
		B	63	13
Karbala	16	A	14	8
Karbala	17	A	34	11
		B	34	11
Karbala	18	A	34	11
		B	34	11
Karbala	19	A	6	5
		B	6	5
Karbala	20	A	8	6
		B	8	6
Karbala	21	A	4	4
		B	4	4
Karbala	22	A	22	10
		B	22	10
Karbala	23	A	2	2
		B	2	2
		1A	7	5
		1B	7	5
Karbala	24	A	12	7
		B	12	7
Karbala	25	A	46	12
		B	46	12
Karbala	26	A	18	9
		B	18	9
Karbala	27	A	20	10
Karbala	28	1A	18	9
		1B	19	9
Karbala	28	2A	16	8
		2B	16	8
Karbala	28	3A	16	8
		3B	16	8
Karbala	28	4A	3	3
		4B	3	3
Karbala	28	5A	11	7
		5B	5	5
Karbala	28	6A	5	5
		6B	5	4
Karbala	28	7A	5	5
		7B	5	4

Table (D.1) Total number of sample units and The minimum sample units required for the section of study area(Continue).

Network ID	Branch ID	Section ID	Actual number of unit (N)	Minimum number of sample unit inspected (n)
Karbala	28	8A	4	4
		8B	4	4
	28	9A	2	2
		9B	9	6
Karbala	29	1A	7	5
	29	2A	11	7
	29	3A	2	2
	29	4A	3	3
	30	1A	8	5
	30	2A	8	6
	30	3A	3	3
	30	4A	18	9
	30	5A	11	7
	30	6A	3	3
	30	7A	13	8
	30	8A	5	5
Karbala	31	1A	13	8
	31	2A	3	3
		2B	3	3
	31	3A	10	7
	31	4A	10	7
	31	5A	9	6
	31	6A	6	5
	31	7A	5	5
	31	8A	4	4
Karbala	32	1A	15	8
		1B	15	8
	32	2A	18	9
	32	3A	9	4
	32	4A	8	5
		4B	8	4
	32	5A	7	5

Table (D.2) PAVER User Defined Reports of Last Condition for Study Area.

Network ID	Branch ID	Section ID	SURFACE	PCI	PCI Category	PCI Pct Climate	PCI Pct Load	PCI Pct Other
Karbala	15	1A	AC	66	Fair	51	36	13
Karbala	15	1B	AC	74	Satisfactory	19	50	31
Karbala	16	1A	AC	63	Fair	21	48	31
Karbala	17	1A	AC	71	Satisfactory	58	34	8
Karbala	17	1B	AC	76	Satisfactory	86	7	7
Karbala	18	1A	AC	87	Good	41	14	45
Karbala	18	1B	AC	84	Satisfactory	90	1	9
Karbala	19	1A	AC	70	Fair	32	34	34
Karbala	19	1B	AC	60	Fair	38	44	18

Table (D.2) PAVER User Defined Reports of Last Condition for Study Area (Continue).

Network ID	Branch ID	Section ID	SURFACE	PCI	PCI Category	PCI Pct Climate	PCI Pct Load	PCI Pct Other
Karbala	20	1A	AC	47	Poor	24	29	47
Karbala	20	1B	AC	55	Poor	14	37	49
Karbala	21	1A	AC	54	Poor	23	16	61
Karbala	21	1B	AC	52	Poor	20	27	53
Karbala	22	1A	AC	81	Satisfactory	28	21	51
Karbala	22	1B	AC	88	Good	9	27	64
Karbala	23	1A	APC	100	Good	0	0	0
Karbala	23	1B	APC	97	Good	100	0	0
Karbala	23_1	1A	APC	85	Satisfactory	65	0	35
Karbala	23_1	1B	APC	80	Satisfactory	100	0	0
Karbala	24	1A	APC	80	Satisfactory	65	25	10
Karbala	24	1B	APC	87	Good	16	51	33
Karbala	25	1A	APC	76	Satisfactory	34	66	0
Karbala	25	1B	APC	86	Good	30	70	0
Karbala	26	1A	APC	66	Fair	52	11	37
Karbala	26	1B	APC	69	Fair	47	38	15
Karbala	27	1A	AC	50	Poor	68	16	16
Karbala	28_1	1A	AC	98	Good	0	17	83
Karbala	28_1	1B	AC	97	Good	68	32	0
Karbala	28_2	1A	AC	94	Good	1	99	0
Karbala	28_2	1B	AC	96	Good	100	0	0
Karbala	28_3	1A	AC	91	Good	18	52	30
Karbala	28_3	1B	AC	94	Good	26	0	74
Karbala	28_4	1A	AC	93	Good	71	0	29
Karbala	28_4	1B	AC	90	Good	47	53	0
Karbala	28_5	1A	AC	97	Good	0	100	0
Karbala	28_5	1B	AC	98	Good	100	0	0
Karbala	28_6	1A	AC	94	Good	0	42	58
Karbala	28_6	1B	AC	85	Satisfactory	0	74	26
Karbala	28_7	1A	AC	97	Good	0	19	81
Karbala	28_7	1B	AC	93	Good	0	44	56
Karbala	28_8	1A	AC	86	Good	30	0	70
Karbala	28_8	1B	AC	83	Satisfactory	0	27	73
Karbala	28_9	1A	AC	83	Satisfactory	0	0	100
Karbala	28_9	1B	AC	68	Fair	20	32	48
Karbala	29_1	1A	AC	40	Very Poor	28	44	28
Karbala	29_2	1A	AC	36	Very Poor	36	29	35
Karbala	29_3	1A	AC	12	Serious	46	33	21
Karbala	29_4	1A	AC	16	Serious	39	36	25
Karbala	30_1	1A	AC	48	Poor	51	20	29
Karbala	30_2	1A	AC	27	Very Poor	46	20	34
Karbala	30_3	1A	AC	32	Very Poor	44	16	40
Karbala	30_4	1A	AC	49	Poor	42	18	40
Karbala	30_5	1A	AC	45	Poor	51	34	15
Karbala	30_6	1A	AC	46	Poor	30	36	34
Karbala	30_7	1A	AC	43	Poor	53	17	30
Karbala	30_8	1A	AC	43	Poor	36	28	36
Karbala	31_1	1A	AC	54	Poor	34	21	45

Table (D.2) PAVER User Defined Reports of Last Condition for Study Area (Continue).

Network ID	Branch ID	Section ID	SURFACE	PCI	PCI Category	PCI Pct Climate	PCI Pct Load	PCI Pct Other
Karbala	31_2	1A	AC	43	Poor	47	28	25
Karbala	31_2	1B	AC	48	Poor	50	12	38
Karbala	31_3	1A	AC	64	Fair	38	2	60
Karbala	31_3	1B	AC	100	Good	0	0	0
Karbala	31_4	1A	AC	53	Poor	59	8	33
Karbala	31_5	1A	AC	53	Poor	53	32	15
Karbala	31_6	1A	AC	43	Poor	51	32	17
Karbala	31_7	1A	AC	89	Good	67	0	33
Karbala	31_7	1B	AC	100	Good	0	0	0
Karbala	31_8	1A	AC	75	Satisfactory	72	18	10
Karbala	32_1	1A	AC	28	Very Poor	47	17	36
Karbala	32_1	1B	AC	76	Satisfactory	41	44	15
Karbala	32_2	1A	AC	42	Poor	42	17	41
Karbala	32_3	1A	AC	65	Fair	52	30	18
Karbala	32_4	1A	AC	75	Satisfactory	38	0	62
Karbala	32_4	1B	AC	76	Satisfactory	63	18	19
Karbala	32_5	1A	AC	58	Fair	38	15	47

Table (D.3) The Review Model Data for Zone of Study area

Age at Insp	PCI	Model	Difference	Status	Network ID	Branch ID	Section ID	Surface	Rank
0.25	100	100	0		Karbala	2	1B	APC	A
6.01	48	70	22		Karbala	14	1A	AC	C
7.01	71	67	-4		Karbala	17	1A	AC	C
8	66	66	0		Karbala	26	1A	APC	A
6.01	50	70	20		Karbala	27	1A	AC	C
7.79	55	66	11		Karbala	1	1	AC	A
8.29	86	66	-20		Karbala	1	A	AC	A
8.29	85	66	-19		Karbala	1	B	AC	A
2.21	97	91	-6		Karbala	10	1A	AC	A
2.21	91	91	0		Karbala	10	1B	AC	A
2.21	93	91	-2		Karbala	11	1A	AC	A
2.21	87	91	4		Karbala	11	1B	AC	A
6	94	70	-24		Karbala	12	1A	APC	A
6	95	70	-25	Out of Bounds	Karbala	12	1B	APC	A
6.21	80	69	-11		Karbala	12-1	1A	AC	A
6.17	80	69	-11		Karbala	12-1	1B	AC	A
7.54	76	67	-9		Karbala	13	1A	AC	B
7.5	68	67	-1		Karbala	13	1B	AC	B
9.01	66	66	0		Karbala	15	1A	AC	B
9.01	74	66	-8		Karbala	15	1B	AC	B
4.01	63	79	16		Karbala	16	1A	AC	C
7.01	76	67	-9		Karbala	17	1B	AC	C
4.01	87	79	-8		Karbala	18	1A	AC	C
4.01	84	79	-5		Karbala	18	1B	AC	C
10.01	70	66	-4		Karbala	19	1A	AC	B
10.01	60	66	6		Karbala	19	1B	AC	B

Table (D.3) The Review Model Data for Zone of Study area (continue).

