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Faculty of Graduate Studies

Design of an Integrated Pavement Management Systems with Geographic Information Systems

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Dedication

This thesis is dedicated to my dear parents and my wife who have encouraged and supported me. Also, to my great family and friends.

Acknowledgment

First of all, I am thankful to the almighty God for granting me good health, strength and peace throughout the research period.

I would like to thank everyone who has contributed to accomplishing this thesis, especially the surveying teams.

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الإقرار

انا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Design of an Integrated Pavement Management System with Geographic Information Systems

اقر بأن ما اشـتملت عليه هذه الرسـالة إنما في نتاج جهدي الخاص، باسـتثناء ما تمت الإشـارة إليه حيثما ورد، وأن هذه الرســالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثيه اخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the Researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **إسم الطالب: ربيع حسام رباية**

Signature: **التوقيع:**

Date: **التاريخ: 2018/9/12**

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List of Abbreviations

AC	Asphalt Concrete
APWA	American Public Works Association
ASTM	American Society for Testing and Materials
DOTD	Louisiana Department of Transportation and Development
DV	Deduct Values
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
ID	Identification
M&R	Maintenance and Rehabilitation
PCI	Pavement Condition Index
PMS	Pavement Management System
PI	Priority Index
VB	Visual Basic Language
TxDOT	Texas Department of Transportation
US	United States
USA	United States of America

Design of an Integrated Pavement Management Systems with Geographic Information Systems

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Abstract

Palestinian road and transportation agencies are facing a monumental challenge in dealing with aging infrastructure. For pavements in particular, it is found that many streets were built 20 or 30 years ago and they are near the end of their economic life. Other streets have been deteriorated because of misuse, overuse and mismanagement. In addition, present and future threats affect the hoped mission of these pavements for rapid, safe and comfort movements of people and goods. Moreover, the current management reveals that the system used is not flexible enough to reflect the changing conditions and poor to assist in making decisions.

This study aims to Design an Integrated Pavement Management Systems with Geographic Information Systems (PMS-GIS). The PMS-GIS provides a systematic process of maintaining, upgrading and operating road pavements. The system also comprises a set of tools to facilitate a more flexible approach that will enable the users to perform tasks more economically, effectively and of higher quality.

The PMS-GIS is presented to facilitate the decision-making process. It is based on the direct integration between pavement management system

(PMS) database accommodated in Microsoft Excel and GIS software in order to fully exploit the capabilities of each individual package. Also, a simple Graphical User-friendly Interface (GUI) has been developed to help the users present PMS results in more understandable way.

The PMS-GIS model was tested by a case study in which the system was fed by 15 km of paved roads from Rafidia Neighborhood in Nablus City. Finally, condition and prioritization analyses were successfully performed to determine ranking for maintenance needs.

Chapter One

Introduction

Pavement represents a critical component of the highway transportation infrastructure. Huge budgets are dedicated annually for maintaining and rehabilitating deteriorate pavements. Deteriorating pavement conditions due to increasing traffic loads and limited funds represents a complex challenge for pavement maintenance and rehabilitation activities. Detecting the pavement failure in early stages leads to avoid future-sever failure and minimize the maintenance cost.

Pavement Management System (PMS) is a tool or systematic method that can provide an inclusive inventory for pavement network and organize the work with saving time and effort. The system also provides the data that refer to the current condition of the pavement network with the ability to store the historical data which helps to predict the future pavement condition. In addition, the system can evaluate the pavements and find out a desirable maintenance needs with priorities under the available funds (Shahin, 2005).

1.1 Background

A perfect maintenance scheme on road networks is one that keeps all sections at a sufficiently high level of functional and structural condition (Agarwal et al., 2004). Due to the increasing traffic on roads, a timely repair that is often critical is constrained by time, budget and other resource availability such as manpower and equipment. This makes a priority ranking scheme for the selection and scheduling of pavement sections for maintenance an essential dimension for study, and an integral part of pavement maintenance management systems (Fwa and Chan, 1993).

According to Kulkarni and Miller (2002), in the early 1970s, pavement maintenance management systems (PMMSs) were introduced and they have evolved continuously in terms of their scope, methodology, and application. Kulkarni and Miller (2002) described these systems by evaluating the past and current practices and identified future directions for the key elements. (Kulkarni and Miller ,2002)

In the early 1980s, the first system that considered the network perspective was developed for the Arizona Department of Transportation (Kulkarni and Miller, 2002). However, systems which were developed again in the 1990s utilize integrated techniques of performance prediction, network-level and project-level optimization, and Geographic Information Systems (GIS) (Kulkarni and Miller, 2002).

A PMS is a set of activities including the planning and programming of investments, maintenance, design, construction, and the periodic assessment of the performance (Hudson, 1983). The PMS performs management at all levels and involves comparing alternatives, coordinating activities, making decisions and seeing that they are implemented in an efficient and economical manner to achieve goals.

Many transportation agencies in all over the world have used, or are actively pursuing the use of, GIS and other spatial technologies for developing PMS applications. For example, according to NCHRP-335 report for 52 agencies in USA, 31 agencies (60%) reported that they are currently using spatial applications for PMS and 14 agencies (27%) indicated that they are not. An additional seven agencies (13%) provided conflicting information; although the PMS respondent indicated that spatial tools were not used or was unsure if they were used, the GIS representative indicated that the PMS did used spatial tools. (NCHRP-335, 2004)

In spite of all these developments in PMS and after this long period of time for five decades, in Palestine we have not used them yet.

In Palestine, there is, generally, no scientific and unified PMS, in which the road conditions are documented and evaluated by the engineers in a systematic way based on scientific mechanisms. The available pavement management practices in Palestine are based on the individual engineering experience only. Also, the maintenance process is carried without defining maintenance priorities in terms of a list of criteria such as road conditions, traffic volume, citizens' complaints or road classification.

In developing countries, 30% to 50% of roads are in poor condition, (Zietlow, G, 2004) and Palestine is not an exception. where, according to the same report (MPWH, 2015), 65% of the road network is in fair to bad condition and they cost the national economy between 2% and 5% of the annual GDP. Mainly, these costs are the result of increased vehicle operating costs, longer travel times, higher accident rates, more freight damages, and additional road rehabilitation cost. (MPWH, 2015).

According to Heggie and Vickers, 1998, when road is allowed to deteriorate from good to poor conditions, each dollar saved on road maintenance increases between $2 and $3. (Heggie and Vickers, 1998) The importance of road maintenance is therefore seen as a priority by decision makers and policy implementers. The challenge in Palestine over the years has been lack of a unified scientific pavement management system and clear strategy for maintenance prioritization. And, to maintain roads in optimum condition with a limited budget and maximize the benefits of a transportation program to its users, a decision support system is essential. Where, studies have shown that PMS with spatial application capabilities can be implemented as decision support tool in the protection and management of investment (Flintsch & Chen, 2007, Ibraheem & Falih, 2012). GIS provides the ability of combining tabular information from road pavement condition in a database and spatial information of road network represented by maps into a common platform. This capability and other analytical functions of GIS allow users to comprehend information from maps more quickly and effectively than from a list of road records in a tabular format that PMS provides. So, these researches well highlight how implement GIS as a decision support system in road management and maintenance in Palestine.

1.2 Problem Statement

Road quality is an important factor in the economic growth of any country.(Acquah and Fosu, 2017) Pavement surface is one of the main components of the transportation infrastructure and greatly affect the comfort, costs and safety of road users. Deterioration and catastrophic failure of these roads may occur because of aging, overuse, misuse and/or mismanagement. Therefore, their maintenance and preservation should have a great national interest.

According to the Ministry of Public Works and Housing (MPWH, 2015), the road network in the West Bank has a total length of 3,783.6 km, table 1.1 shows the road classification and length in West Bank. (MPWH, 2015).

Table 1.1:Road network in West Bank (MPWH, 2015)

West Bank	**Paved Roads**				**Un Paved Roads**	**Total**
	Main	Regional	Local	Total		
	663.6	1,149.0	1,484.8	3,297.4	486.2	3,783.6

Where. The main urban roads are found within main cities. They connect nearly all Palestinian communities and are generally of poor quality. The Secondary Roads are narrow roads mainly within and around built-up areas. They have a total length of 1,484.8 km, are usually one-lane roads and are rarely wider than 6 meters. Some of the Main and Regional Roads within the West Bank are Israeli bypass roads. These roads are built for Israeli settlers and soldiers so that they can easily bypass Palestinian communities (MPWH, 2015).

In Palestine, transportation agencies are facing a great challenge in dealing with an aging road infrastructure. For pavements in particular, it is sought that many streets were built 20 or 30 years ago and they are near the end of their economic life (Jendia & Al Hallaq, 2005). That's mean the old of these roads are 30-40 years at now. According to MPWH report, 65% of the road network is in fair to bad condition and they cost the national economy between 2% and 5% of the annual GDP (MPWH, 2015).

The traditional pavement management system that is currently in use in Palestine reveals that: (Jendia & Al Hallaq, 2005)

- There is a lack of documentation.
- There is no use of database programs in storing and processing system data in road maintenance management.
- The system is not flexible enough to modify work plans and schedules to reflect changing circumstances.
- The system is poor to assist in making decisions.

From the above fore mentioned points, there is a strong need for a comprehensive Pavement Management System (PMS) that involves:

- **Databases:** Facilitate the physical data of the system to be managed and allow data storage, retrieval, display and update, and access to information and queries.
- **GIS Capabilities:** Allow manipulating, analyzing and reporting pavement conditions' data to be represented in a geographic format.

- **Evaluation Systems:** Assist to make cost-effective and timely decisions related to the maintenance and rehabilitation of pavement.

- **Modeling Systems:** Provides information about maintenance needs, costs, priorities, etc.

Pavements are complex structures involving many variables, such as materials, construction, loads, environment, performance, maintenance, and economics. Thus, various technical and economic factors must be well understood to design pavements, to build pavements, and to maintain better pavements. Moreover, the problems relating to road maintenance are still more complex due to the dynamic nature of road networks where elements of the network are constantly changing, being added or removed. This means that the pavement management process needs to deal with a large amount of data in terms of documenting, updating and analyzing. This is what is lacking in the institutions concerned with the management of pavement in Palestine, where this lack leads to making inappropriate decisions in the maintenance procedures and allocation of financial Thus, there is a need to apply a scientific approach to manage the maintenance of the road network effectively. A good system can deal with all these variables and identify priorities for conservation in order to ensure the achievement of the desired goals of maintenance to the fullest. Adapting Pavement Management Systems (PMS) will enable highway agencies to manage and maintain the networks in an effective manner and the integration of this system with the GIS provides many of the characteristics lacking in the pavement management system in Palestine and assisted decision makers in making appropriate maintenance decisions on a scientific basis.

1.3 Importance of the Study

The importance of this study lies in the establishment of a new model called PMS-GIS model use to manage the pavement in a simply based on a unified scientific basis and solve the problems found in the pavement management system in Palestine, which were mentioned earlier in this research, the model is a spatial decision support model that integrates pavement database in a MS Excel program and spatial database in ArcGIS environment.

Where, PMS-GIS model provides

1- Ability of documenting and combining tabular information from road pavement condition in a database.

2- Represent the spatial information of road network by maps into a common platform.

3- Allow users to comprehend and absorb information from maps more quickly and effectively than from a list of road records in a tabular format that PMS provides.

4- Help non-experienced and experienced decision makers in pavement management processes to make appropriate decisions in maintenance operations and budget distribution at proper time.

1.4 Objectives and Scope

The main objective of this research is to design a PMS integrated with GIS that can develop priorities for road maintenance activities in Palestine. Towards achieving this broader goal, the study aims to satisfy some other objectives:

- To investigate the current pavement management practices, principles and related challenges.
- To select the most significant factors that influence decision making in maintenance prioritization. (to make it as uniform in all road agency)
- To explore, summarize and report good practices in methods of pavement maintenance management with GIS from real life and research.

The proposed PMS-GIS model was designed in the first stage and tested in the second stage by an application on a case study from Nablus city. The study area consists of 15 km of paved roads from Rafidia neighborhood surrounding the new campus of An-Najah National University.

1.5 Research Organization

The chapters in this dissertation are arranged carefully in the order or sequence of steps to make it clear and understandable. While, Chapter One provides detailed information about the nature of this study, Chapters Two is oriented as a literature review and previous case studies about the main topic of this study, Chapter Three is the methodology and model design. This chapter describes the research methodology adopted in this study. Chapter Four is the application: a case study from Nablus City. This Chapter presents the development of a PMS-GIS model in Nablus. Finally, Chapter Five summarizes the findings and conclusions of this research as well as the suggested recommendations.

The chapters in this thesis are arranged carefully in the order or sequence of steps to make it clear and understandable. Where, Chapter One provides detailed information about the nature of this study. Chapter Two covers the related literature and some of the previous case studies about the main topic of this study. Chapter Three consists of the methodology and the model design, while Chapter Four covers the application of the model on a case from Nablus City. Finally, Chapter Five summarizes the findings and conclusions of this research as well as the suggested recommendations.

The flowchart in Figure 1.1 describes the research organization presented in this thesis.

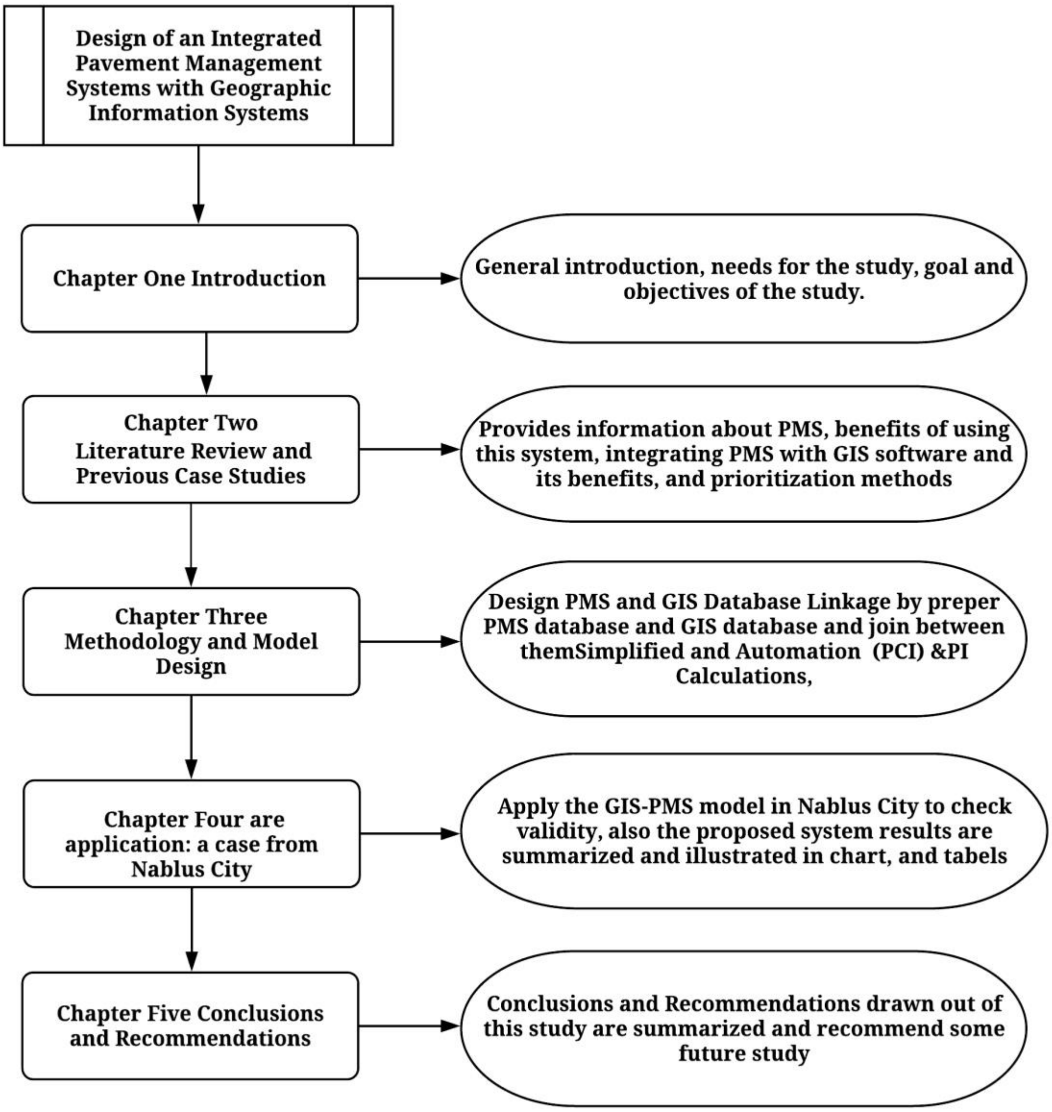


Figure 1.1: Thesis Organization.