Age at Insp	PCI	Model	Difference	Status	Network ID	Branch ID	Section ID	Surface	Rank
3.28	72	83	11		Karbala	2	1B	APC	A
10.01	47	66	19		Karbala	20	1A	AC	B
10.01	55	66	11		Karbala	20	1B	AC	B
10.01	54	66	12		Karbala	21	1A	AC	B
10.01	52	66	14		Karbala	21	1B	AC	B
10.01	81	66	-15		Karbala	22	1A	AC	B
10.01	88	66	-22		Karbala	22	1B	AC	B
3.01	100	85	-15	Out of Bounds	Karbala	23	1A	APC	B
4.01	97	79	-18		Karbala	23	1B	APC	B
3.84	85	80	-5		Karbala	23-1	1A	APC	B
4.01	80	79	-1		Karbala	23-1	1B	APC	B
4.01	80	79	-1		Karbala	24	1A	APC	B
4.01	87	79	-8		Karbala	24	1B	APC	B
8.05	76	66	-10		Karbala	25	1A	APC	A
8.01	86	66	-20		Karbala	25	1B	APC	A
7.84	69	66	-3		Karbala	26	1B	APC	A
3.01	98	85	-13		Karbala	28-1	1A	AC	E
3.01	97	85	-12		Karbala	28-1	1B	AC	E
3.01	94	85	-9		Karbala	28-2	1A	AC	E
3.01	96	85	-11		Karbala	28-2	1B	AC	E
3.01	91	85	-6		Karbala	28-3	1A	AC	E
3.01	94	85	-9		Karbala	28-3	1B	AC	E
3.01	93	85	-8		Karbala	28-4	1A	AC	E
3.01	90	85	-5		Karbala	28-4	1B	AC	E
3.01	97	85	-12		Karbala	28-5	1A	AC	E
3.01	98	85	-13		Karbala	28-5	1B	AC	E
3.01	94	85	-9		Karbala	28-6	1A	AC	E
3.01	85	85	0		Karbala	28-6	1B	AC	E
3.01	97	85	-12		Karbala	28-7	1A	AC	E
3.01	93	85	-8		Karbala	28-7	1B	AC	E
3.01	86	85	-1		Karbala	28-8	1A	AC	E
3.01	83	85	2		Karbala	28-8	1B	AC	E
3.01	83	85	2		Karbala	28-9	1A	AC	E
3.01	68	85	17		Karbala	28-9	1B	AC	E
6.01	40	70	30		Karbala	29-1	1A	AC	E
6.01	36	70	34	Outlier	Karbala	29-2	1A	AC	E
6.01	12	70	58	Outlier	Karbala	29-3	1A	AC	E
6.01	16	70	54	Outlier	Karbala	29-4	1A	AC	E
2.01	100	92	-8		Karbala	3	10A	APC	A
2.01	100	92	-8		Karbala	3	10B	APC	A
2.01	98	92	-6		Karbala	3	1A	APC	A
2.01	100	92	-8		Karbala	3	1B	APC	A
2.03	90	92	2		Karbala	3-1	1A	AC	A
0.01	98	100	2		Karbala	3-1	1B	AC	A
14.01	60	58	-2		Karbala	4	1A	AC	A
14.01	46	58	12		Karbala	4	1B	AC	A
3.01	77	85	8		Karbala	5	1B	AC	C
0.01	80	100	20	Out of Bounds	Karbala	5	1A	AC	C
3.04	85	85	0		Karbala	6	1A	AC	C

Table (D.3) The Review Model Data for Zone of Study area (continue).

Age at Insp	PCI	Model	Difference	Status	Network ID	Branch ID	Section ID	Surface	Rank
3.04	82	85	3		Karbala	6	1B	AC	C
3.04	73	85	12		Karbala	7	1A	AC	C
3.01	70	85	15		Karbala	7	1B	AC	C
3.1	86	85	-1		Karbala	8	1A	APC	A
3.01	90	85	-5		Karbala	8	1B	APC	A
3.05	90	85	-5		Karbala	9	1A	APC	A
3.05	85	85	0		Karbala	9	1B	APC	A
3.05	85	85	0		Karbala	9	1C	APC	A
18.02	48	42	-6		Karbala	30-1	1A	AC	E
18.02	27	42	15		Karbala	30-2	1A	AC	E
18.02	32	42	10		Karbala	30-3	1A	AC	E
18.02	49	42	-7		Karbala	30-4	1A	AC	E
18.02	45	42	-3		Karbala	30-5	1A	AC	E
18.02	46	42	-4		Karbala	30-6	1A	AC	E
18.02	43	42	-1		Karbala	30-7	1A	AC	E
18.02	43	42	-1		Karbala	30-8	1A	AC	E
4.26	54	77	23		Karbala	31-1	1A	AC	E
4.29	43	77	34	Outlier	Karbala	31-2	1A	AC	E
4.29	48	77	29		Karbala	31-2	1B	AC	E
4.26	64	77	13		Karbala	31-3	1A	AC	E
4.26	53	77	24		Karbala	31-4	1A	AC	E
4.26	53	77	24		Karbala	31-5	1A	AC	E
4.26	43	77	34	Outlier	Karbala	31-6	1A	AC	E
4.26	89	77	-12		Karbala	31-7	1A	AC	E
4	75	79	4		Karbala	31-8	1A	AC	C
16.26	28	47	19		Karbala	32-1	1A	AC	E
8.27	42	66	24		Karbala	32-2	1A	AC	E
8.27	65	66	1		Karbala	32-3	1A	AC	E
8.27	75	66	-9		Karbala	32-4	1A	AC	E
8.27	76	66	-10		Karbala	32-4	1B	AC	E
8.27	58	66	8		Karbala	32-5	1A	AC	E
8	50	66	16		Karbala	2	1A	APC	A
16.05	76	48	-28		Karbala	32-1	1B	AC	E

APPENDIX E

Statistical Analysis Results of Develop Models

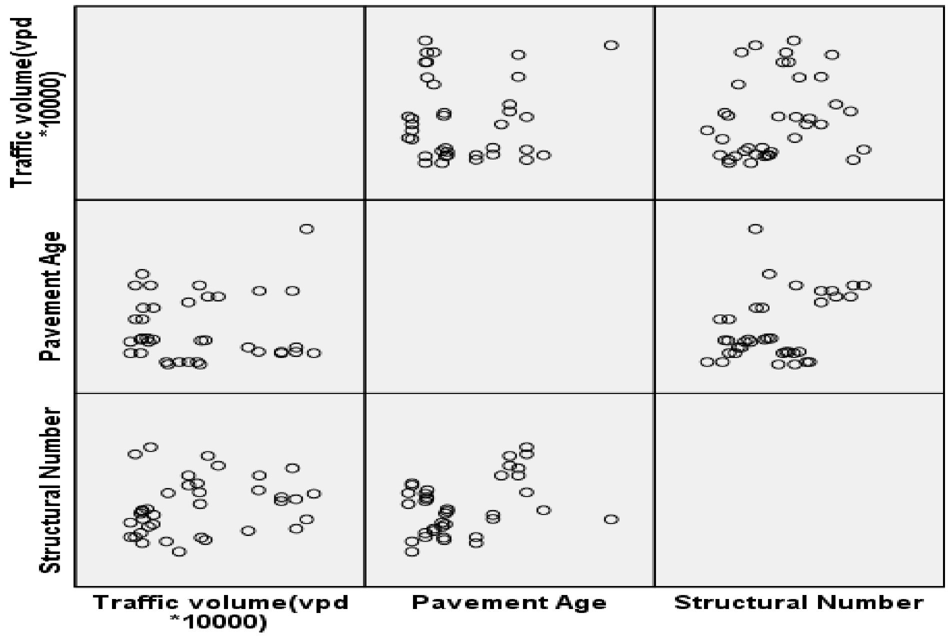


Figure (E-1A) scatter plot show the Correlation Between the Independent Variable of the First Developed Model for the Selected Roadway in Karbala City.