Chapter Two

Literature Review and Previous Case Studies

2.1 Introduction

The quality of road pavement significantly affects travel, and poor conditions put people's safety at risk (World Bank, 2011). Over time, the strength and quality of pavements deteriorate due to the impact of pressure on surfaces mainly from heavy loads and weather conditions (Surrey County Council, 2015). For these reasons, pavement maintenance has become an important aspect of highway management and infrastructure development in the field of transportation. This chapter, covers the related literature and some of the previous case studies about GIS in PMS and the suitability of GIS as a tool for pavement management, the chapter divide by three main sections upon the topics that required in research.

2.2 Pavement Management System (PMS)

The PMS concept was established in the United States during the recent economic period. The PMS model was manufactured by the Washington State Highway Department in the mid-1970s. This model included progress in the performance forecasting model and cost model based on data bank data collected in Washington state over time (6-8 years). Later on, many state departments of transportation originated their own PMS procedures desirable for their needs and necessities (Niju, 2006).

2.2.1 Operating Pavement Management: Levels and Process

Road management has the purpose of maintaining and improving the existing road network to enable its continued use by traffic in an efficient and safe manner. Road management can be seen as a process that is attempting to optimize the overall performance of the road network over time.

1-Pavement Management Levels

Pavement management can take place at two main levels: network and project levels. The network level focuses on creating the competent use of budgetary resources for the whole pavement network. On the other hand, project level is specific to a given pavement segment that has been recognized for possible rehabilitation. Network level includes the assessment of all pavements below an agency jurisdiction. The analysis of this level is best utilized for complete budget estimates and projected considerations. The network level requires aggregated information. Thus, this level has more interest to use by the manager.

Project level focuses on a particular pavement segment and normally comes afterward network level in local agencies. This level is a sequence of steps to find out the cause, extent of pavement deterioration and analyzing life cycle cost. Additionally, it attempts to establish an accurate deterioration model. In order to make detailed design decisions and to provide additional knowledge about pavement condition and causes of deterioration for an individual project, it must collect more data than the network level and performing a detailed evaluation with additional testing such as: coring, material and nondestructive testing (Broten, 1996).

In this research, both levels will be dealt with in order to establish a fully integrated model for the management of pavements in Palestine.

2- PMS Process

The implementation of PMS to a particular pavement network is carried through a systematic operation that includes several tasks on a periodic basis. This system is used universally with a very slight difference, as covered in the following steps:

1- Network Definition

The primary step in establishing a PMS is the network identification. A network is a consistent combination of pavements for M&R management. The pavement manager could be responsible for managing the pavement. The pavement network firstly, must be divided into branches and then into a unique section. A section can be defined as a smallest management unit while considering the selection of M&R treatments. Several factors should be taken into account as dividing branches into sections; these factors are pavement structure, traffic, construction history, surface type, and pavement condition (Shahin, 2005).

In this research, the road network is defined and divided according to the method used in the operation and maintenance manual for the roads of the West Bank, which will be explained in detail at a later stage

2- Pavement Inventory

Pavement inventory is the basis of each PMS, usually contains the physical characteristics of the pavements and normally these data do not change amid maintenance actions.

The main intention of the inventory is to provide data for identifying the pavement's physical features. The minimum information needs for establishing pavement inventory are listed below (Washington State Department of Transportation, 1994):

- Pavement section ID and name.
- Starting and ending location for each pavement section.
- Functional classification.
- Number of lanes.
- Pavement rank.
- Pavement surface.
- Pavement thickness.
- Pavement width.
- Pavement length.
- Pavement surface area
- Construction date (last surface).
- Average Daily Traffic (ADT).

It is important to mention that the precise type of inventory data needed is reliant on the agency and the PMS software necessities. Sometimes in inventory data collection more information is being collected such as: drainage condition, sidewalk condition, and number of traffic signs which may be used at project level that usually comes after network level.

In this research the form from ASTM D6433 will be used for Distress data collection. Figure 2.1 shows ASTM D6433 inventory sheet

ASPHALT SURFACED ROADS AND PARKING LOTS
CONDITION SURVEY DATA SHEET
FOR SAMPLE UNIT

SKETCH:

BRANCH________ SECTION________ SAMPLE UNIT________
SURVEYED BY________ DATE________ SAMPLE AREA________

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE

Figure 2.1: ASTM D6433 inventory sheet

3- Pavement Condition Evaluation

After preparing the pavement inventory for the whole network pavement condition, evaluation can be set out. Pavement inspection is one of the vital steps in PMS that encompasses distresses survey. The inspection can be carried out manually or utilizing automated data collection vehicles. The vehicle may comprise cameras, profiling devices, and laser sensors, the collected data are changed to a tape for more processing, either by a software program or by individuals (WSDT, 1994). Manual visual inspections are usually carried out by one or two people involving driving pavement sections at slow speeds and stopping from time to time, or by walking through the whole sections. Data collection by walking is more accurate than driving but it is costly and needs more time.

4- Pavement Performance Definition:

The pavement performance has been defined as the serviceability history of the pavement surface and this requires a determination of the types and causes of distress, as well as the extent of pavement deterioration (AASHTO, 1990). Recent literature classified pavement performance as; Functional Performance Structural Performance and overall performance. Those three types of performance were defined as follows (Easa. S and Ki-kuchi. S, 1989):

A. **Structural Performance:** This is a measure of pavement condition in terms of the appearance of various forms and distress and their relative importance in triggering pavement preservation actions. This type of performance reflects the owner (or agency) concern. Measures used for these types of performance such as: surface distress index (SDI), Distress Rating, Pavement condition Rating, and Pavement Condition Index (PCI), which would be adopted later in this research.

B. **Functional Performance:** This is measuring the quality of finding conditions which is an assessment of how the pavement will serves the public travelling. Mainly the index used for measuring the performance is a roughness index, and in goes under different names such as: Present Serviceability Index (PSI), Pavement Rideability Index (PRI), and Riding Comfort Index (RCl).

C. **Overall Performance:** That is a composite measure of structural and functional performance Indicators. Overall performance Indicators have been designated by several names including pavement serviceability index (PSI). Pavement condition rating (PCR), each of them is a composite Indicators of roughness and distress. Another type of Index is, Pavement Quality index (PQI), which is a composite index of roughness, distress, and deflection has been also introduced.

The evaluation of pavement condition includes consideration of specific problems that exist in the pavement. This requires a determination of the types of causes and distresses, as well as the extent of pavement deterioration. It is also important that condition surveys be conducted after new construction or rehabilitation work. Such monitoring is a tool for network assessment and provides information regarding the rate of distress buildup. These survey results are major input when determining whether to undertake a major rehabilitation project. (AASHTO, 1990).

From the previous discussion one can conclude the necessity of a Pavement Performance indicators, to monitor the performance of pavement in each stage of its life cycle. On the other hand, this pavement performance indicator has to be developed to match the nature of each country and sometimes the nature of each city, as pavement deterioration can happen due to environmental and factors. More over the type of traffic that is using the network whither this city is consider.

5- Using (PCI) as a Pavement performance indicator

In the 1950s, pavement condition ratings were carried out by a panel of raters who led along the pavement and personally rate the condition of the pavement on a numerical scale or a verbal description. This form of rating, developed by the American Association of State Highway Officials (AASHO), used a 0-5 scale. It was known as the Present Serviceability Rating (PSR). Despite the fact that this was simple, the evaluations did not give sufficient designing premise to endorsing the sort and degree of repair and rehabilitation work to be done on harmed pavements. To deal with this issue, researchers formed scientific that were able to give the condition of pavement sections based on the type, severity and extent of distresses. This led to the development of a more objective means of condition rating in the late 1950s. This index, known as the Present Serviceability Index (PSI) was based on the relationship between panel ratings and measurements such as rutting and roughness(Lee, 1998). The equation used to calculate the PSI is shown below. This provided an index that can be calculated from objective measurements of roughness, cracking, patching and the slope variance of the pavement section under consideration.

$$PSI = 5.03 - \log(1 + SV) - 1.38(RD)^2 - 0.01(C + P)^{1/2}$$

Equation 0-1

where PSI= Present Serviceability Index

SV=slope variance of section obtained using CHLOE Profilometer

RD= mean rut depth (cm)

C=cracking (m/1000 sq. m)

P=Patching (sq. m/1000 sq. m)

The PSR and PSI were widely accepted among several states. However, during the late 1960s,

In 1962, AASHTO (Roberts et al. 1991) studied a quantifiable measurement of pavement distress types. The Present Serviceability Index was established by AASHTO during the study. This index is a number which is indicative of the pavement ability to serve traffic and it's based on combination of profile meter readings (roughness) and visual inspection (distress types). In this method, each distress is considered as an independent variable, and all independent variables are combined linearly or non-linearly to reproduce user ratings based on pure data synthesis. The developed index ranges from 0 to 5.

Pavement condition was investigated in 1981 by US Army Corps of Engineers (Shahin2002). The study resulted in the development of a single rating number called Pavement Condition Index (PCI) using the PAVER method to represent the condition of the pavement. PAVER is one the most detailed distress evaluation method implemented to data. This method depends on detailed visual inspection of up to 19 different pavements distresses for flexible pavement. The PCI is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition. It measures pavement structural integrity and surface operational condition. The essential concept behind PCI is to consider both distress severity and value as a negative deduct on the pavement condition The PCI index uses only one pavement condition parameter which is distress types in determining the pavement condition index. The PCI is determined as follows: (Shahin, 1981). The method of calculating the PCI indicator is illustrated in Figure 2.2.

$$PCI = C - \sum \sum a\ (Ti, Sj, Dij) \times, Dij)\ x\ F \qquad \textbf{Equation 0-2}$$

Where,

T i = distress type

S j = severity level.

D i j = density of distress.

C = constant (usually 100).

a = weighing factor.

F = adjustment factor for multiple distress.

The World Bank's Highway Design and Maintenance Model, HDM-3, includes a deterministic mechanistic-empirical based on roughness progression prediction methodology. In 1993 the World Bank commended updating their software to version HDM-4. Although HDM-4 provides a more refined and flexible program, the majority of the underlying principles have remained unchanged (Bennett 1996).

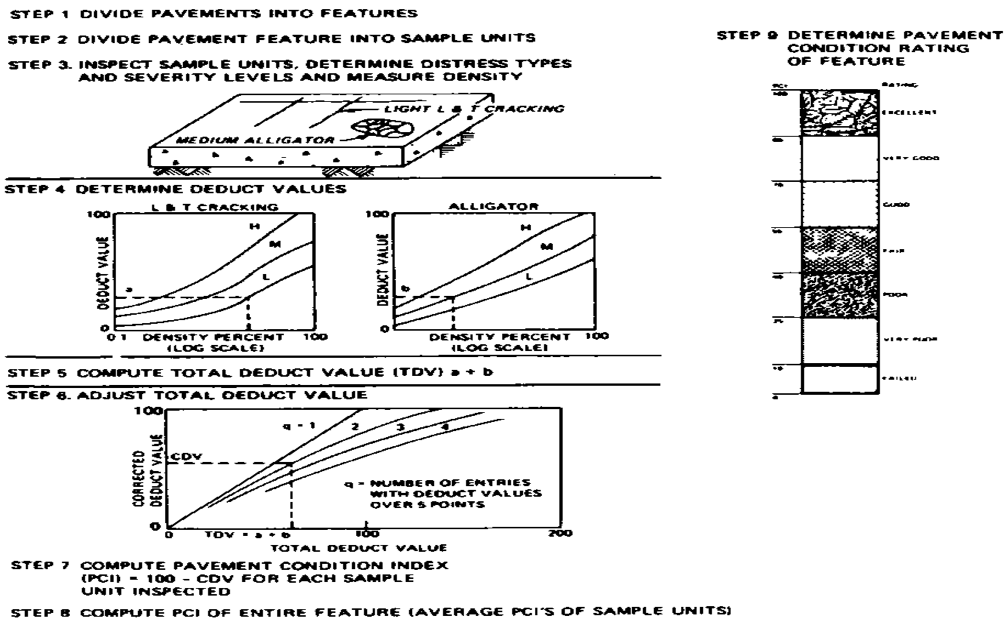


Figure 2.2: Steps for determining PCI of a pavement section. (Shahin, 1981).

As has been mentioned before there is several types of road performance indicator. Amongst them is the PCI method, which has been adapted in this research due to the following reasons:

- **Easy to conduct:** As it does not need special equipment for measuring only rod and tape are used which is neither expensive nor complicated.

- **Widely used**: As many researchers, have adapted it, especially in several studies that has been a conducted in the world, more over a simplified method of the PCI method is developed by (Yazurved Sai Vishwaksen Aravalli, 2015), which will be discussed later on.

• **Comprehensive:** As it includes 19 different types of distresses as will be discussed later on,

• **Comparable:** its result can be compared to some international indicators such as the IRI levels specified by the World Bank for developing countries.

6- Pavement Distresses

The PCI method considers a total of 19 distress types, each with three levels of severity and density. Following is a brief description of each distress type (Darwish, 1993):

1. Alligator cracking: it is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. It occurs only in areas subjected to repeated traffic loading. Such as wheel paths. It is considered a major structural distress and is usually accompanied by rutting.

2. Bleeding: it is a film of bituminous materials on the pavement surface which creates a shiny, glasslike, reflecting surface that usually becomes sticky, it occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface.

3. Block Cracking: Block cracks are interconnected cracks that divide the pavement into approximately rectangular pieces. It is normally occurring over a large proportion of pavement area. But sometimes will occur only in non-traffic areas.

4. Bumps & Sags: bumps are small localized, upward displacements of the pavement surface. Sags are small abrupt, downward displacement of the pavement surface.

5. Corrugation: it is a series of closely spaced ridges and valleys occurring at fairly regular intervals usually less than 3m along the pavement. It is usually caused by traffic action combined with an unstable pavement surface or base.

6. Depression: It is localized pavement surface areas with elevations slightly lower than those of the surrounding pavement. It is created by settlement of the foundation soil or is a result of improper construction.

7. Edge cracking: Edge cracks are parallel to and usually 0.3 to 0.6m of the outer edge of the pavement, it can be caused by frost weakened base or sub-grade near the edge of the pavement.

8. Joint Reflection cracking: It occurs only on asphalt-surfaced pavements, which have been laid over a Portland concrete cement PCC slab. It is not load related and mainly caused by the thermal or moisture induced movement of the PCC slab beneath the AC surface.

9. Lane/Shoulder Drop Off: It is a difference in elevation between the pavement edge and the shoulder. It is caused by shoulder erosion, shoulder settlement. Or by building up the roadway without adjusting the shoulder level.

10. Longitudinal and Transverse cracking: Longitudinal cracks are parallel to the pavement's centerline or laydown direction. It 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 (3) daily temperature cycling, or by cracking beneath the surface course. Transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of laydown. Condition (2) or (3) above may cause it.

11. Patching and utility cut patching: A patch is an area of pavement, which has been replaced with new material to repair the existing pavement. It is considered a defect no matter how well it is performing (a patch area or adjacent area usually does not perform as well as an original pavement section.) Generally, some roughness is associated with this distress.

12. Polished Aggregate: When the aggregate in the surface becomes smooth to the touch, adhesion with vehicle tires is considerably reduced. It is indicated when the number on a skid resistance test is low. It is caused by repeated traffic applications.

13. Potholes: Potholes are small (usually less 0.9m in diameter), Bowl-shaped depression in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. Potholes are generally structurally related.

14. Railroad crossing: They are depression or bumps around and/or between tracks. If the crossing does not affect ride quality. It should not be counted.

15. Rutting: It is a surface depression in the wheel paths. It usually caused by consolidated or lateral movement of the materials due to traffic loads.

16. Shoving: It is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading. This distress normally occurs in unstable liquid asphalt mix pavements.

17. Slippage Cracking: They are Crescent or half-moon shaped cracks having two ends pointing away from the direction of traffic. It occurs when there is low strength surface mix or poor bond between the surface and the next layer of the pavement surface.

18. Swell: It is characterized by an upward bulge in the pavement surface. It is usually caused by frost action in the sub-grade or by swelling soil.

19. Weathering and Raveling: They are the wearing away of the pavement surface caused by the loss of asphalt or tar binder and dislodged aggregated particles. These distresses indicate that either the asphalt binder has hardened appreciably or that a poor-quality mixture is present. **Appendix (A)** illustrates distress details in a comprehensive way.

2.2.2 Prioritization Methods / Approaches

Priority ranking, as used in PMS, is a process used to rank the pavement sections in an order of urgency for maintenance and repair. The prioritization process is the main step of PMS, before the decision makers take the final decision on execution of maintenance program.