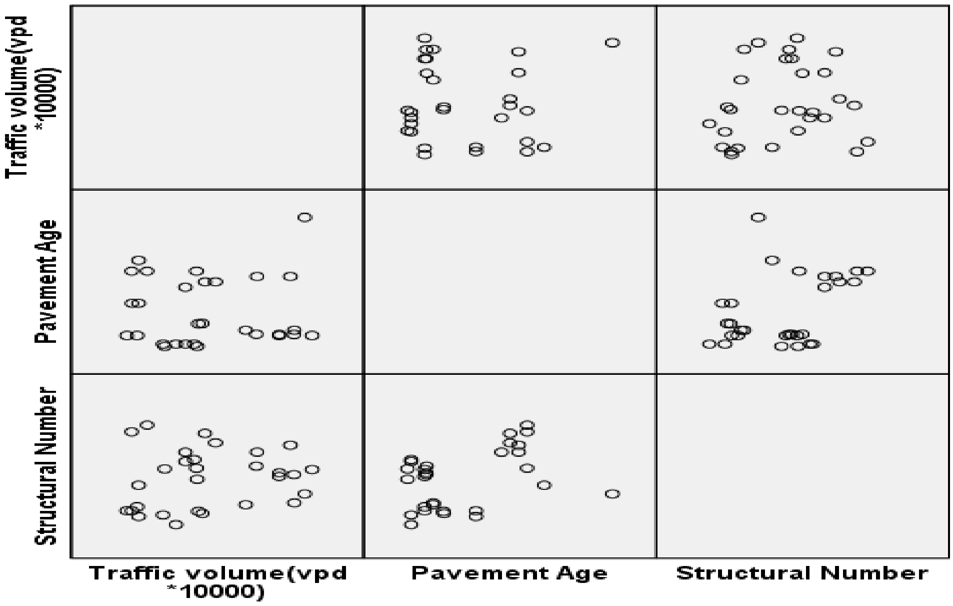


Figure (E-1B) scatter plot show the Correlation Between the Independent Variable of the Second Developed Model for the Selected Roadway in Karbala City.

Table (E.1) Statistical Analysis Layout for the first developed model (CI_1)

A- Curve Fit between PCI and ADT

A.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	213037.800	1	213037.800	193.177	.000
Residual	39701.200	36	1102.811		
Total	252739.000	37			

The independent variable is Traffic volume(vpd *10000).[a]

a. The equation was estimated without the constant term.

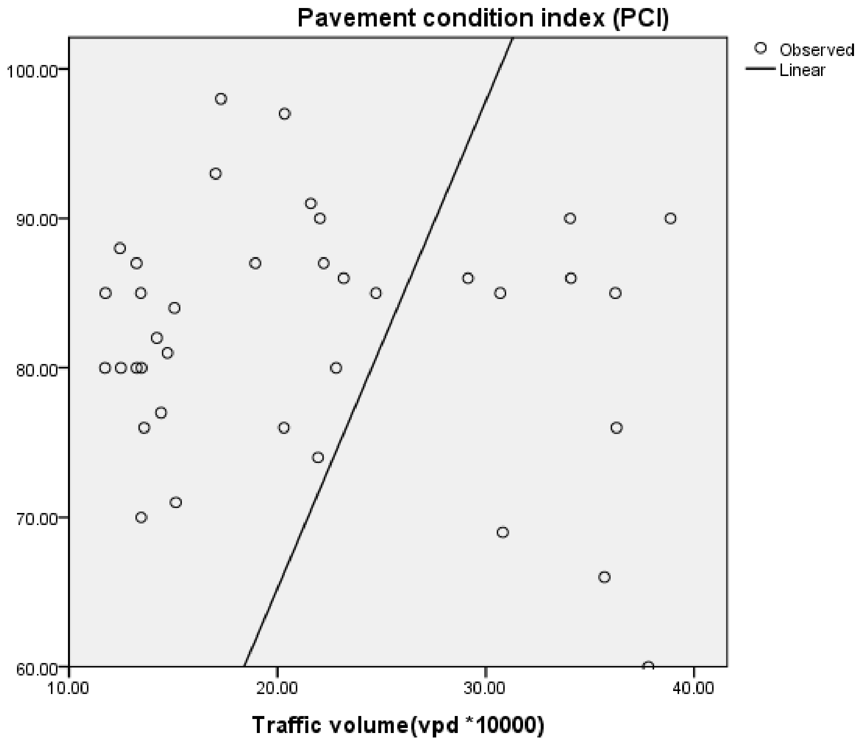


Figure (E-A.2) Linear Curve for PCI with ADT

B-Curve Fit between PCI and Age

B.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	177283.302	1	177283.302	84.582	.000
Residual	75455.698	36	2095.992		
Total	252739.000	37			

The independent variable is Pavement Age.[a]

a. The equation was estimated without the constant term.

Figure (E-B.2) Linear Curve for PCI with Age

C-Curve Fit between PCI and SN

C.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	240385.616	1	240385.616	700.527	.000
Residual	12353.384	36	343.150		
Total	252739.000	37			

The independent variable is Structural Number.[a]

a. The equation was estimated without the constant term.

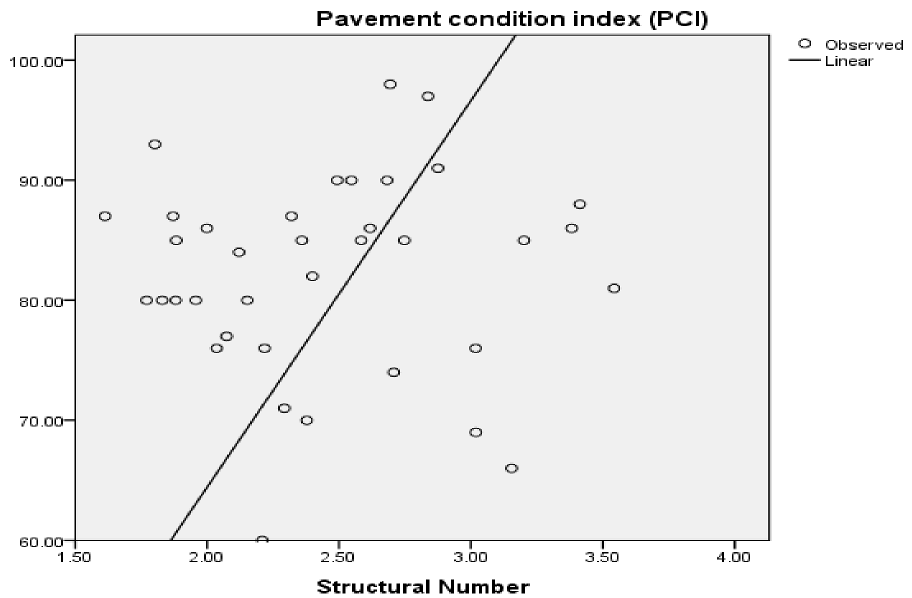


Figure (E-C.2) Linear Curve for PCI with ADT

D. outliner boundary for first develop model.

Extreme Values

			Case Number	Value
Pavement condition index (PCI)	Highest	1	4	98.00
		2	15	97.00
		3	17	93.00
		4	16	91.00
		5	3	90.00[a]
	Lowest	1	5	60.00
		2	36	66.00
		3	37	69.00
		4	27	70.00
		5	23	71.00
Pavement Age	Highest	1	5	14.00
		2	27	10.00
		3	22	9.00
		4	28	9.00
		5	29	9.00
	Lowest	1	4	2.00
		2	3	2.00
		3	18	2.21
		4	17	2.21
		5	16	2.21[b]
Traffic volume(vpd *10000)	Highest	1	11	38.87
		2	5	37.80
		3	34	36.27
		4	13	36.21
		5	36	35.69
	Lowest	1	6	11.73
		2	30	11.75
		3	29	12.44
		4	20	12.49
		5	25	13.24
Structural Number	Highest	1	28	3.54
		2	29	3.41
		3	1	3.38
		4	2	3.20
		5	36	3.15
	Lowest	1	18	1.61
		2	19	1.77
		3	17	1.80
		4	32	1.83
		5	33	1.87

a. Only a partial list of cases with the value 90.00 are shown in the table of upper extremes.

b. Only a partial list of cases with the value 2.21 are shown in the table of lower extremes.

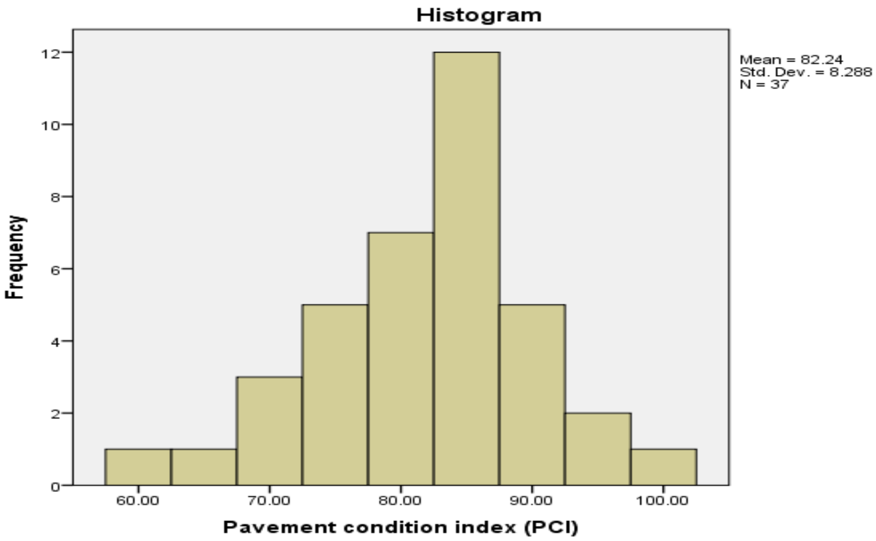


Figure (D.1)frequency distribution histogram for pavement condition index of first model

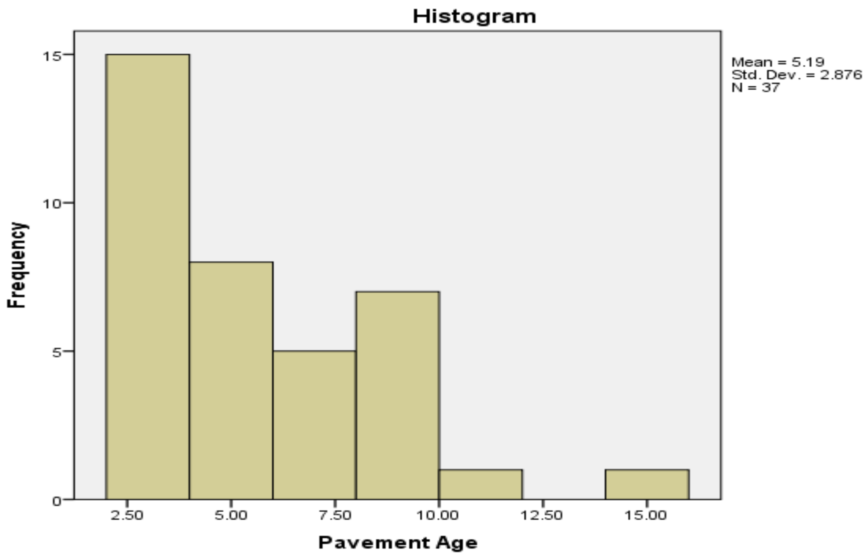


Figure (D.2)frequency distribution histogram pavement age of first model

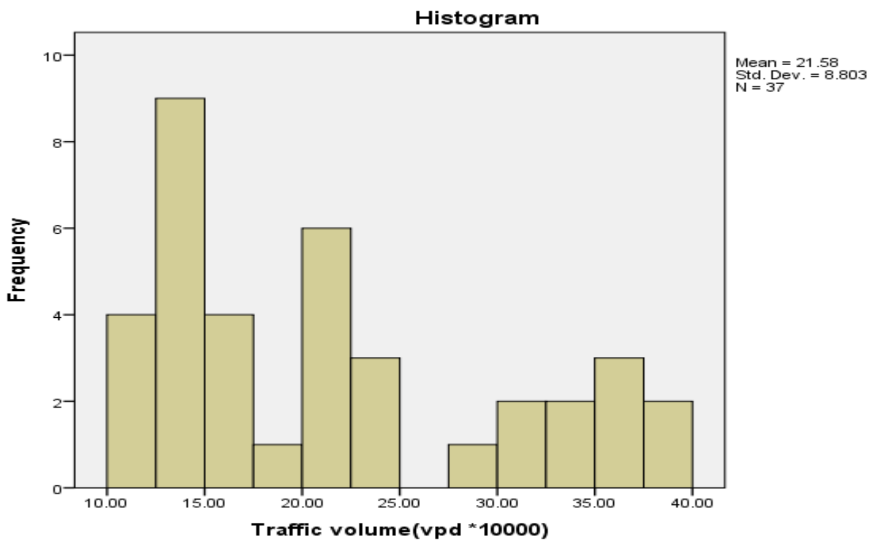


Figure (D.3)frequency distribution histogram traffic volume of first model

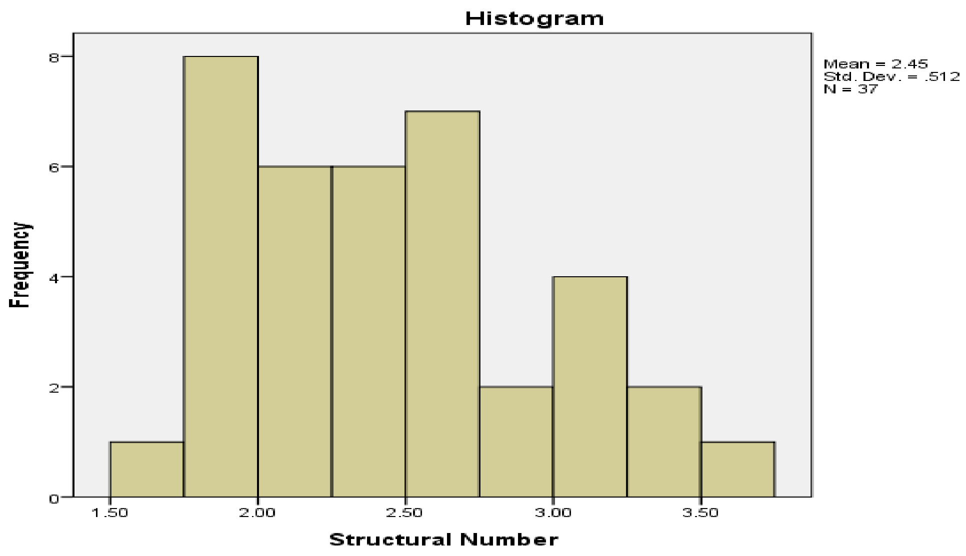


Figure (D.4)frequency distribution histogram for structural number of first model

F. Regression Analysis Layout for the first developed model (CI_1)

F.1 Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Structural Number , Traffic volume(vpd *10000), Pavement Age[b]	.	Enter

a. Dependent Variable: Pavement condition

b. All requested variables entered.

F.2 Coefficients

Model		95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	74.957	90.384					
	Traffic volume(vpd *10000)	-.368	-.003	-.137	-.339	-.192	.945	1.058
	Pavement Age	-3.197	-2. 018	-.748	-.843	-.833	.848	1.179
	Sutractural Number	3.486	10.285	.031	.538	.382	.806	1.241