Priority setting techniques as used in the PMS cover a wide spectrum of methods and approaches ranging from simple priority lists based on engineering judgment to complex network optimization models as shown in Table 2.1 (Haas et al., 1994). These prioritization methods can be further divided as: (1) Ranking Methods (2) Optimization Methods (3) Artificial Intelligence Techniques (4) Analytical Hierarchy Process Method.

Table 2.1: Different classes of priority methods (Haas et sal., 1994)

	Class of Method	Advantages	Disadvantages
1	Simple subjective Ranking of projects based on judgment, overall condition index, or decreasing first cost	Quick, simple;	subject to bias and inconsistency; may be far from optimal
2	Ranking based on parameters, such as serviceability or distress; can be weighted by traffic	Simple and easy to use;	may be far from optimal, particularly if traffic weighting not used
3	Ranking based on condition analysis and traffic, with economic analysis	Reasonably simple;	may be closer to optimal
4	Annual optimization by mathematical programming model for year-by-year basis over analysis period	Less simple;	may be close to optimal; effect of timing not considered
5	Near optimization using heuristics including benefit-cost ratio and marginal cost effectiveness	Reasonably simple; Suitable for microcomputer	close to optimal results
6	Comprehensive optimization by mathematical programming model taking into account the effects of M,R&R timing	can give optimal program (maximization of benefits)	Most complex and Computationally demanding;

In this research the ranking methods will be discussed and used because it is simpler and applicable with available data then use the best method that give closer result with optimal.

2.2.2.1 Ranking Methods

1- Composite Index Ranking Method

The ranking of pavement sections for maintenance is done on the basis of the priority index calculated by combining different pavement indices. These indices are estimated by considering parameters like pavement distresses, riding quality, traffic conditions, economic analysis, functional class, accident details, geometric deficiencies, structural capacity, skid resistance, pavement age, engineering judgment, etc. The prioritization program should not only be based on current pavement condition, for making it efficient future pavement condition should also be considered. As generally the treatments are applied at least one year after the condition surveys are carried out, giving the time to require for relative prioritization and organizing for funds. (Butt, 1995).

2- Economic –Based Methods

The prioritization methods based on economic analysis can be of two types: (1) using optimal benefit/cost ratio (2) using incremental benefit/cost ratio. In the first method, prioritization process uses the optimal M&R recommendations and corresponding benefit/cost ratios (or effectiveness/cost (E/C) ratio) for each pavement section of the network produced from the dynamic programming. The higher the E/C ratio of a section, the higher the priority of that section for repair. The available budget is allocated to the pavement sections as per the priority list till the budget is completely exhausted. The second methodology is a heuristic method for budget optimization. In this method all feasible M&R alternatives of a section are identified and the corresponding inflated initial cost, present-worth costs, and weighted benefits are obtained. This information is then used in the program to produce optimal M&R recommendations for each pavement section, including initial cost and type of treatment. The budget optimization also gives the total network-weighted benefits corresponding to optimal M&R recommendations (Butt, 1995).

the Composite Index Ranking Method will be used in the research to get the prioritization of the road to be maintained that's because the method is simpler in calculate, easy to apply, data base needed is available, the results are explained to decision makers and this research aims to develop PMS in small transportation agency. This method was used in O&M manual for Palestinian municipalities to rank the priority of maintenance road, this use will be discussed at a later stage to be adopted as a basis for rank the priority of maintenance road in this study.

2.3 GIS in Pavement Management

2.3.1 Introductions and General Background

Pavement Management Systems (PMS) with spatial application capabilities are employed as decision support mechanisms in the protection and management of investment (Flintsch & Chen, 2007).

That is, PMSs are developed at a local level to enhance the process of decision-making – more specifically, to gain an insight into the implications of decisions, and limit adverse impacts and maintenance costs. The fact that the PMS incorporates technology is considered essential for promoting and enhancing decision-making (Abo-Hashema et al., 2006).

However, the maintenance of the pavement is not exact science. It is expected that two different road parts of the same type do not have the same repair methods. Each part of the road requires good judgment by experienced staff (Haas et al., 1994). Keeping the road condition to an acceptable level involves routine maintenance work in the form of removing surface corrugation, patching, filling ruts, pouring cracks, bleeding surfaces, among other things.

The rehabilitation, overlay and resurfacing are considered major maintenance activities (AASHTO, 1993). Aging roads are more vulnerable to natural disasters, which often disrupt the service provided by these road networks (Housner and Thiel, 1995). Road maintenance and utility works, also making it difficult to independently address road network maintenance activities. Facilities on new utility lines cut road maintenance dates, especially in areas where the size of the network and the number of roads is limited to maintenance and repair programs. This is one reason why the broadening GIS applications are more extensively integrated into PMS (Rhind, 1989).

This is necessary since funding for road repair and maintenance is limited, and the corresponding agencies must be able to prioritize every project to optimize the 40% of public funds that are spent nationally on pavements

(Tavakoli et al., 1992). In order to facilitate the different functions of PMS. PMS is usually implemented within GIS environment which requires a certain architectural model to be designed and taken into consideration. Among those architectural models is one that was introduced by (Peter Keenan, 2007) shown in Figure 2.3.

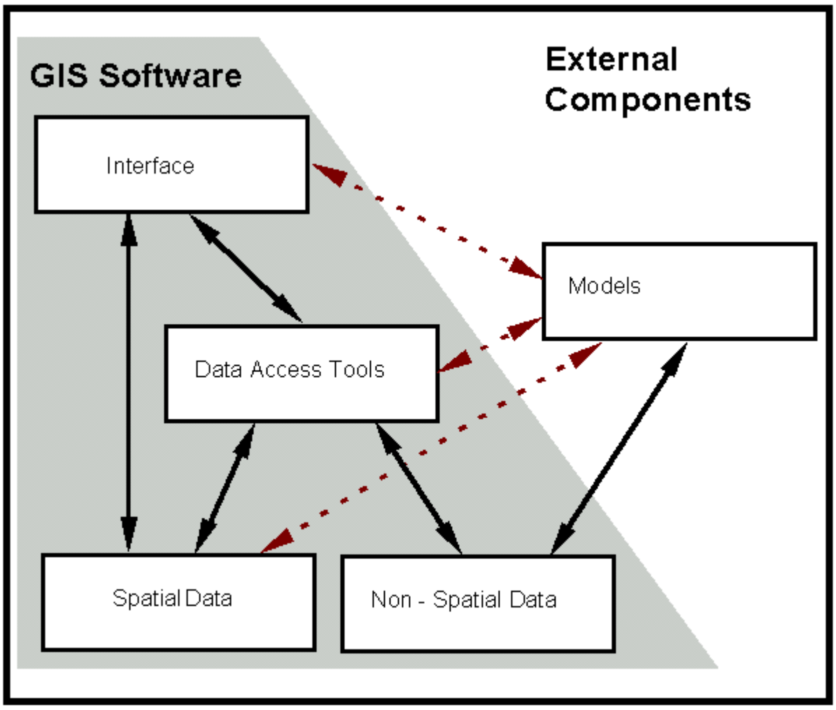


Figure 2.3: Spatial Decision Support System(SDSS)-integrating models with G1S(Keenan, 2007)

(Keenan, 2007) has divided his model into two main components: external component and GIS software. The external component can lie the representation of the knowledge gained from PMS procedure, either it was pavement condition indicator, pavement deteriorating model or traffic influence on pavement condition. On the other hand, GIS Software can give the spatial representation for the pavement data. Resulting in analytical techniques that are unique to both spatial and thematic analysis and provides the user with a decision-making environment that enables the analysis for geographical information to be carried out in a flexible manner.

As to the database integration method, (Murphy, 2013) discussed three approaches for linking PMS with GIS:

1. Seamless integration: the PMS is carried out inside the GIS by sharing a common database;
2. Database linkage: exporting PMS data then importing it into the GIS for demonstrating or querying;
3. Exporting of map: exporting map from the GIS then importing it into the PMS for utilizing it in the map presentation.

Database linkage can be considered as a cheaper method among the aforementioned approaches. In this method data are exported from one of the databases such as: Structural Query Language (SQL), Microsoft Access or Microsoft Excel then imported into the attribute table in GIS. Each pavement section is linked with one row in the attribute table. Figure 2.4 shows GIS and database integration. Database linkage is a suitable way for an agency where they want to update the databases (GIS database and PMS database) separately.

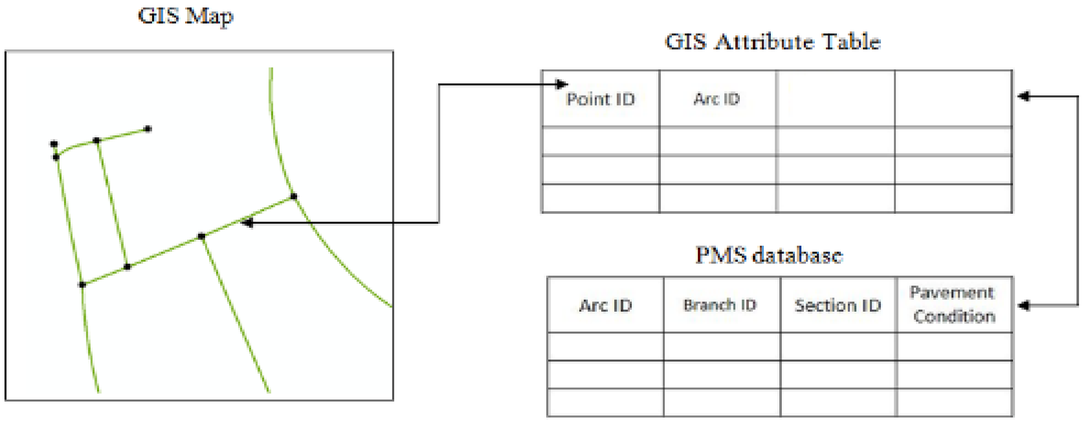


Figure 2.4: GIS- PMS database integration. (Ahmed, 2013)

2.3.2 Dynamic Segmentation

This tool facilitates the decision-making process for PMMS. Attributes are dynamically segmented to create a graphical representation of GIS (results shown in Figure 2.5.

The dynamic segmentation technique has the capability to translate a linear feature into segments, which would mean to link several sets of attributes to any given road segment and create a graphical representation for the user to visualize. Dynamic segmentation is developed by GIS analysts. It allows for interactive query on output elements that is quick and easy to use. The application capabilities save time and effort, provide structure and overlapping data on one street, use accurate methods to calculate road maintenance regions and volumes, and prioritize the need for road segments (Williams and Schuman, 1995).

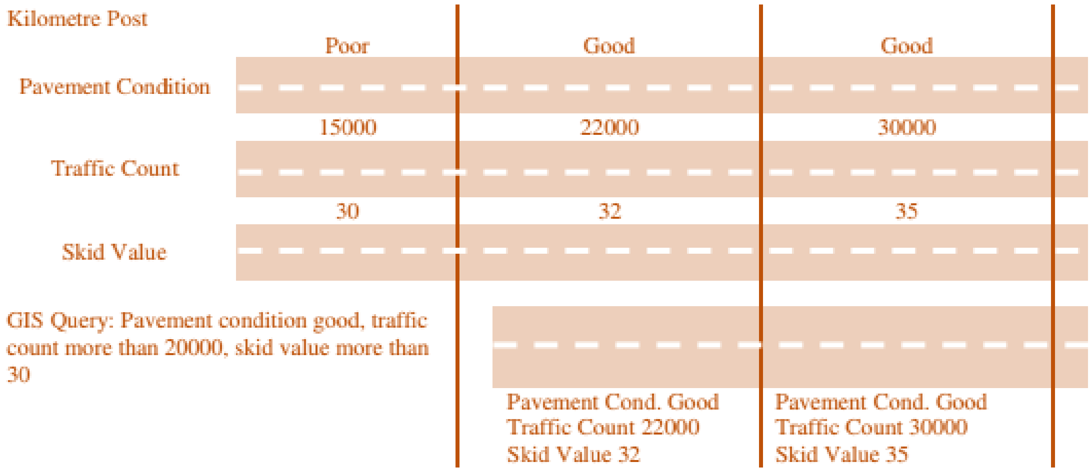


Figure 2.5: Illustration of Dynamic Segmentation (Al- Swailmi and Al-Mulhem, 1998)

2.3.3 Spatial Analysis Applications for Pavement Management and Previous Case Study

Introduction

Spatial analysis technologies are useful alternative tools for the (PMMS) because platform management and asset management systems are supported by the accumulation of a vast amount of information and are available in a wide range of reference systems, forms and media. (Flintsch and Chen, 2007).

The application assists in the analysis of several planning and operational problems on pavement management that include scale, time, and format, whereas the measurement, mapping, monitoring, and modeling of spatial phenomena are enhanced (Miles and Ho, 1999). This technology has the capability to efficiently integrate, store, and query spatially referenced data to support many relevant decision-making processes.

(Goodchild & Longley, 1999) define these as a collection of methods that are effective spatial data. These combine manipulation, transformations and other techniques that show less obvious patterns and anomalies that can enhance and support decisions on road pavement prioritization. These data form geographical features referenced by positions and attributes in analogue or readable digital formats (OMB, 2010). Spatial analysis lets a user query, map, create, and analyze cell-based raster data, and conduct comprehensive raster or vector analysis. As a result, the user can confidently derive new information from existing data and question information across multiple data layers. Fully integrated cell-based raster data using traditional vector data sources is also made possible.

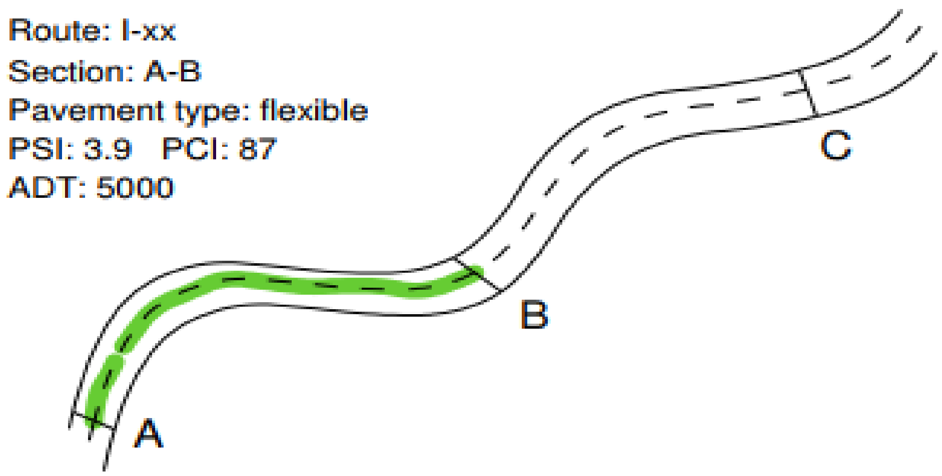


Figure 2.6: Spatial Application Function Scheme (Flintsch & Chen, 2007)

Spatial applications generate a simplistic view of a complex system. The technology relies on the branch of geometrical mathematics, topology, which concerns spatial relationships that correlate spatial entities. Topology is about interconnection, affinity, enclosure, and other geometric properties of objects (NHI, 1997). Figure 2.6 presents the spatial information on the roadway with tabular or attribute information on pavement structure, condition, and age.

Applications in this dimension facilitate data integration which could be traffic and Maintenance and Rehabilitation (M&R) history or inventory, data collection which includes the processing of gap detection among others, and output presentation such as the average pavement condition. (Flintsch et al., 2004).

A spatial tool is designed to support the capture, manipulation, analysis, modeling, and display of spatially referenced data through a system of computer hardware, software, personnel, organizations, and business processes. It is principally applied for solving comprehensive management and planning problems (Lewis & Sutton, 1993).

The proper selection of spatial instruments, the development of the correct basic map, and the linking of these characteristics to spatial information and mapping are a major concern in the development and implementation of spatially supported pavement management systems (PMS) (AASHTO, 2001).

2.4.3.1 Previous Case Study at the International Level

1- ILLINOIS GIS-Based PMS System (ILLIPIMS)

ILLIPIMS is an application developed out of a base map using ESRI’s ARC/INFO® in ESRI's and is advanced with the ArcView® GIS 3.2. The modification adopts the data in an earlier tool, the Illinois Pavement

Information and Management System (ILLINET) and enhanced with the capabilities of GIS to include non-Interstate pavements (Bham et al., 2001).

ILLIPIMS is unique for its on screen, sequential spatial information particularly useful in reporting, analyzing, modifying, predicting and displaying pavement and traffic information for the complete Interstate system of Illinois. Details include type of pavement rehabilitation, traffic information and pavement condition. Any selected section of the interstate map can be plotted to reflect the historical trend of information. Visuals are represented in graphical display either in a map, a graph, or a chart; with color coded dynamic legends that make information more understandable by the user (Bham et al., 2001).