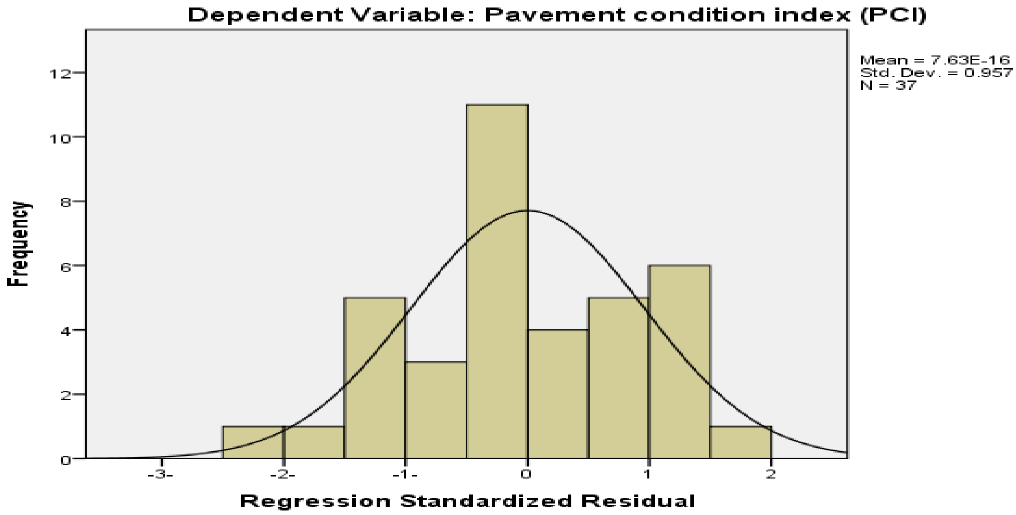


Figure (F-D.3) Histogram

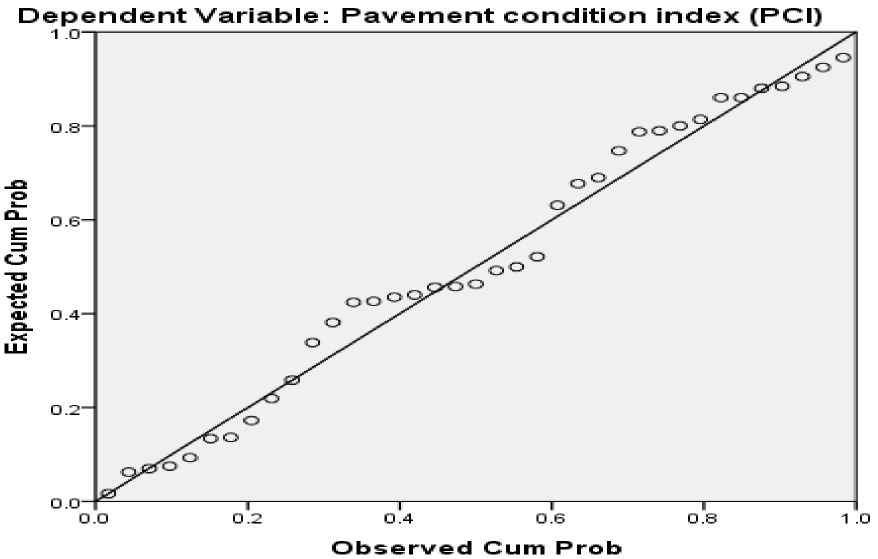


Figure (F-D.4) Normal P-P Plot of Regression Standardized Residual

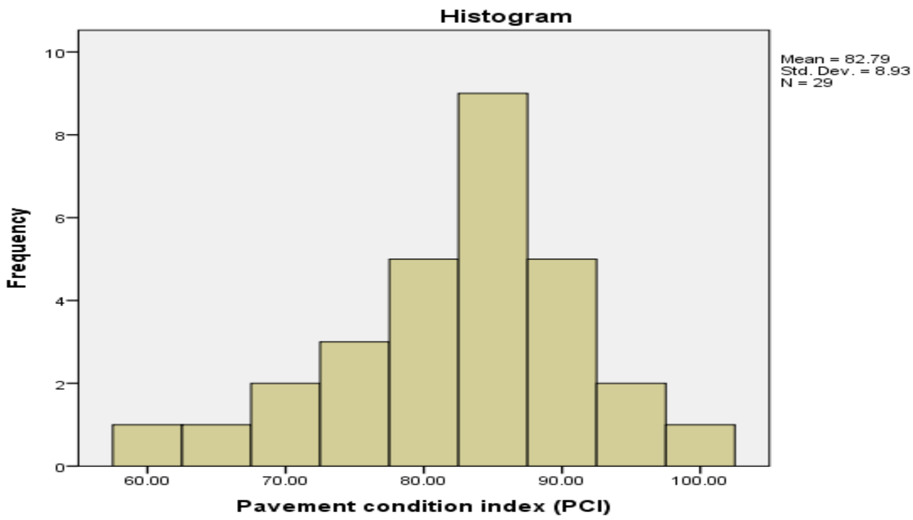


Figure (F.1)frequency distribution histogram for pavement condition index of second model

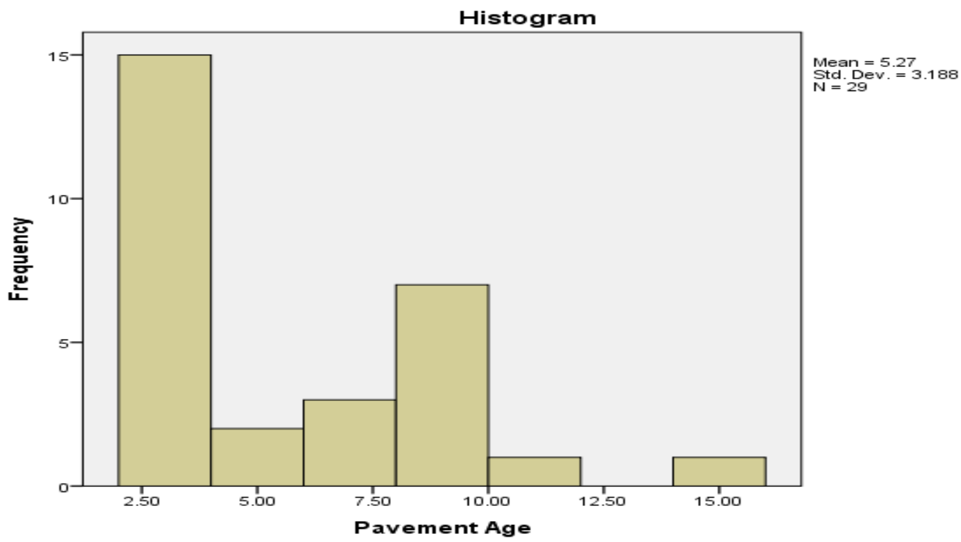


Figure (F.2)frequency distribution histogram pavement age of second model

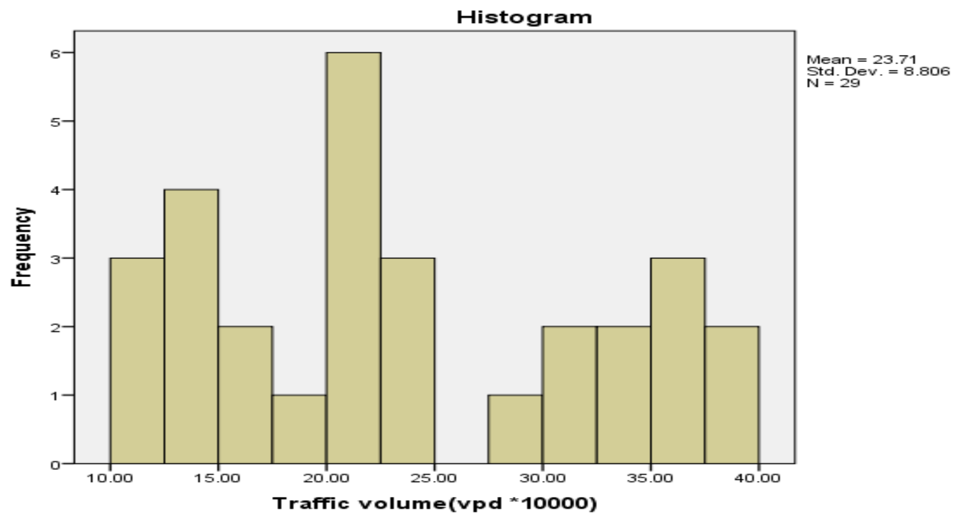


Figure (F.3)frequency distribution histogram traffic volume of second model

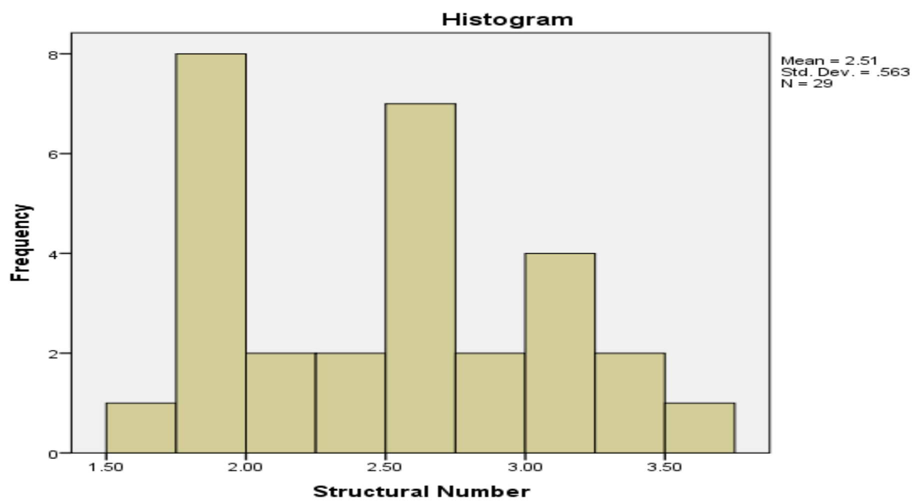


Figure (F.4)frequency distribution histogram for structural number of second model

G. outliner boundary for first develop model.

Extreme Values

			Case Number	Value
Traffic volume(vpd *10000)	Highest	1	7	38.87
		2	5	37.80
		3	26	36.27
		4	9	36.21
		5	28	35.69
	Lowest	1	22	11.75
		2	21	12.44
		3	16	12.49
		4	23	13.25
		5	19	13.46
Pavement Age	Highest	1	5	14.00
		2	19	10.00
		3	18	9.00
		4	20	9.00
		5	21	9.00
	Lowest	1	4	2.00
		2	3	2.00
		3	14	2.21
		4	13	2.21
		5	12	2.21[a]
Structural Number	Highest	1	20	3.54
		2	21	3.41
		3	1	3.38
		4	2	3.20
		5	28	3.15
	Lowest	1	14	1.61
		2	15	1.77
		3	13	1.80
		4	24	1.83
		5	25	1.87
Pavement condition index (PCI)	Highest	1	4	98.00
		2	11	97.00
		3	13	93.00
		4	12	91.00
		5	3	90.00[b]
	Lowest	1	5	60.00
		2	28	66.00
		3	29	69.00
		4	19	70.00
		5	18	74.00

a. Only a partial list of cases with the value 2.21 are shown in the table of lower extremes.

b. Only a partial list of cases with the value 90.00 are shown in the table of upper extremes.

Table (G.2) Statistical Analysis Layout for the Second Developed model CI_2

A- Curve Fit between PCI and ADT

A.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	172327.870	1	172327.870	168.177	.000
Residual	28691.130	28	1024.683		
Total	201019.000	29			

The independent variable is Traffic volume(vpd *10000).[a]

a. The equation was estimated without the constant term.

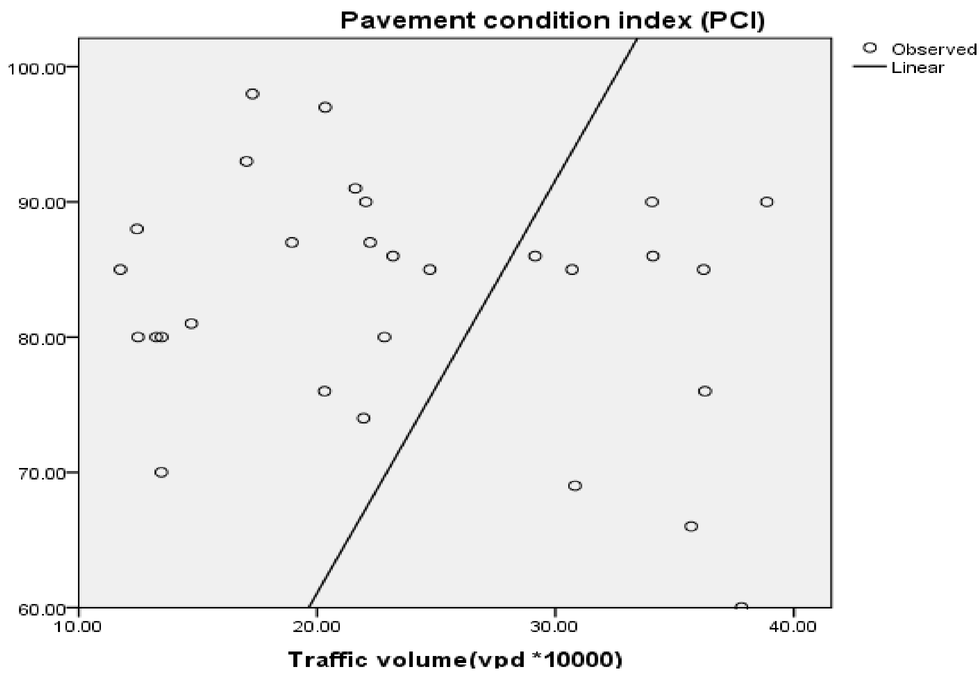


Figure (G-A.2) Linear Curve for PCI with ADT

B-Curve Fit between PCI and Age

B.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	133054.675	1	133054.675	54.816	.000
Residual	67964.325	28	2427.297		
Total	201019.000	29			

The independent variable is Pavement Age.[a]

a. The equation was estimated without the constant term.

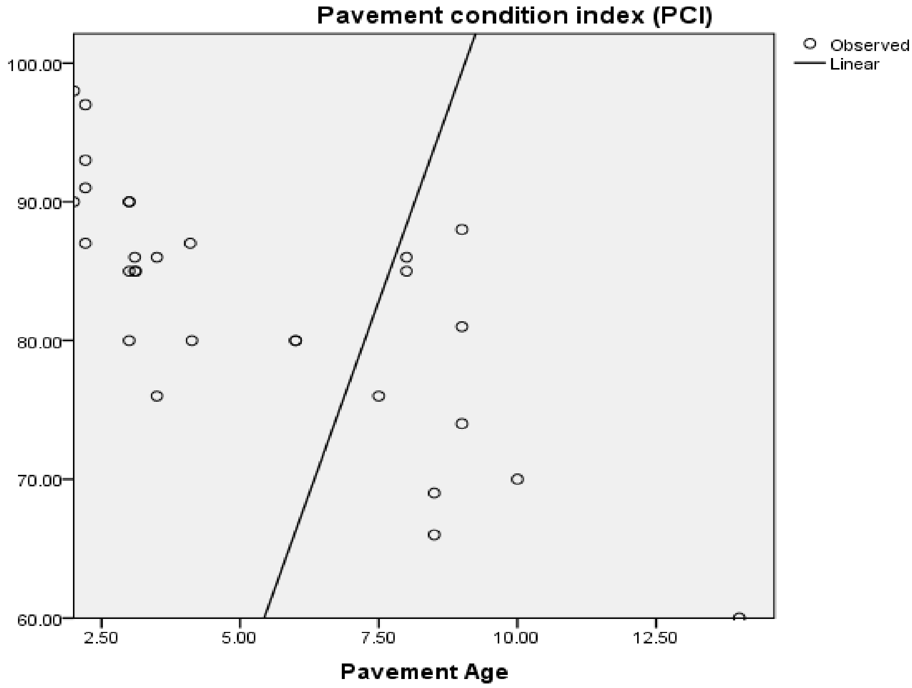


Figure (G-B.2) Linear Curve for PCI with Age

C-Curve Fit between PCI and SN

C.1 ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	189517.718	1	189517.718	461.383	.000
Residual	11501.282	28	410.760		
Total	201019.000	29			

The independent variable is Structural Number.[a]

a. The equation was estimated without the constant term.

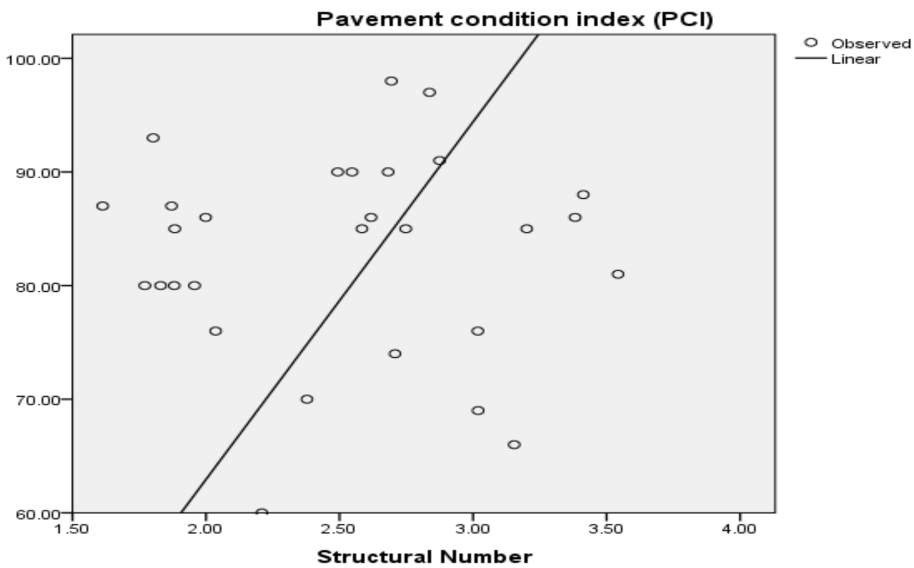


Figure (G-C.2) Linear Curve for PCI with ADT

D- Regression Analysis Layout for the Second Developed Model CI_2

D.1 Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Structural Number, Traffic volume(vpd *10000), Pavement Age[b]	.	Enter

a. Dependent Variable: Pavement condition

b. All requested variables entered.