2- Condition Assessment of Clemson University's Parking Network and Development of a Framework to Support Pavement Management

This project consists of developing a useful and efficient network-level PMS for Clemson University parking lot network. The study area includes all the parking lots in the Clemson University. A review of the existing pavements management practices for parking lots was made and the network level Clemson University Pavement Management System (CU-PMS) was developed. Existing data was used for the initial analyses and procedures to collect future data are presented.

CU-PMS consists of an inventory, condition assessment, and its analysis. This will identify maintenance options, help prioritize rehabilitating parking sections for immediate attention, and anticipate future deterioration. The information is directed toward achieving the best possible value for the available funds in providing smooth, safe, and economical pavement surfaces. This report documents the methods used for the development of a PMS, the recommendations for implementation of the system, and the recommendations for the preservation of pavements in the study area. The project is a case study to demonstrate the effectiveness of PMS on Clemson parking network and also serves to provide parking and transportation services with better decision-making process.

Also, this project work to simplify the distress evaluation procedure and improve the effectiveness of pavement condition index value, some spreadsheets used for calculating the deduct values of pavement were developed from figures in ASTM D6433. These developed spreadsheets are able to be simply employed to obtain the deduct values by inputting the distress density, which can be obtained from field survey. Based on the type of distress shown in ASTM D6433, various spreadsheets were established for these applications. However, the user is suggested to use both figures and formulas as evaluating the primary road pavement.

These formulas were generally developed by separating each curve into two sections and then conducting regression analysis for each section of the curve. These developed formulas were used in the spreadsheet to calculate the deduct values. Figure 2.7 show deduct value formulas and charts for Fatigue Cracking

Fatigue Cracking		
	X	Y
Low	0.1	4.61
Medium	0.1	7.50
high	0.1	11.75

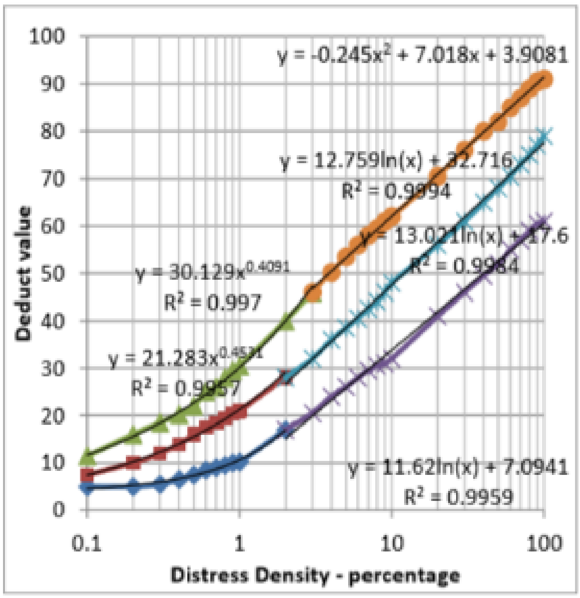


Figure 2.7: DV formulas and charts for Alligator Cracking(Aravalli, 2015)

3- Development of PCI-based Pavement Performance Model for Management of Road Infrastructure System

The objective of this research was to develop a pavement condition index based on the LTPP and Mn/ROAD pavement distress data. The PCI was selected as the performance indicator, being derived from distresses data in either the LTPP or Mn/ROAD databases. The goal was also to develop a programmed Excel™ templates to use imported distress data and directly calculate the PCI for various test sections. A secondary goal of this research was to use the PCI in unique performance modeling approach. This study documents these developments and their advantages, such as (i) quantification of PCI as a new performance measure used for existing LTPP or Mn/ROAD databases, (ii) modeling of pavement condition data using historical data converted to Master PCI curves, (iii) demonstration and comparison of models for different pavement networks, and (iv) the use of programmed Excel™ templates for PCI based pavement performance modeling.

In this study, the focus on performance modeling was for the asphalt concrete pavement (ACP) sections. However, the methodology can be also applied and implemented for the Portland Cement Concrete (PCC) pavement sections. Figure 2.8 shows an example of the DV-density curve for fatigue cracking (low severity).

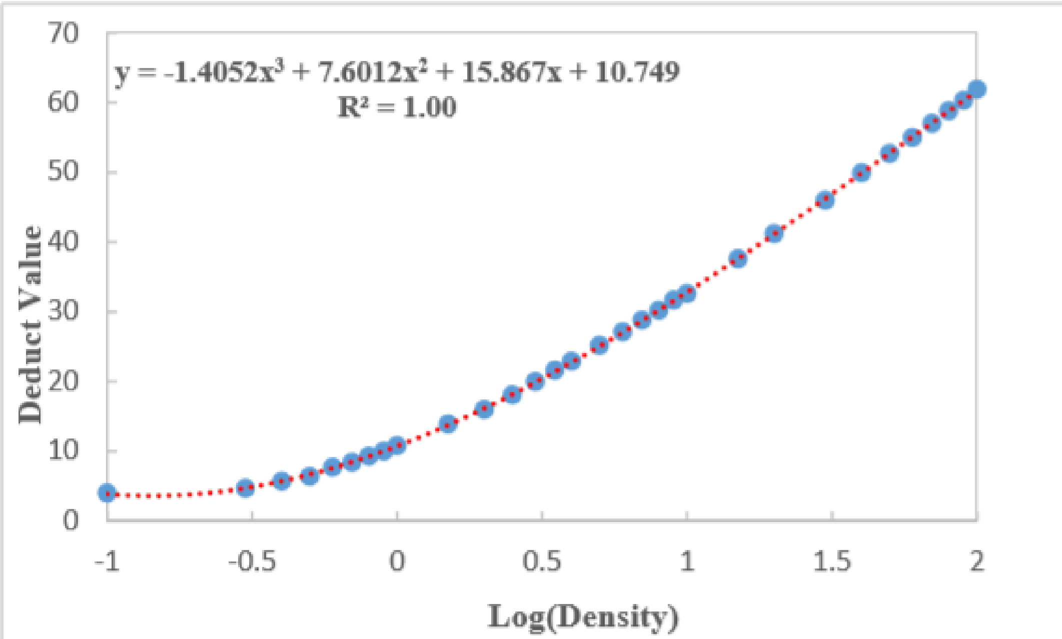


Figure 2.8: DV formulas and charts for Alligator Cracking(L Severity)(Wu, 2015)

2.4.3.2 Previous Case study at the Arab World Level

1- PMMS Model in Al-Ain City

A PMMS application in Al-Ain has been developed in response to the rapid expansion of road networks in the emirate of Abu Dhabi over the last two decades, which necessitates the protection of these investments. The road network includes over 600 kilometers of centerline dual carriageway paved main roads and 3,000 kilometers of single carriageway paved secondary roads (Abo-Hashema et al., 2006).

Pavement management is supported by spatial technology capabilities to facilitate the archiving of maintenance activities, facilitating various activities onsite and follow-up, and as a decision prioritization tool. The criticality of PMMS relates to the fact that the life cycle cost on newly built roads is three to seven times more than the expense of preventive maintenance. Thus, keeping the road pavement condition at an acceptable level is very important (Abo-Hashema et al., 2006). The Al-Ain PMMS Model supports and enhances a number of activities (Abo-Hashema et al., 2006):

1. Interactive and batch data entry and update;
2. Querying, reporting, and spatial displaying;
3. Thematic representation of information;
4. Maintenance decision support; and
5. Road maintenance needs and analysis.

The framework crafted particularly in this tool places PMMS as a segment of the Pavement Management System (PMS) program, as an overlay that does not replace PMS. Figure 2.9 illustrates the overlay concept which correlates PMMS and PMS (Abo-Hashema & Sharaf, 2000; Abo-Hashema et al., 2006; Pinard, 1987).

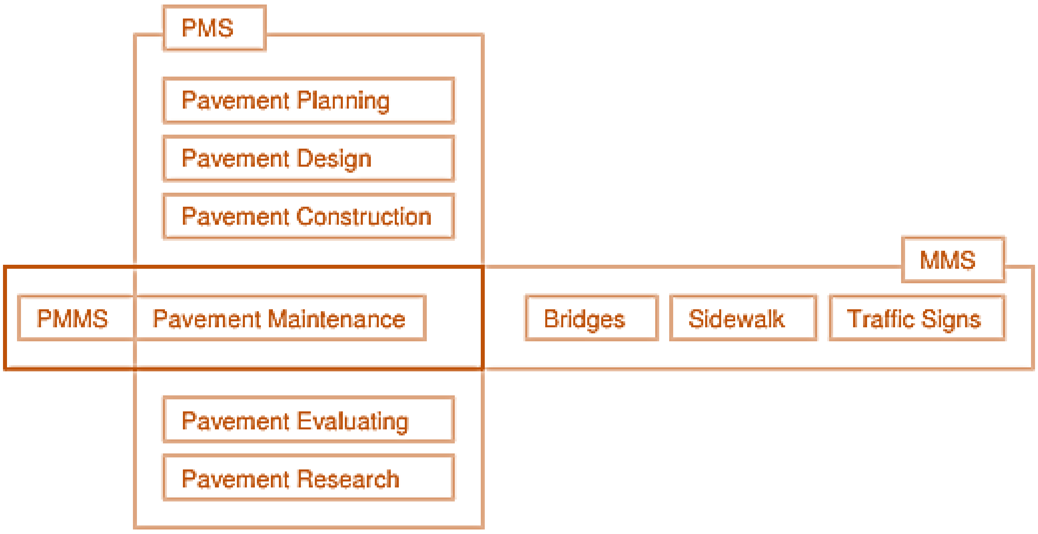


Figure 2.9: Pavement Maintenance Management System (PMMS) Versus Pavement Management System (PMS) (Abo-Hashema et al. 2006)

Concurrently, the Al-Ain Model defines a fully integrated PMMS and GIS, which allows a liberal interface of data. There are three methods of referencing pavement sections: route milepost, node link, and branch section. The main roads use an identification system based on the node-link method. This means that nodes define key points and the sections between these nodes in each direction are defined as the links. Typically, nodes define intersections, boundaries, and changes in the pavement quality such as surface type. A pavement section comprises three traffic lanes extending 50 meters away from a node. A section is split into sample units of 100 meters length for each traffic lane (Abo-Hashema & Sharaf, 2004).

Section inventory is performed, which is followed by a comprehensive distress survey using the Pavement Performance Prediction Modeling (PAVER) model Pavement Condition Index (PCI) values, and a distress map is generated. A distress map is very useful because it provides a complete picture of the locations of pavement surface distress and confirms inspection on these nodes (Pinard, 1987).

A pavement segment is examined for materials failing using a cut out sample layer. The process validates the recommended maintenance treatment determined earlier and requires laboratory materials testing on in-situ density, sieve analysis, moisture density relation, and the equivalent plasticity index and California bearing ratio. Lab tests are performed after the visual inspection survey is completed (Abo-Hashema et al., 2006).

An important feature of the Al Ain PMMS program is the agility between the network condition and maintenance needs. Decision priority setting uses a simple worst first rule over all candidate pavement sections.

Figure 2.10 shows distress maps for main and secondary roads. Black indicates the first stage, dark grey is used for the second stage, and grey indicates the third stage. Network identification begins the sequence of activities, which is followed by data collection procedures which come through two levels of study: network and project levels. The network level study determines a maintenance plan for main and secondary roads. On a project level, the application generates a final list of projects with detailed scope of work for independent projects. Decision prioritization is enhanced with excellent displaying and querying, materials investigation or road geometric assessment results. These maintenance decisions are archived, and distress maps and all relevant spatial applications are stored for future use.

The work of (Abo-Hashema et al, 2006) is interesting, with its suggestion that human decision is above science. As far as the project management system management framework applies a logical approach to supporting decision prioritization, it is ultimately self-feelings take over. This is especially true in areas where there is a strong sense of traditionalism and religious focus, and decision-making priorities are not entirely dependent on the severity of pavement deterioration, given the implicit importance of certain roads for the people.

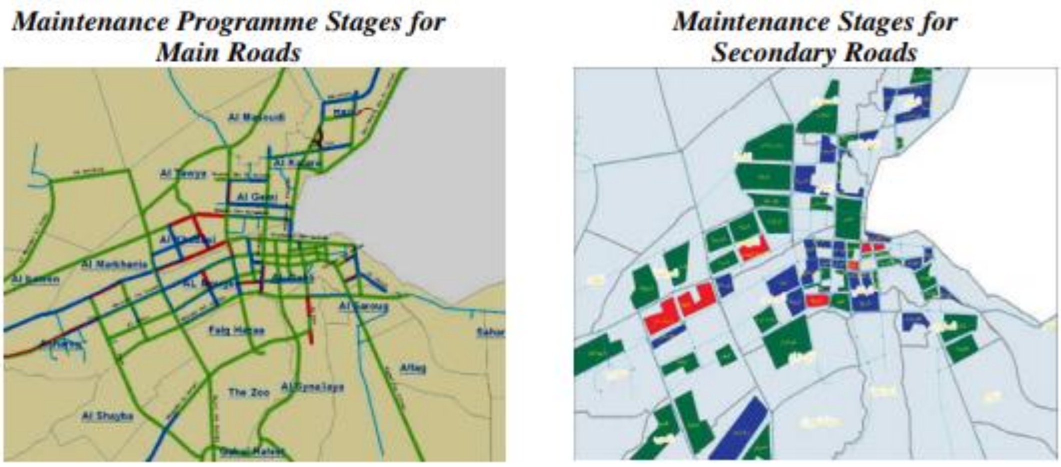


Figure 2.10 Maintenance Programme Stages for Main and Secondry Roads Abo-Hashema et al (2006)

2- GIS Application on PMMS in Jeddah Municipality

As the first National GIS Symposium in Saudi Arabia was held in 2005, the GIS technology in the Jeddah municipality is a benchmark in road pavement PMMS for on screen visual data capture for performance analysis and proper visualization, ground survey, model creation, generation of maps, and for the identification of M&R using unique numbers. The tool effectively supports the supervising engineers, inspectors and department managers in the dimensions of data visualization, data analysis for the purpose of M&R decisions, financial control, asset management and generation of maps (Mansour, 2005).

First of all, the paving sections are grouped into small units that identify the polygons and combine to complete the pavement branch, which is a road from its start to end. Each area forms a network and when they are all set up make the city, archiving on the platform management system (Mansour, 2005).

The work in the Jeddah municipality integrates the micro paver database otherwise known as the access database, and the spatial database or Geomedia warehouse. In doing so, the user can visualize graphically the data for thematic mapping on the road pavement section PMMS (Mansour, 2005).

Figure 2.11 shows the section distress where the micro-paver software computes for the pavement condition index PCI on every section, and the deterioration curve is plot. When the maintenance of pavement is done on time, pavement condition is kept between satisfactory and good, which will affect the cost for rehabilitation and keep it to the minimum. However, if the maintenance of pavement is ignored or delayed, the condition of the pavement drops to a very poor state, which will greatly increase the cost.

The application supports priority setting on the pavement for proper maintenance time.

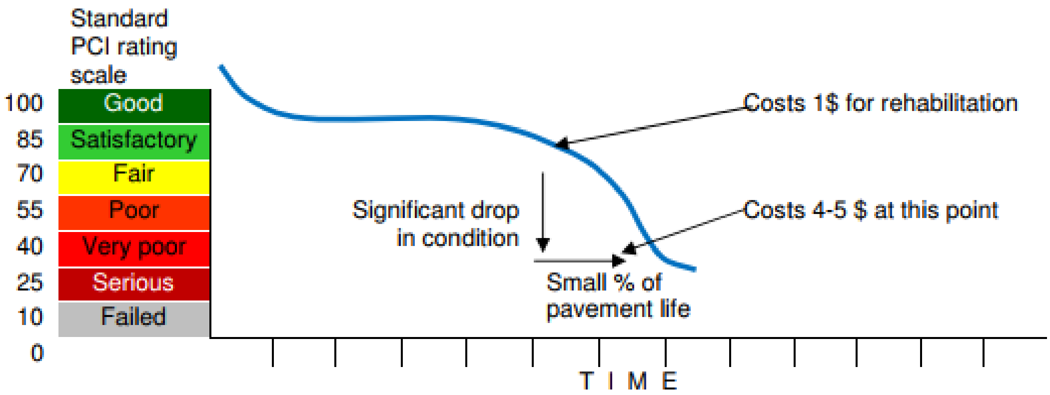


Figure 2.11: Pavement Condition Index (PCI). (Mansour ,2005)

2.4.3.3 Previous Case study at the Local Level

1- Gaza PMMS

Pavement Maintenance Management Systems (PMMS) for the city of Gaza are prioritized after the overall condition of network sections is defined, and each segment treatment is determined with its equivalent cost (Jendia & Al Hallaq, 2005).

In choosing, a logical order is generated by a ranking index formula which is a combination of section condition, traffic exposure and functional classification (Ali & Al-Qatabi, 1995). A decision made on prioritization is followed with a budget formulation document, more particularly for clarity.

This equation is the basis for the prioritization on PMMS for road pavements in Gaza.

$$PI = \frac{1}{PCI} x\ TF\ x\ FC\ x\ MF\ x\ SR$$

Equation 0-3

Where:

PI = Priority Index.

TF = Traffic Exposure Factor. FC = Road Classification Factor.

MF = Maintenance History Factor.

SR = Special Factor to emphasize Priority of Specially Designated Routes.

The application requires an orderly process which begins with a proper inventory of the Gaza road network comprising management segments. Each pavement segment condition is examined and a valuation of the condition is performed using a specific criterion. The treatment strategy and cost implications are then defined on each pavement section. Prioritization is done and is concluded by documenting report results (WSDT, 1994).

The city road network has an existing street coding on roads and built structures that are classified into these categories:

1. Major roads which transverse through the entire city and hold numbers taking the Identification, or ID, form or X00 where X is between 1 and 9.
2. Main roads are of considerable lengths and widths with assigned ID form or XX0.
3. Local access roads have small lengths and widths, numbered in the ID form of XXX. Omar Al-Mukhtar and Al Rasheed Streets are set as reference roads. The first stretches longitudinally from west to east and has road ID 200. The second is transversely parallel to the sea shore from north to south with road ID 100 (Jendia & Al Hallaq, 2005).

Figure 2.12 illustrates the Gaza PMMS prioritization process.

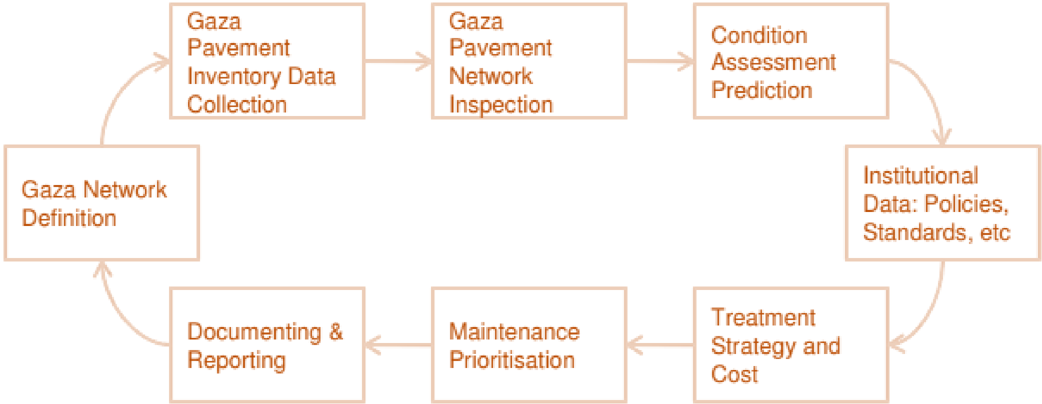


Figure 2.12: Gaza PMMS Process for Road Pavement Prioritization (Jendia & Al Hallaq, 2005)

Network data collection is conducted once these pavements are in manageable sections. Inventory requires detailed information on pavement condition, traffic, cost and funding. It should include a description of the physical features. Institutional data is also essential in the prioritization equation. This outlines administration goals, policies, standards, resources, budget details and annual constraints (Ali & Al-Qatabi, 1995).

It is thought that over the long run, the Gaza PMMS database will preserve a large amount of historical pavement condition information which can be used to develop pavement performance models, useful in the prediction of pavement performance (Jendia & Al Hallaq, 2005).

2- Evaluation of Implementation of Municipal Roads' Maintenance Plans in Palestine: A Pilot Case Study

The aim of this paper is to evaluate the application of the recently prepared O&M Manual in the ten pilot Palestinian municipalities in the preparation of the maintenance of roads part of their O&M Plans Figure 2.13 show the target area for this study (Issa & Abu-Eisheh, 2017).

Also, the objectives of this paper include assessing the compliance with the approved criteria for determining priorities for maintenance work related to pavement assets, as well as the level of implementation of the annual plans one year after their preparation, and the reasons for non-compliance, if any.

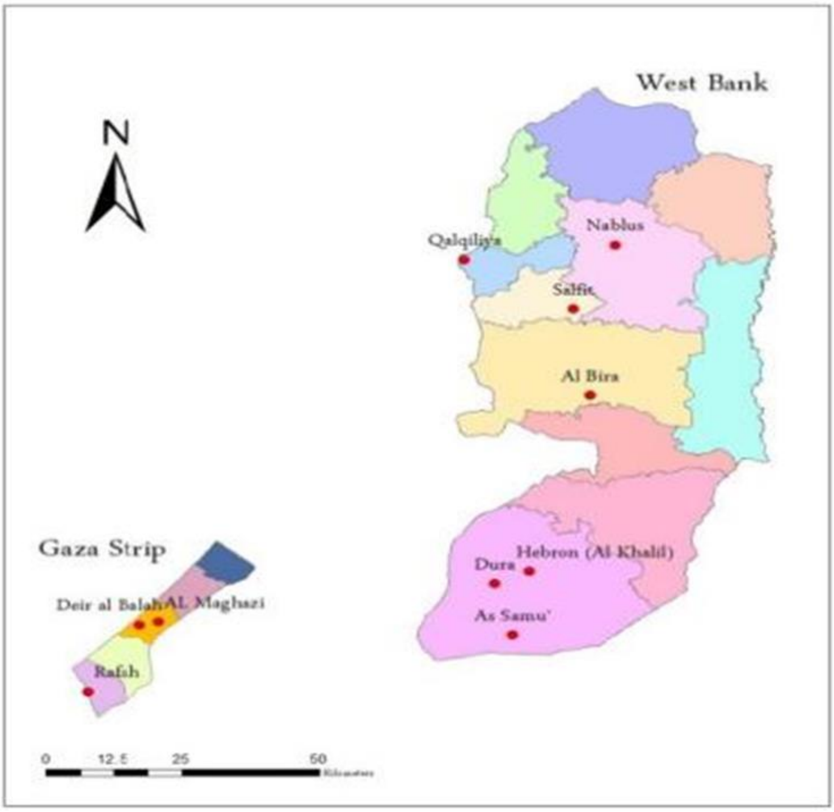


Figure 2.13: Location of targeted pilot municipalities. (Issa & Abu-Eisheh, 2017

The objectives also included examining the degree of satisfaction of municipal engineers in the procedures followed. (Issa & Abu-Eisheh, 2017).

The results of the paper show that the preparation and implementation of the operation and maintenance manual had a positive impact on the 10 pilot municipalities. The level of use of the manual was rated as very high and the level of utilization of the training and training workshops was high, reflecting the ability of municipal staff at all stages of road maintenance. Both results reflect the good satisfaction and high confidence of the municipal engineers in the operation and maintenance manual prepared in terms of implementation and guidance in identifying their needs and formulating their road maintenance priorities. (Issa & Abu-Eisheh, 2017).

The Guide has identified policies, procedures, scope, responsibilities, legal and mandatory requirements, including relevant schemes, tools and models, catalog of damage (Universal Group for Engineering and Consulting, Implementation of Operation and Maintenance-2nd Cycle. Final Report, The Municipal Development and Lending Fund, Ramallah, Palestine, 2014.)

The procedure identified in the manual were proposed after a thorough investigation of regional and international experience in the preparation of such evidence and in the development and implementation of road maintenance management practices. Examples of experiences and practices investigated are those in countries such as Jordan, Saudi Arabia, the United Kingdom, South Africa, the Organization for Economic Cooperation and Development, the World Bank and the United States of America (Issa & Abu-Eisheh, 2017).

In the O&M Manual for Palestinian Municipalities, regional and international experience and practices have been considered as previously indicated. The criteria adopted to prioritize road maintenance consist of five indicators: pavement status, classification of functional routes, average daily traffic, the importance of the road to society, and citizen complaints. The weight of each indicator was determined in view of regional and international practices, and feedback from the Municipal Development and Lending Fund (MDLF) and municipal representatives (Issa & Abu-Eisheh, 2017).

In prioritizing maintenance work for the municipal road network, the Operation and Maintenance Manual identified priority indicator (PI) of the five declared indicators of different weights. The dominant indicator of weight is the pavement condition, set to 0.45. Through literature, the status of the pavement is also ranked first in terms of weight among other indicators ranging from 0.2 to 0.7, the pavement conditions weights were 0.2, 0.33, 0.45 and 0.7, respectively. The estimated weight in Palestine is 0.45 as a result of the accumulation of road maintenance, which is considered one of the main assets in Palestine. All of the target municipalities have adopted this weight, with the exception of one municipality. For each indicator, the remaining weight is less as shown in equation 3.2 shown below (Issa & Abu-Eisheh, 2017).

The PI is calculated using the following equation, as defined in the O&M Manual:

$$\mathbf{PI=0.13\times F1+0.45\times F2+0.12\times F3+0.20\times F4+0.10\times F5} \qquad \textbf{Equation 0-4}$$

Where

F1, F2, F3, F4, and F5 are functional classification of roads, pavement condition, average daily traffic, Importance of Road to Community, and citizen’s complaints.

The O&M Manual is considered one of the most important studies in this research. Because is the only study at the local level, which discuss the issue of the pavement management in Palestine. Where it's provides a clear mechanism for evaluating the status of the pavements and arranging them according to the amount of faults on the one hand and the ranking priority of maintenance on the other hand.

After the above discussion about the manual and its positive effect and excellent result in municipal where apply the research well take it as main reference where its need and comply.

2.4 Summary

This chapter explores pavement maintenance management in different agencies in the world. Various aspects of pavement maintenance management were investigated, including pavement maintenance in general, pavement inspection and monitoring practices, and pavement maintenance. Other topics explored in the research include pavement maintenance management practices among local road authorities, particularly their pavement condition assessment, pavement maintenance management systems, major issues affecting pavement maintenance management among local authorities.

Based on the outcomes of the literature review, pavement maintenance management refers to various practices that help improve pavement surfaces to avoid accidents and risks to safety as well as traffic and experiences on the road. Pavement maintenance may be corrective or conducted for emergency purposes. Nevertheless, the most important action during pavement maintenance is prevention. Preventive measures help local road authorities assess road conditions and make plans to increase the life span of pavement and, thereby, reduce spending on pavement maintenance as well as disruptions to traffic. For this reason, local road authorities are recommended to adopt prevention as an aspect of pavement maintenance management.

In Palestine the responsibilities of road maintenance activities are divided between the Ministry of Public Works and Housing (MoPWH), in charge of all the roads outside the municipal boundaries, and the municipalities in charge of all the roads inside their boundaries. The municipalities operate under the guidance and support of the Ministry of Local Government (MoLG). (Issa & Abu-Eisheh, 2017).

The current road maintenance practices in Palestine are not based on scientific methodological methods. Most of the Municipalities use one criterion for determining maintenance Priorities, the "worst first" criterion. And therefore, current practices in determining road maintenance plans do not deal with the generally known stages including those relating to the establishment of road inventories, clear the road paving situation, the overall assessment of Pavement conditions, identification of appropriate maintenance rehabilitation measures and priority setting (Issa & Abu-Eisheh, 2017).

Based on the above, there has been a need to develop and adopt appropriate methods to assist in the decision-making process related to maintaining and upgrading the pavement structures of the roadway network in Palestine, this research aims to proposing a systematic approach for road maintenance and in identifying a decision-making model that help the local agency in Palestine in creating their operational and maintenance plans, and in prioritizing their annual maintenance activities based on scientific base and in spatial environmental through integrating Pavement Management System (PMS)with Geographic Information System (GIS) .

Chapter Three

Methodology and Model Design

3.1 Introduction

Based on the findings from the literature review, it is essential to develop a GIS-based Pavement Management model to manage pavement maintenance effectively. This chapter deals with the structure of the proposed PMS approach. The proposed model includes the affecting factors, which are determined from the literature review phase, also, automation and simplified calculation. This model should also take into account the need of local road authorities for such a model.

As an initial step, or general structure of decision support, the relevance of a (Spatial Decision Support System) SDSS for pavement maintenance prioritization and the use of GIS in pavement maintenance and management are reviewed. Subsequently, the structure and functionality of the model under consideration are covered. Finally, the evaluation methods and the foreseen output of the model under consideration are discussed.

3.2 Simplified Pavement Condition Index (PCI) Calculation

As discussed earlier, PCI is a numerical index between 0 and 100 values that is used to indicate the general condition of the surface of a pavement section, with 100 value representing the best possible condition and 0 value representing the worst possible condition. The PCI survey procedure and calculation method has been standardized by ASTM for roads and parking lots pavements (ASTM, 2007). The terminologies defined by ASTM standard are also used in development of automated PCI calculation templates. The next paragraphs provide some basic definitions for PCI calculation used in the ASTM procedure.

Pavement Section: A contiguous pavement area with a uniform structure, maintenance, usage history, and condition. A section should have similar traffic volume, structure and geometric characteristics

Pavement Distress: External indicators of pavement condition deterioration caused by loading, environmental factors, or a combination thereof. Typical distresses are cracks, rutting, and weathering of the pavement surface. Each distress, based upon its effect on pavement performance and riding quality, are classified into three severity levels: Low (L), Moderate (M), and High (H). A completed distress identification manual was provided by Federal Highway Administration (FHWA) in 2003 (FHWA, 2009).

Depending on the type of distress density and severity, the amount of distress within the pavement section is measured either in square meters (square feet), linear meters (feet) or the number of occurrences. For instance, fatigue and block cracking are measured in square feet or square meters, whereas for longitudinal and transverse cracking, are measured in linear unit.

Distress Density: The percentage to indicate the ratio of distress within an area. It is obtained by dividing the total quantity of each type of distress at each level of the total area of the pavement section.

Deduct Value (DV): Statistical weight number of distresses to determine a combined condition index for pavement sections. According to **ASTM 6433-07**, for each distress type and severity level, there is a distress deduct value curves for deduct value determination (ASTM, 2007).

Corrected Deduct Value (CDV): Adjustment of the cumulative deduct value or the total deduct value (TDV). The CDV adjusts the TDV to fit for a range of 0-100 by using a set of CDV-TDV adjustment curves. The maximum of CDV (maxCDV) is used to calculate PCI (PCI=100-maxCDV). If there is only one deduct value, then the TDV is used in place of the maxCDV in determining the PCI (ASTM, 2007).

3.3 Simplified Priority Index (PI) Calculation

In prioritizing maintenance work for the road network, the O&M Manual identified priority indicator (PI) of the five declared indicators of different weights. The dominant indicator of weight is the pavement condition, set to 0.45. Through literature, the status of the pavement is also ranked first in terms of weight among other indicators ranging from 0.2 to 0.7, the pavement conditions weights were 0.2, 0.33, 0.45 and 0.7, respectively. The estimated weight in Palestine is 0.45 as a result of the accumulation of road maintenance, which is considered one of the main assets in Palestine. All of the target municipalities have adopted this weight, with the exception of one municipality. For each indicator, the remaining weight is less as shown in equation 5.1 shown below (Issa & Abu-Eisheh, 2017).

The PI is calculated using the following equation, as defined in the O&M Manual:

$$\mathbf{PI = 0.13 \times F1 + 0.45 \times F2 + 0.12 \times F3 + 0.20 \times F4 + 0.10 \times F5} \qquad \textbf{Equation 0-1}$$

Where:

F1, F2, F3, F4, and F5 are functional classification of roads, pavement condition, average daily traffic, Importance of Road to Community, and citizen's complaints.

3.4 Automation of PCI and PI Calculations

The existing ASTM PCI method provides an objective assessment of the pavement condition, in addition, the O&M Manual for Palestinian Municipalities provides a detailed explanation of the method of calculating the Priority Index (PI) and clarifies all the factors that affect the process of prioritizing the maintenance of the road. However, labor-intensive can be a large road network. Because there are a lot of calculations needed to be completed, even for the small pavement network. It is therefore, useful to develop a tool for automating the PCI and PI calculation of road at the project level and network level.

The following sections describes the development of mathematical formulas based upon the available DV curves found in the ASTM 6433-07 procedure and Priority Index (PI) according to the O&M Manual for Palestinian Municipalities; this is followed by describing how these equations are used in an automated PCI and PI calculation Excel template.