D.2 Coefficients

Model		95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	78.409	96.137					
	Traffic volume(vpd *10000)	-.484	-.076	-.229	-.492	-.273	.976	1.025
	Pavement Age	-3.180	-1.968	-.768	-.868	-.845	.845	1.183
	Struactural Number	2.799	9.733	-.005	.597	.359	.827	1.210

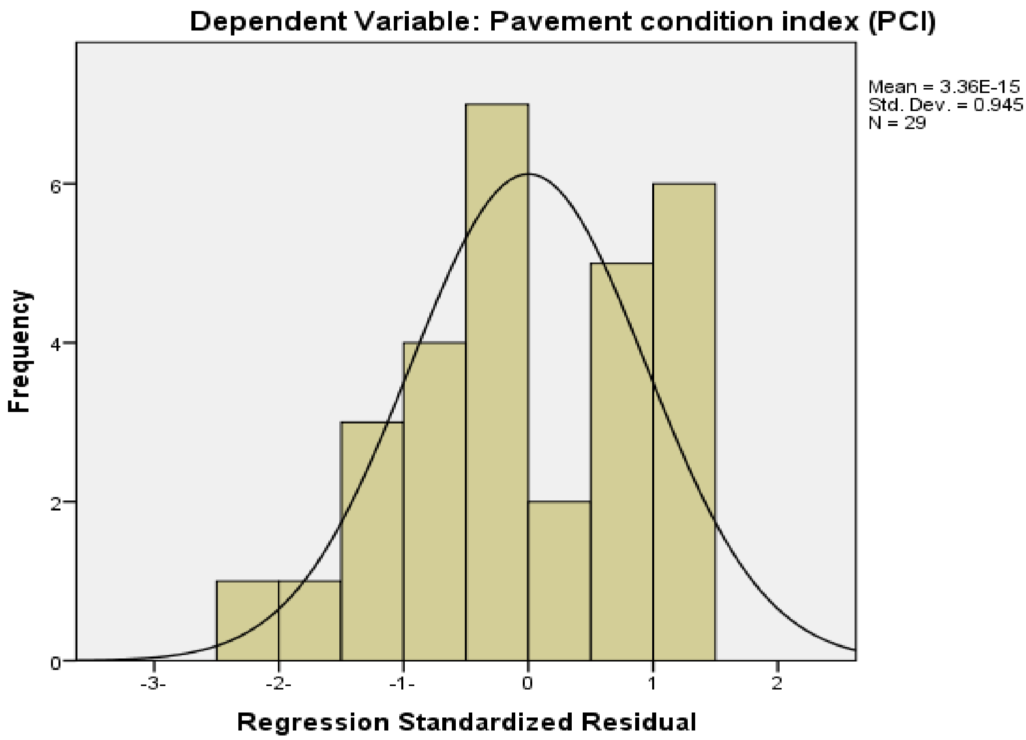


Figure (D.3) Histogram.

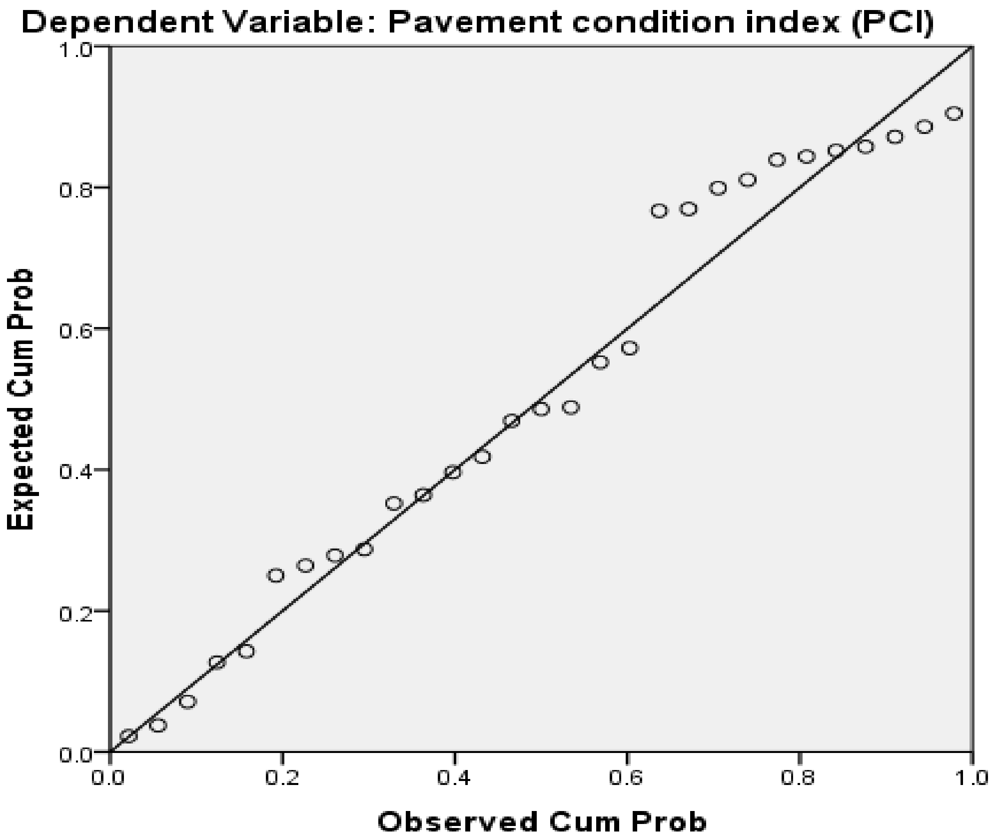


Figure (D.4) Normal P-P Plot of Regression Standardized Residual

Statistical Analysis of Irrespective Weight

Statistical analysis is made for 35 questionnaire samples as show in Figure (E-3.1). Three questionnaire samples are excluded and repeat the test as show in Figure (F-3.2).

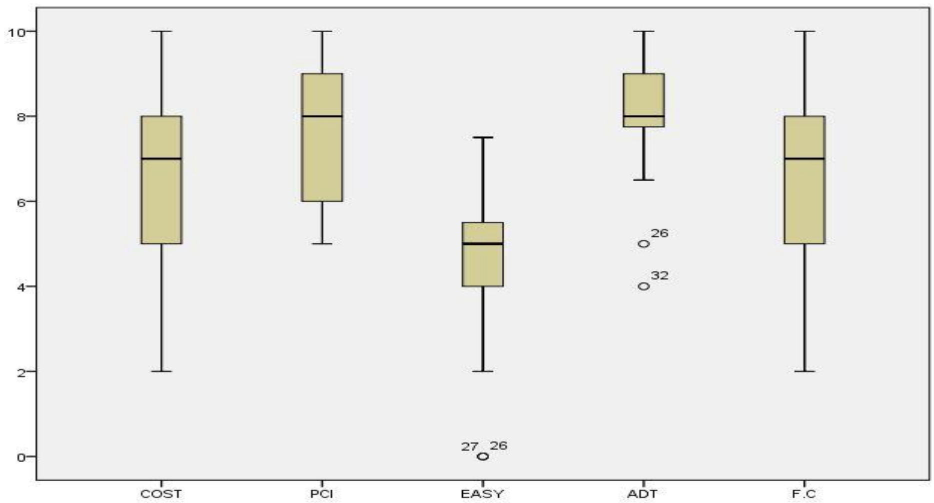


Figure (E-3.1) Statistical Analysis is Made for 35 Questionnaire Samples.

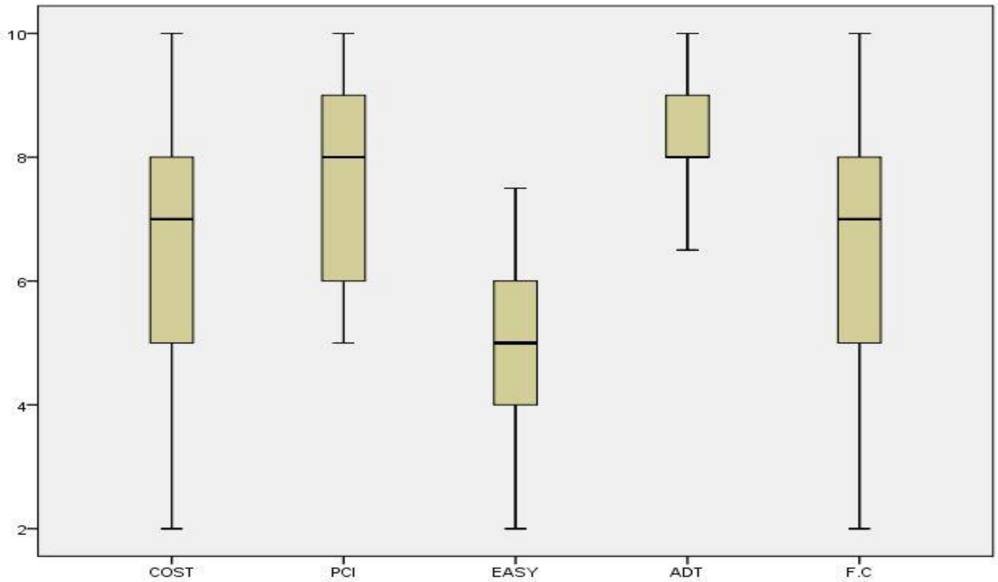


Figure (E-3.2) Statistical Analysis is Made for 32 Questionnaire Samples

Check Sample Size

The equation of sample size as shown below:

$N= (S\,Z\,/E)^2$ .... (1)

For 95% degree of confidences and acceptable error of ±1 with std. deviation , depended on eq. (1) the sample size determined as shown in Table (F-3.3).