3.4.1 DV Curves Nonlinear Math Functions

The family of DV curves provides a reference for manually determining the deduct values. However, in this research will be used mathematical equations derived through two international studies. As previously mentioned in the literature review. A total of 91 nonlinear (multinomial) functions and plots were developed to be used for the determination of DVs. The same approach was used to determine the CDVs, the regression analysis shows the polynomial function between DV and logarithm of density with high degree of accuracy. The plots, regression analysis and nonlinear equations for all of the distresses can be found in Appendix (B).

3.4.2 Excel Template for PCI&PI Calculation

According to ASTM, the procedure used to determine PCI for a pavement section can be divided into following four steps:

(1) Convert raw data to distress density (%) using area of surveyed section as denominator;

(2) Find deduct value (DV) using DV-Density graph;

(3) Sum the largest 7 DVs resulting in total deduct value (TDV);

(4) Find corrected deduct value (CDV) using CDV-TDV graph and PCI equal to 100-CDV.

The next phase is to implement all of the mathematical functions and algorithms into an Excel template. The nonlinear (multinomial) functions for DV curves are derived directly from ASTM. The algorithm used to determine maximum CDV and PCI is followed in Section 4.3.

The template provides user-friendly transformation of regions to PCI and PI values for each road section data. The format developed was made compatible with the dataset available.

In addition, many Visual Basic (VB) codes have been used to connect the sheet and mathematical equations to achieve the process of automation in the calculation of the required values. All code shown in Appendix(C). A screenshot of the template is shown in Figure 3.1.

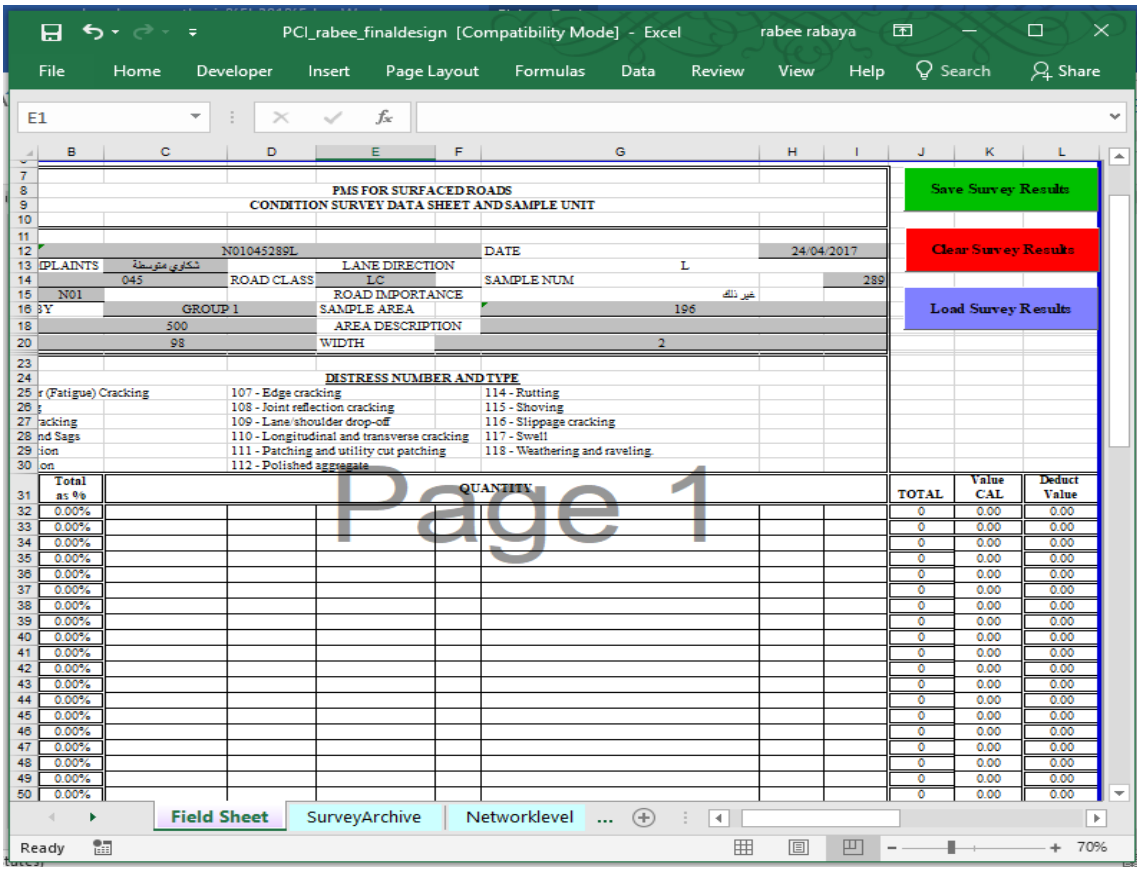
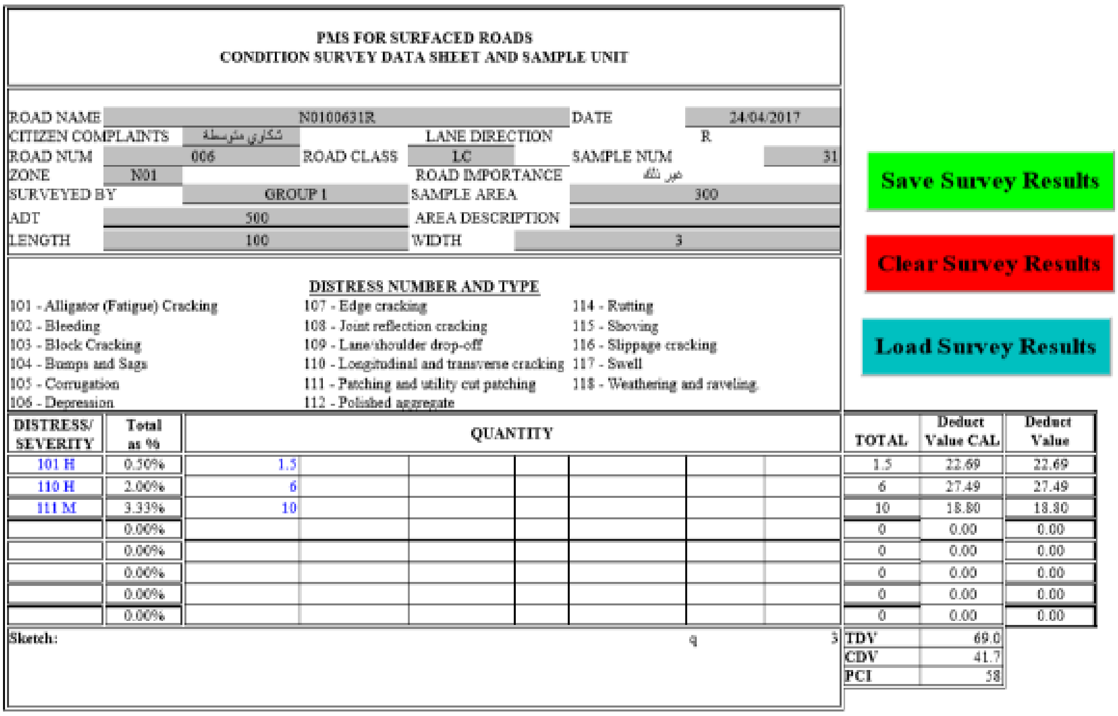


Figure 3.1: A screenshot of the Excel template

The first Excel sheet (titled as "Field Sheet ") the template includes the type, quantity, severity level of each distress, section ID, survey date, and other basic inventory data. Figure 3.2 shows the first Excel sheet.



PMS FOR SURFACED ROADS
CONDITION SURVEY DATA SHEET AND SAMPLE UNIT

ROAD NAME N0100631R DATE 24/04/2017
CITIZEN COMPLAINTS شكاوي متوسطة LANE DIRECTION R
ROAD NUM 006 ROAD CLASS LC SAMPLE NUM 31
ZONE N01 ROAD IMPORTANCE غير ذلك
SURVEYED BY GROUP 1 SAMPLE AREA 300
ADT 500 AREA DESCRIPTION
LENGTH 100 WIDTH 3

DISTRESS NUMBER AND TYPE

101 - Alligator (Fatigue) Cracking
102 - Bleeding
103 - Block Cracking
104 - Bumps and Sags
105 - Corrugation
106 - Depression
107 - Edge cracking
108 - Joint reflection cracking
109 - Lane/shoulder drop-off
110 - Longitudinal and transverse cracking
111 - Patching and utility cut patching
112 - Polished aggregate
114 - Rutting
115 - Shoving
116 - Slippage cracking
117 - Swell
118 - Weathering and raveling.

DISTRESS/ SEVERITY	Total as %	QUANTITY	TOTAL	Deduct Value CAL	Deduct Value
101 H	0.50%	1.5	1.5	22.69	22.69
110 H	2.00%	6	6	27.49	27.49
111 M	3.33%	10	10	18.80	18.80
	0.00%		0	0.00	0.00
	0.00%		0	0.00	0.00
	0.00%		0	0.00	0.00
	0.00%		0	0.00	0.00
	0.00%		0	0.00	0.00

Sketch: q 3

TDV	69.0
CDV	41.7
PCI	58

Save Survey Results
Clear Survey Results
Load Survey Results

Figure 3.2: The first Excel sheet "field sheet "

Also, the sheet contains three buttons first of them is Save Survey Results button in green color, this button is pressed when you have finished entering all the data for the road segment to calculate the PCI and PI value. The entered data and account results are saved in the fields assigned to that information and results when you press this button. The second button is Clear Survey Results button in red color, when you press this button you will see a screen containing all the data entered and this button gives you two options. The first option is to delete all entered data and the second option is to delete the selected data only.

This button is used when needed to delete erroneous entries or to delete data that has been modified. Where, through these buttons the model can built a historical sequence of the road condition and the changes over time. Figure 3.3 shows Clear Survey Results button screen.

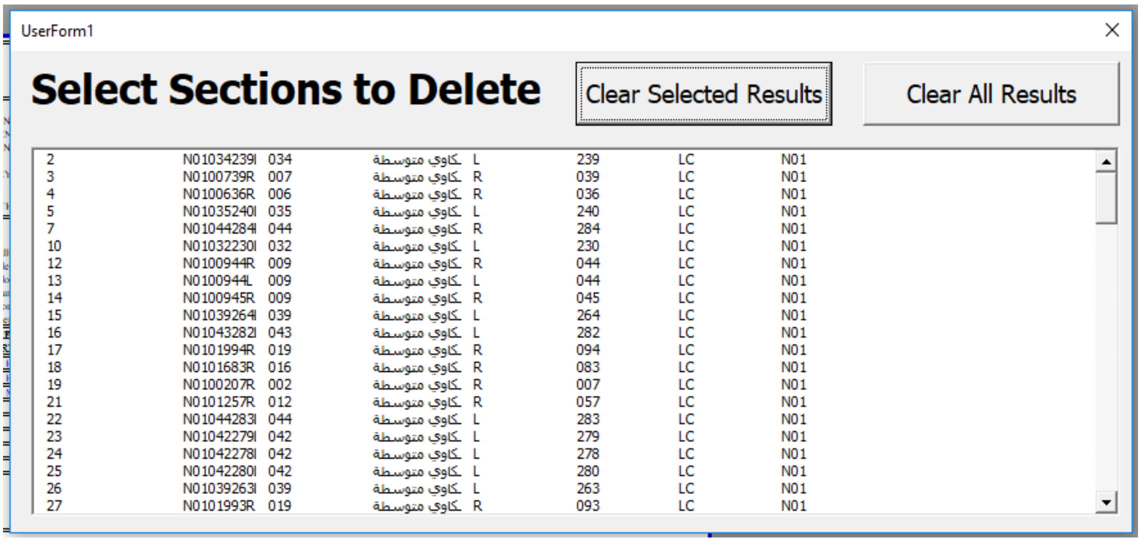


Figure 3.3: Clear Survey Results button screen

The third button is Load Survey Results button in blue color, this button is used to modify some data from a previous entry. When you press the button, you will see a screen that contains all the previous entries where the data you intend to modify are selected and then press on the load button in the pop-up screen. Figure 3.4 shows the Load Survey Results button screen.

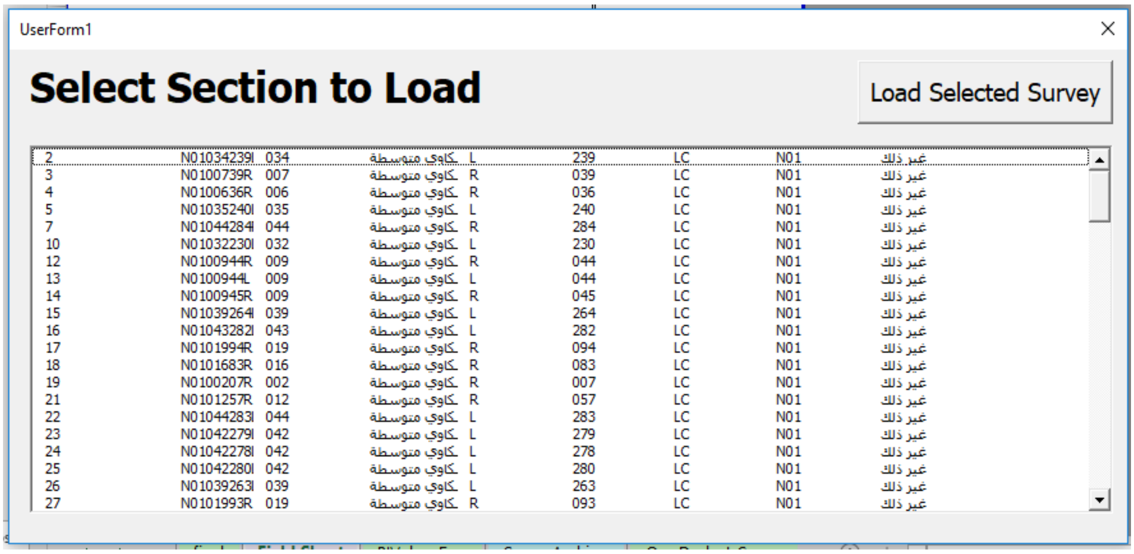


Figure 3.4: Load Survey Results button screen.

The second sheet (titled as "Survey Archive ") and it contains all data was entered in Field Sheet arranging in table to be the main resource of data needed in PCI and PI calculations. In this sheet there is a column named ROADName, which contains a unique code for each road section. Where the method of coding used in the O&M manual of the municipalities in Palestine was adopted with the addition of some modifications to encoding roads and road sections in this research. The value of this field is obtained by associating the order of the elements used in the encoding process. As explained in the following Tables 3.1&3.2. Figure 3.5 shows the second sheet titled as "Survey Archive"

Table 3.1: The method of coding in O&M manual of the municipalities in Palestine,2014

Items	Zone	Road Classification	Road Number	Road Segment
number of digits	xx	Xx	xxx	xx
Value	01-99	AR=Arterial Road CR=Collector Road LR=Local Road	001-999	01-99

Table 3.2: the method of coding in this research

Items	Governorate	Zone	Road Number	Road Segment	Direction of lane
number of digits	x	Xx	xxx	xx	x
Value	The first letter from Gov name	01-99	001-999	01-99	R= Right L=Left

SURVEYID	ROADName	ROADNUM	SectionNUM	ZONE	LANEDIRECTION	FIROADCLASS	FIROADADT	FIPCI	FICITIZATIONCOMPLAINTS	FIROADIMpORTANCE	PI	PCI
1	N01034239L	034	239	N01	L	50	100	46	0	25	42	54
2	N0100739R	007	039	N01	R	50	100	6	0	25	24	94
3	N0100636R	006	036	N01	R	50	100	31	0	25	35	69
4	N01035240L	035	240	N01	L	50	100	27	0	25	33	73
5	N01032230L	032	230	N01	L	50	100	15	0	25	28	85
6	N0100944R	009	044	N01	R	50	100	29	0	25	34	71
7	N0100945R	009	045	N01	R	50	100	23	0	25	31	77
8	N01039264L	039	264	N01	L	50	100	4	0	25	23	96
9	N01043282L	043	282	N01	L	50	100	40	0	25	39	60
10	N0101994R	019	094	N01	R	50	100	10	0	25	25	90
11	N01044283L	044	283	N01	L	50	100	59	0	25	47	41
12	N01042279L	042	279	N01	L	50	100	62	0	25	49	38
13	N01042278L	042	278	N01	L	50	100	37	0	25	37	63
14	N01042280L	042	280	N01	L	50	100	83	0	25	58	17
15	N01039263L	039	263	N01	L	50	100	33	0	25	36	67
16	N0101993R	019	093	N01	R	50	100	37	0	25	38	63
17	N01045289L	045	289	N01	L	50	100	0	0	25	21	100
18	N0102097R	020	097	N01	R	50	100	20	0	25	30	80
19	N0102096R	020	096	N01	R	50	100	36	0	25	37	64
20	N01045288L	045	288	N01	L	50	100	20	0	25	30	80
21	N01045287L	045	287	N01	L	50	100	34	0	25	36	66
22	N0102095R	020	095	N01	R	50	100	45	0	25	41	55
23	N0101052R	010	052	N01	R	50	100	32	0	25	35	68
24	N01033237L	033	237	N01	L	50	100	25	0	25	32	75
25	N01033235L	033	235	N01	L	50	100	28	0	25	33	72
26	N0101050R	010	050	N01	R	50	100	28	0	25	33	72
27	N0101049R	010	049	N01	R	50	100	46	0	25	42	54
28	N01033234L	033	234	N01	L	50	100	35	0	25	37	65

Figure 3.5: The second sheet "Survey Archive "

The third sheet (titled as "Project level") in this sheet the project level pavement management approach was applied by obtaining the PCI and PI values for all road section. Figure 3.6 shows the third sheet "Project level ".

SURVEYID	ROADName	ROADNUM	CITIZEN COMPLAINTS	LANE DIRECTION	SectionNUM	ROADCLASS	ZONE	ROAD IMPORTANCE	ADT
2	N01034239L	034	شكاوي متوسطة	L	239	LC	N01	غير ذلك	500
3	N0100739R	007	شكاوي متوسطة	R	039	LC	N01	غير ذلك	500
4	N0100636R	006	شكاوي متوسطة	R	036	LC	N01	غير ذلك	500
5	N01035240L	035	شكاوي متوسطة	L	240	LC	N01	غير ذلك	500
11	N01032230L	032	شكاوي متوسطة	L	230	LC	N01	غير ذلك	500
12	N0100944R	009	شكاوي متوسطة	R	044	LC	N01	غير ذلك	500
14	N0100945R	009	شكاوي متوسطة	R	045	LC	N01	غير ذلك	500
15	N01039264L	039	شكاوي متوسطة	L	264	LC	N01	غير ذلك	500
60	N01030222L	030	شكاوي متوسطة	L	222	LC	N01	غير ذلك	500
61	N0101786R	017	شكاوي متوسطة	R	086	LC	N01	غير ذلك	500
64	N0101784R	017	شكاوي متوسطة	R	084	LC	N01	غير ذلك	500
66	N01030220L	030	شكاوي متوسطة	L	220	LC	N01	غير ذلك	500
69	N01030221L	030	شكاوي متوسطة	L	221	LC	N01	غير ذلك	500
70	N0101785R	017	شكاوي متوسطة	R	085	LC	N01	غير ذلك	500
86	N0101051R	010	شكاوي متوسطة	R	051	LC	N01	غير ذلك	500
88	N0100423R	004	شكاوي متوسطة	R	023	LC	N01	غير ذلك	500
89	N0100424R	004	شكاوي متوسطة	R	024	LC	N01	غير ذلك	500
91	N01021106R	021	شكاوي متوسطة	R	106	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
92	N01021105R	021	شكاوي متوسطة	R	105	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
93	N01021104R	021	شكاوي متوسطة	R	104	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
94	N01021103R	021	شكاوي متوسطة	R	103	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
95	N01021102R	021	شكاوي متوسطة	R	102	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
96	N01021101R	021	شكاوي متوسطة	R	101	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
97	N01040273L	040	شكاوي متوسطة	L	273	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
98	N01040272L	040	شكاوي متوسطة	L	272	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
99	N01040271L	040	شكاوي متوسطة	L	271	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000
100	N01040270L	040	شكاوي متوسطة	L	270	AR	N01	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	10000

Figure 3.6: The third sheet "Project level"

The forth sheet (titled as" Network level ") the network level pavement management approach was applying in this sheet by obtaining the PCI and PI values for the roads in general by using the weighted mean method. Where, in this method, the contribution in PCI value from each section in the road are calculated based on the area of sections not length because the width of sections not equal for all sections. All sections are calculated for the small sample size to achieve the highest accuracy. Figure 3.7 shows the forth sheet "Network level".

$$\mathrm{PCIroad} = \frac{\mathrm{Area1} * \mathrm{PCI1} + \mathrm{Area2} * \mathrm{PCI2} + \mathrm{Area3} * \mathrm{PCI3}}{\mathrm{Total\ Area\ for\ road}}$$

Where:

Area(i)=width(i)*length(i)

The length almost equal 100 m upon the PCI standard calculation, so the width is the main variable in PCI calculation and this value take into consideration in data collection and build PMS database stages.

Also, PI value for the road in general is calculated using the same method as in PCI:

$$\mathrm{PIroad} = \frac{\mathrm{Area1} * \mathrm{PI1} + \mathrm{Area2} * \mathrm{PI2} + \mathrm{Area3} * \mathrm{PI3}}{\mathrm{Total\ Area\ for\ road}}$$

The fifth and sixth sheets (titled as "PCI Eqs." and "Detective value Eqs.") this sheet includes all mathematical equations and its limits that are used in DV calculation. Figure 3.8 shows the fifth sheet "PCI Eqs." and Figure 3.9 shows the sixth sheet "Detective Value Eqs."

ID	ROAD	COMPLAINTS	DIRECTION	ROAD_NUM	CLASS	ZONE	SectionNum	ROAD_IMPORTANCE	ADT	PCI	PI
1	N01034239L	شكاوي متوسطة	L	034	LC	N01	239	غير ذلك	500	54	42
2	N0100739R	شكاوي متوسطة	R	007	LC	N01	039	غير ذلك	500	93	24
3	N0100636R	شكاوي متوسطة	R	006	LC	N01	036	غير ذلك	455	65	37
4	N01035240L	شكاوي متوسطة	L	035	LC	N01	240	غير ذلك	83	73	33
5	N01032230L	شكاوي متوسطة	L	032	LC	N01	230	غير ذلك	133	84	28
6	N0100944R	شكاوي متوسطة	R	009	LC	N01	044	غير ذلك	111	79	30
7	N01039264L	شكاوي متوسطة	L	039	LC	N01	264	غير ذلك	500	83	28
8	N01043282L	شكاوي متوسطة	L	043	LC	N01	282	غير ذلك	250	60	39
9	N0101994R	شكاوي متوسطة	R	019	LC	N01	094	غير ذلك	333	77	32
10	N01044283L	شكاوي متوسطة	L	044	LC	N01	283	غير ذلك	300	57	40
11	N01042279L	شكاوي متوسطة	L	042	LC	N01	279	غير ذلك	278	43	47
12	N01045289L	شكاوي متوسطة	L	045	LC	N01	289	غير ذلك	500	82	29
13	N0102097R	شكاوي متوسطة	R	020	LC	N01	097	غير ذلك	300	66	36
14	N0101052R	شكاوي متوسطة	R	010	LC	N01	052	غير ذلك	500	68	35
15	N01033237L	شكاوي متوسطة	L	033	LC	N01	237	غير ذلك	278	69	35
16	N0101683R	شكاوي متوسطة	R	016	LC	N01	083	غير ذلك	500	73	33
17	N01027172L	شكاوي متوسطة	L	027	LC	N01	172	غير ذلك	500	60	39
18	N0101892R	شكاوي متوسطة	R	018	LC	N01	092	غير ذلك	500	48	44
19	N01031228L	شكاوي متوسطة	L	031	LC	N01	228	غير ذلك	300	46	45
20	N01030222L	شكاوي متوسطة	L	030	LC	N01	222	غير ذلك	500	85	28
21	N0101786R	شكاوي متوسطة	R	017	LC	N01	086	غير ذلك	286	57	40
22	N0100423R	شكاوي متوسطة	R	004	LC	N01	023	غير ذلك	500	42	47
23	N01021106R	شكاوي متوسطة	R	021	AR	N01	106	ي ويمر بالمنطقة التجارية او بالقرب من	10000	69	41
24	N01040273L	شكاوي متوسطة	L	040	AR	N01	273	ي ويمر بالمنطقة التجارية او بالقرب من	10000	58	47
25	N0101156R	شكاوي متوسطة	R	011	LC	N01	056	غير ذلك	500	53	42
26	N01048295L	شكاوي متوسطة	L	048	LC	N01	295	غير ذلك	500	70	35
27	N01037247L	شكاوي متوسطة	L	037	LC	N01	247	غير ذلك	500	58	40
28	N01022113R	شكاوي متوسطة	R	022	LC	N01	113	غير ذلك	500	58	40
29	N0100206R	شكاوي متوسطة	R	002	LC	N01	006	غير ذلك	500	69	35
30	N0101257R	شكاوي متوسطة	R	012	LC	N01	057	غير ذلك	500	62	38

Figure 3.7: The forth sheet " Network level "

Distress Type	Distress Range	DV Range	Distress Type	DV Selected
101 H	0-3	11.74585722		
101M	0-2	7.497782621		
101L	0-2	4.60745		
101 H	3-100	3.337316798	101 H	11.74585722
101M	2-100	-12.3819605	101M	7.497782621
101L	2-100	-19.66193878	101L	4.60745
102M	0-3	-2.999858381	102 H	-2.999858381
102 H	3-100	1.69222815	102M	0.852182097
102M	3-100	1.273905975	102L	1.92704E-05
102L	3-100	0.07559034	103H	-6.366851179
102H	0-3	0.852182097	103M	-9.47507849
102L	0-3	1.92704E-05	103L	-13.36570145
103H	0-4	-6.366851179	104H	19.44611072
103H	4-100	4.003633098	104M	7.484697575
103M	0-6	-9.47507849	104L	0.327761196
103M	6-100	2.213274887	105H	11.18056212
103L	0-10	-13.36570145	105M	5.937349
103L	10-100	0.861683967	105L	0.386815249
104H	0-1	19.44611072	106H	13.798273
104H	1-100	28.04464136	106M	8.320317
104M	0-100	7.484697575	106L	3.371545
104L	0-1	0.327761196	107H	6.524091239
104L	1-100	1.467447333	107M	3.139084736
105H	0-2	11.18056212	107L	1.084651
105H	2-100	22.62902371	108H	2.522184298
105M	0-2	5.937349	108M	1.387337
105M	2-100	9.937567989	108L	-1.399887
105L	0-2	0.386815249	109H	6.159156
105L	2-100	2.83558906	109M	4.415069
106H	10-100	28.3504741	109L	0.150787
106H	0-10	13.798273	110H	4.790006123
106M	10-100	16.82730909	110M	-5.658589326
106M	0-10	8.320317	110L	3.458252
106L	0-10	3.371545	111H	7.105930696
106L	10-100	-41.00523016	111M	2.92929
107H		6.524091239	111L	-1.404415
107M		3.139084736	112L	-1.404415
107L		1.084651	112M	0
108H	0-7	2.522184298	112H	0
108H	7-100	42.724652	113H	55.32362614
108M	0-5	1.387337	113M	32.33983093
108M	5-100	-19.69396502	113L	18.41177203
108L	0-7	-1.399887	114H	5.552842526
108L	7-100	0.86582083	114M	4.997045925

Figure 3.8 screen shot from the fifth sheet " PCI Eqs "

The seventh sheet (titled as" CDV ") and it contains the mathematical Equations used to determine Corrective Detective Value. Figure 3.10 shows the seventh sheet (" CDV Eqs ").

Distress List	
Code	Number
101 - Alligator (Fatigue) Cracking	101
102 - Bleeding	102
103 - Block Cracking	103
104 - Bumps and Sags	104
105 - Corrugation	105
106 - Depression	106
107 - Edge cracking	107
108 - Joint reflection cracking	108
109 - Lane/shoulder drop-off	109
110 - Longitudinal and transverse cracking	110
111 - Patching and utility cut patching	111
112 - Polished aggregate	112
113 - Potholes	113
114 - Rutting	114
115 - Shoving	115
116 - Slippage cracking	116
117 - Swell	117
118 - Weathering and raveling.	118

Distress List	**Deduct Coefficient Parameters**		**Max Extent**
	Y	**X**	
101 L	4.60745	0.1000	100
101 M	7.497782621	0.1000	100
101 H	11.74585722	0.1000	20
102 L	1.92704E-05	0.1000	65
102 M	- 2.999858381	0.1000	30
102 H	0.852182097	0.1000	100
103 L	- 13.36570145	0.1000	30
103 M	-9.47507849	0.1000	15
103 H	- 6.366851179	0.1000	100
104 L	0.327761196	0.1000	10
104 M	7.484697575	0.1000	100
104 H	19.44611072	0.1000	100
105 L	0.386815249	0.1000	100
105 M	5.937349	0.1000	100
105 H	11.18056212	0.1000	20
106 L	3.371545	0.1000	65
106 M	8.320317	0.1000	30
106 H	13.798273	0.1000	100

Fatigue Cracking		
	X	Y
Low	0.1	4.61
Medium	0.1	7.50
high	0.1	11.75

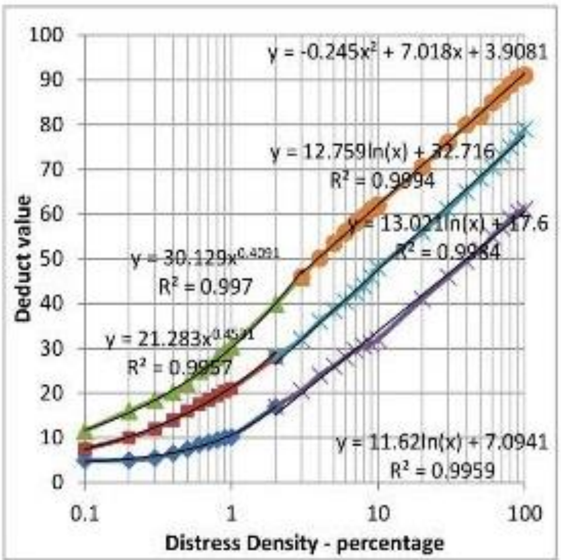


Figure 3.9: The sixth sheet " Detective value Eqs "

If	Eq
Q=1	y = x
Q=2	y = 0.5994x + 5.7421
Q=3	y = 0.5681x + 2.5118
Q=4	y = 0.5218x + 1.5156
Q=5	y = 0.5039x - 1.1146
Q=6	y = 0.4757x - 0.6059
Q=7	y = 0.4353x + 2.5678

q=1	X	
	Y	0
q=2	X	
	Y	5.7421
q=3	X	
	Y	2.5118
q=4	X	
	Y	1.5156
q=5	X	
	Y	-1.1146
q=6	X	
	Y	-0.6059

Figure 3.10: The seventh sheet (" CDV ")

The eighth sheet (titled as" PI Eqs ") this sheet includes all mathematical equations limits, and coefficients that are used in PI calculation. Figure 3.11 shows the tables in eighth sheet (" PI Eqs ").

معامل الاولية (Fi)الخاص بنوع الطريق

المعامل	نوع الطريق	الرقم
100	Arterial-الطرق الشريانية	1
75	Collector-الطرق التجميعية	2
50	Local-الطرق المحلية	3
25	Parking-ساحات المواقف العامة	4

معامل الاولية (Fi) لشكاوى المواطنين

المعامل	نوع الطريق	الرقم
100	Severe Complains-شكاوى كثيرة	1
66	Mid Complains-شكاوى متوسطة	2
33	Little Complains-شكاوى قليلة	3
0	No Complains- لا توجد شكاوى	4

معامل الاولية (Fi) لحالة الرصفة الاسفلتية PCI

الرقم	تقييم السطح	قيمة ال PCI
1	10 (ممتاز)Excellent	10
2	9 (ممتاز)Excellent	20
3	8 (جيد جدا)Very Good	30
4	7 (جيد)Good	40
5	6 (جيد)Good	50
6	5(مقبول)Fair	60
7	4(مقبول)Fair	70
8	3(ضعيف)Poor	80
9	2(ضعيف جدا)Very Poor	90
10	1(منهار/فاشل)Failure	100

معامل الاولية (Fi) لأهمية الطريق بالمجتمع

الرقم	نوع الطريق	المعامل
1	طريق شرياني ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	100
2	طريق تجميعي ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	75
3	طريق محلي ويمر بالمنطقة التجارية او بالقرب من اماكن هامة	50
4	غير ذلك	25

حساب الأولويات PI

العنصر	الوزن WI
نوع / تصنيف الطريق Functional Classification	0.13
حالة الرصفة PCI Pavement Condition	0.45
حجم المرور ADT Average Daily Traffic	0.12
أهمية الطريق للمجتمع Importance of Road to Community	0.2
شكاوى المواطنين Citizens Satisfaction	0.1
المجموع	1

حساب معامل الاولية

العنصر	المعامل Fi	الوزن Wi	Fi*Wi
نوع / تصنيف الطريق Functional Classification	20	0.13	2.6
حالة الرصفة PCI Pavement Condition	50	0.45	22.5
حجم المرور ADT Average Daily Traffic	60	0.12	7.2
أهمية الطريق للمجتمع Importance of Road to Community	80	0.2	16
شكاوى المواطنين Citizens Satisfaction	43	0.1	4.3
PI			52.6

Figure 3.11: The eighth sheet ("PI Eqs ")

3.5 Developing Integrated PMS-GIS Model

3.5.1 Introduction

GIS is one of the latest techniques followed by using computers to save quantities massive tabular data with large areas of the maps that cannot be saved properly on a paper. Data are saved with maps in a consistent type so it is easy for the user to display the tabular data with maps in a variety of styles and also it allows the user to conduct computational and statistical processing to extract the results that help in making a quick and appropriate decision.