Table (E-3.3) Descriptive Statistics and sample size.

	N	Mean	Std. Deviation	sample size
COST	32	6.39	2.105	17
PCI	32	7.61	1.684	11
EASY	32	5.00	1.289	7
ADT	32	8.34	.979	2
F.C	32	6.88	2.000	15
Valid N (listwise)	32			

APPENDIX F

MATLAB R2015a

This appendix shows develop special program to accomplish the calculations which is the most efficient and effective application for this way. MATLAB R2015a is developed to determine the priority of section roads.

I. Main Program:

```
clc;
clear;
close all;

Filename = 'Info.xlsx';          %% FIle name of Data.

[ ID, Sec, Cost, Benefit, n ] = Readfile( Filename );

N_ID = ID;

Rank = zeros(n,1);

max_ID = zeros(n,1);

max_g = zeros(n,1);

for i=1:n

    [ m_ID, m_g ] = ith_trial( N_ID, Cost, Benefit );

    [ N_ID ] = Final( m_ID, N_ID );

    Rank(i,1) = i;

    max_ID(i,1) = m_ID;

    max_g(i,1) = m_g;

    Section(i,1) = Sec(m_ID);

end
```

```
%    xlswrite('Result.xlsx','Rank',1,'A1')
%    xlswrite('Result.xlsx','Section',1,'B1')
%    xlswrite('Result.xlsx','Repeat',1,'C1')
   xlswrite('Result.xlsx',Rank,1,'A2')
   xlswrite('Result.xlsx',Section,1,'B2')
   xlswrite('Result.xlsx',max_g,1,'C2')
```

II. Read File Program:

```
%   Detailed explanation goes here

        [num,txt] = xlsread(Filename);    %% Read file Excel for information.

         Cost = num(:,1);                      %% Cost of section I.D./m2.

         Benefit = num(:,2);                %% PCI Benefit.

         Sec_int = txt(:,1);                   %% Name of Section procedure.

         n = length(Cost);                  %% Numbers of Section (alternatives).

         len = length(Sec_int);             %%

         Section = Sec_int(3:len);          %% Name of Section

         id = 1:n;                        %% ID of Scetion

         ID = reshape(id,n,1);              %% ID of Scetion
end
```

الخلاصة

تواجه مدينة كربلاء المقدسة تحديا كبيرا بسبب التدهور الكبير في البنية التحتية لشبكة الطرق. تؤدي طريقة الإدارة غير السليمة (إن وجدت) إلى زيادة التدهور . هذه الدراسة، تهدف الى استحداث نظام أسبقيات مرشد في نظام إدارة صيانة رصفات الطرق (PMMS) على مستوى الشبكة.

استخدم برنامج (6.5.7) PAVER لحساب قيم ال (PCI) لمنطقة مختارة من شبكة الطرق في مدينة كربلاء. تم إجراء المسح البصري للتحقق من نوع ومستوى الخطورة ومدى الفشل في مقاطع ووحدات العينة المختارة من الطرق. ويبلغ طول المنطقة قيد الدراسة ٥٦,٨ كيلومترا متضمنة كل الأنواع الوظيفية تقريبا للطرق الحضرية. تحقق جمع البيانات لعدد (١٠٩) من مقاطع الطرق متضمنة: 20 مقطع شرياني رئيسي، ٢٨مقطع شرياني ثانوي، ١٤مقطع تجميعي، و مقطع ٤٧ مقطع محلي. وعلاوة على ذلك، قد تم جمع البيانات لكل مقطع من مقاطع الطرق وتقييمها باستخدام برنامج (6.5.7) PAVER. كذالك، فقد تم احتساب مؤشر حاله ألرصفه (PCI) لمقاطع مختلفة وإيجادها لأعمار تصميمية مختلفة وتطوير نموذج إحصائي للتنبؤ بحاله ألرصفه. تم ربط نظم المعلومات الجغرافية (GIS) مع برنامج (6.5.7) PAVER لإخراج النتائج و إظهار اسبقيه الصيانة وإعادة التأهيل للشبكة بأكملها والتي تمت باستخدام قيم (PCI) الحرجة.

فظلا عن مؤشر الأسبقيات البسيطة المعتمدة على قيمه (PCI) الناتجة من مخرجات برنامج (6.5.7) PAVER، تقدم الدراسة مؤشرات أخرى لكل مقطع من مقاطع الطريق. الأول، مؤشر اسبقيه الصيانة (MPI) والذي يعتمد على عوامل متعددة تم التحقيق فيها من خلال معرفة الخبراء حول العوامل التي تؤثر على تحديد الأولويات وأوزانها باعتماد على الاستبيان المصمم مسبقا. ويرتبط MPI بعوامل متعدد منها؛ التكلفة المناسبة للصيانة المقترحة، سهولة الصيانة المقترحة، متوسط الحركة اليومية والتصنيف الوظيفي للطريق بالإضافة إلى مؤشر حاله الرصيف (PCI). الثاني، مؤشر الأسبقيات التكميلي للفوائد والتكاليف (BCR) والذي يوفر عملية الترتيب المثلى نظرا للاستفادة وتكلفة الصيانة.

تقدم الدراسة عرضا فعالا للإخراج والترتيب للمنطقة المختارة من نظام شبكه الطرق على أساس مؤشر (MPI) وطريقة (BCR) الإضافية. لكن الاختبار الإحصائي يظهر أنه لا يوجد فرق كبير بين ترتيب جميع أساليب تحديد الأولويات. الطرق المستحدثة يمكن استخدامها كامتداد لطريقه المعتمدة على قيمه PCI.

بالاضافه إلى ذلك، فإن الموديل الإحصائي المطور لل PCI تبين أن ٧٠٪ من التباين في PCI يمكن تفسيرها من خلال نموذج الانحدار المتعدد فيما يتعلق (العمر، متوسط الحركة اليومية، ورقم الهيكل (SN)) وأظهرت الدراسة أن ٣٥٪ من مقاطع الطرق في منطقة الدراسة المختارة لها حالة جيدة (PCI = (٨٥-١٠٠))، ٢٦,٥٪ لها حالة مرضية (PCI = (٧٠-٨٥))، ١٢٪ لها حالة عادلة (PCI = (٥٥-٧٠))، ١٨٪ لها حالة سيئة (PCI = (٤٠-٥٥))))، ٦,٥٪ لها سيئة للغاية (PCI = (٢٥-٤٠))، ٢٪ لها حالة خطيرة (PCI = (١٠-٢٥))، و٠٪ لها حالة فاشلة = (٠-١٠)).

ويمكن استنتاج أن الطريقتان المطورتان لتحديد الأولويات لمنطقه الدراسة يمكن استخدامها بنجاح بالإضافة إلى طريقه الترتيب البسيط من برنامج PAVER. أيضا، الموديلات المطورة لPCI قدمت علاقة جيدة مع كل من المتغيرات المستقلة؛ العمر، متوسط الحركة اليومية ورقم الهيكل، ويمكن استخدامها لتقدير حالة رصف الطرق.

جمهوريه العراق

وزاره التعليم العالي والبحث العلمي

جامعه كربلاء

كليه الهندسه / قسم الهندسه المدنيه

تطوير برنامج أولوية لنظام أداره صيانة الطرق

رسالة مقدمه إلى

قسم الهندسة المدنية/ كليه الهندسة في جامعه كربلاء كجزء من متطلبات نيل

درجه الماجستير في علوم الهندسة المدنية / اختصاص هندسة البنى التحتية

من قبل

سجى جاسم محمد الاسدي

(بكالوريوس هندسه مدنيه ٢٠١٤)

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