In this research GIS was utilized the Pavement Management and Maintenance System in study area in Nablus city to assist in the preparation of a suitable database of paved roadways. GIS acts as a Management Information System which can be best described as a system to store and deliver reliable data, in an efficient manner to the required planning process.

3.5.2 PMS and GIS Database Linkage

As mentioned in the previous the main method for linking PMS and GIS is database linkage process. In this study the latest version of GIS software has been utilized so as to establish the database and develop the system. ArcGIS 10 which is developed by “Environmental Systems Research Institute” (ESRI) was the primary GIS software utilized to perform the required integration with PMS. Figure 3.12 shows ArcGIS interface.

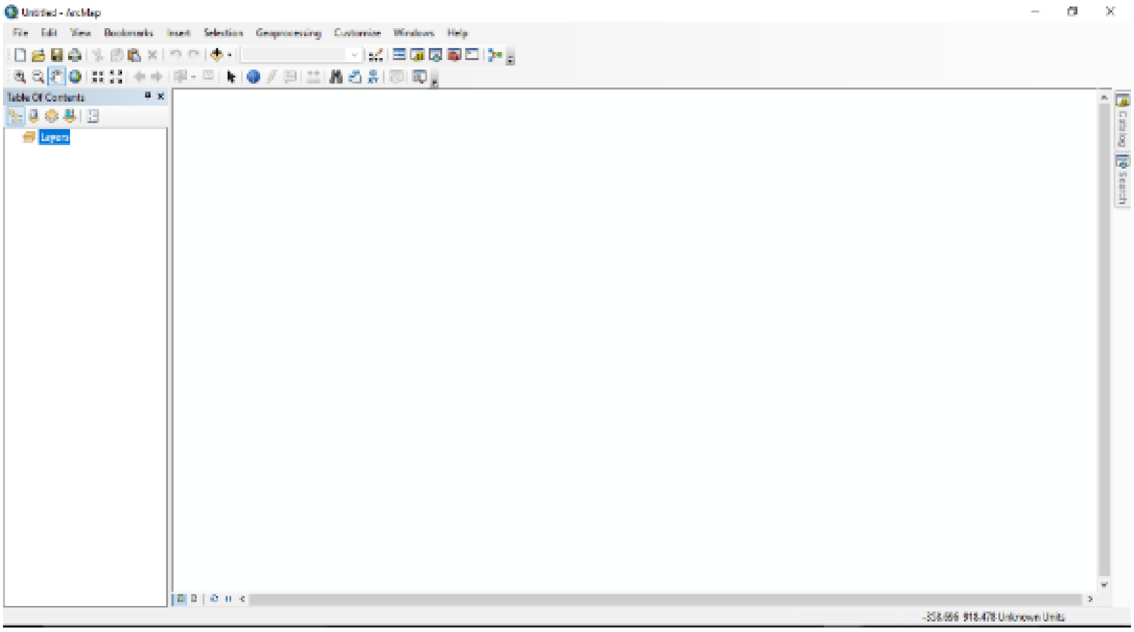


Figure 3.12: The main interface of ArcGIS (ArcMap).

Applying PMS-GIS model aims to:

- Act as storage for pavement inventory data.
- Link pavement data with the referenced map.
- Display the current and future pavement condition on a thematic map.
- Display the proposed M&R actions on a thematic map.
- Provide an easy access to the pavement segments.
- Assist in conducting statistical analysis.
- Assist in conducting “what if” queries to the pavement segments.
- Assist in decision making process.

• Act as a tool in monitoring and updating pavement maintenance process.

In order to link PMS data with GIS, and also to accomplish the above objectives, the following steps should be performed properly:

1. Importing a base map
2. Projection the imported map.
3. Preparing a pavement network (shapefile).
4. Integration PMS data base with a GIS data base
5. Symbology of output map.

1. Importing a base map

Spatial data modeling necessitates the availability of a topographic base map in geographical information system software, which would serve as a foundation to be further populated with other additional data.

2. Define Projection Map

After adding the base map to ArcMap, the other map to be added should be Define Projection to base map Coordination System in ArcGIS.

3-Preparing a Pavement Network

This is the key process in the integration of GIS with PMS. Where the objective of this process is to create a spatial database consistent with the outputs of the pavement management operations. This process is necessary to facilitate data collection by producing appropriate field maps for field survey for road defects. Process of preparing pavement network passing through several steps. And these steps and processes were modeled by ArcMap model builder to automate this process and accomplish it as quickly and effortlessly as possible. The steps are:

1- Obtaining road network from a reliable source or create it manually by GIS.

2- Checking and treating the road network and repair any defect or recurrence. At this stage, the start point and the end point of each road are determined.

3- Dividing the roads network into sections with a length of 100 meters using the X tool.

4- After the implementation of the previous three steps we extract a new layer from the road network then reverse its direction by Flip tools.

5- Adding a new field with name lane direction to the tow roads network layer, in the first layer the value of new filed is "R" letter and its refer to Right direction and in the second layer the value is "L" letter and its refer to left direction. This process is implemented to obtain a representation of both direction of movement and it's one of the PMS coding requirements.

6- Merging between the two-road networks by merge tool to get one road network layer represent the tow direction.

7- Intersecting between the final road network layer and zone layer with tolerance 1 meter to get new field in road network contain in which zone the road are locate. Also, it's one of the PMS coding requirements.

8- At this stage, all components of the PMS coding system are available in the same layer. As explained earlier in this study, the following Table 3.3 shows the components of the coding process to be used.

Table 3.3: The method of coding in this research

Items	Governorate	Zone	Road Number	Segment Number	Direction of lane
Number of digits	X	xx	xxx	xx	x
Value	The first letter from Gov name	01-99	001-999	01-99	R= Right L=Left

At this stage a new field will be created with the name of PCI. This field contains the unique code for each road section, the value of this field will be obtained by using the following python code by ArcMap field calculator tool based on the adopted method.

```
PCIname= str( !zone!)+str(!ROAD_NO_!).zfill(3)+str
(!segment_no!).zfill(2)+str( !lane_di!)
```

Note: .zfill(2) is a python function to include leading zeros

After completing all the previous stages, the road network will be ready to link with the PMS database that was created in the Excel sheet as will be explained in the following process. Figure 3.13 shows the ArcMap model used in preparing a pavement network.

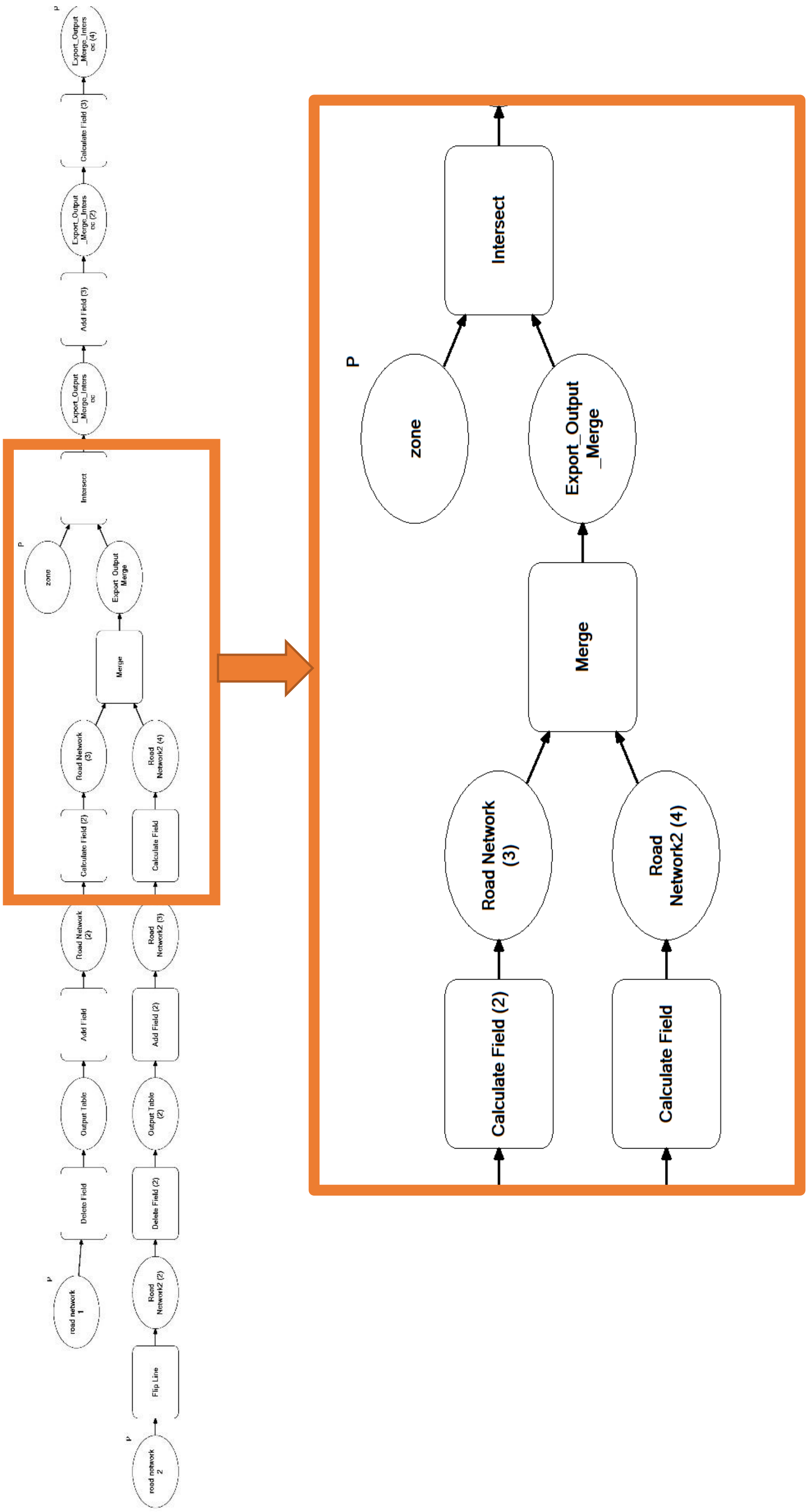


Figure 3.13: Preparing a pavement network model

4- Integration PMS data base with a GIS data base

According to the three-database integration methods, previously mentioned in the literature review, the Seamless integration method will be applied in this research where, the PMS data base are carried out inside the GIS by sharing a common database.

This method provides the ability to automate all connections dynamically between PMS data base and GIS data base to facilitate the connection process and save time and effort.

This process passing through three steps:

1- Creating dynamic PMS data base from the excel sheet through :- /control panel /administrative tools/ ODBC Data Sources (32-bit) tool, Figure 3.14 shows the Open Database Connectivity (ODBC) Data Sources (32-bit) tools

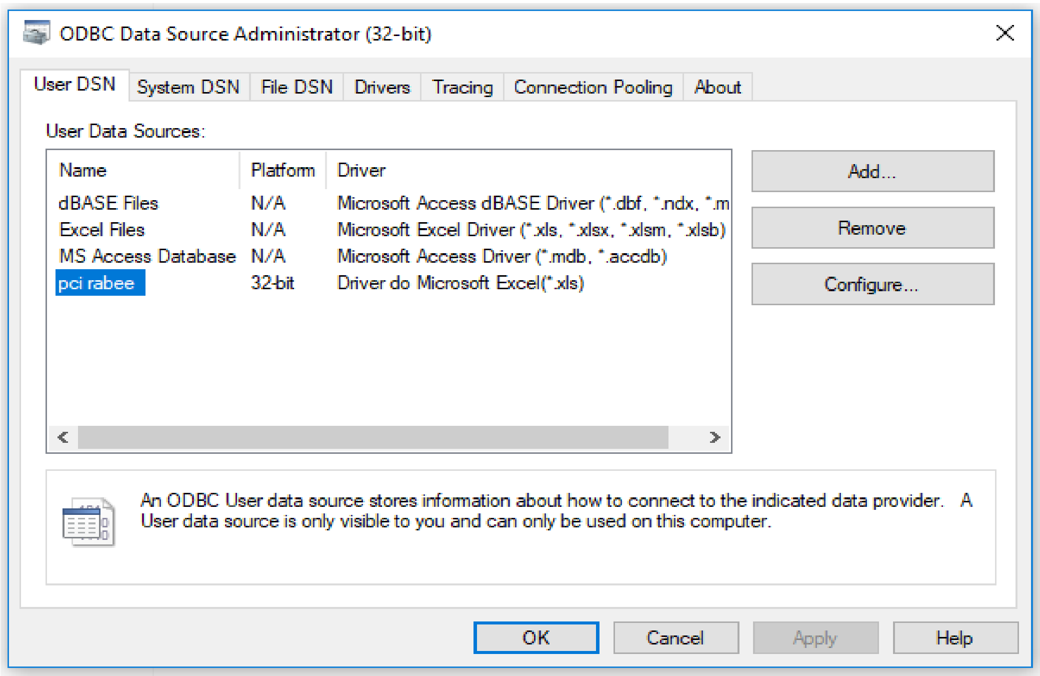


Figure 3.14: Open Database Connectivity (ODBC) Data Sources (32-bit) tools

2- Defining the dynamic connection created in previous steps in arc catalog by adding Object Linking and Embedding, Database (OLE DB) Connection as shown in Figure 3.15.

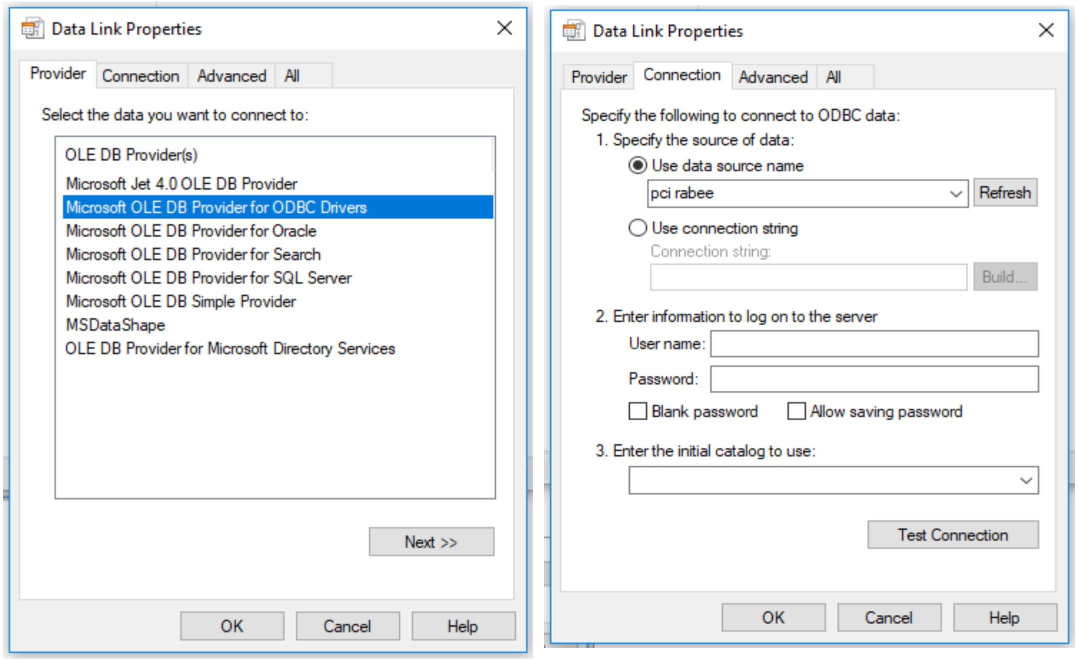


Figure 3.15: ODBC Data Sources (32-bit) tools

After the preparation of this stage, the PMS database becomes dynamically linked with the GIS. This means that any changes, additions or subtraction in the Excel sheet will be automatically reversed in the GIS.

3- Joining between road network shape and PMS database, the method one-to-one will be used in join, which will be join by the unique fields prepared in the previous stages in PMS database and GIS database. Figure 3.16 shows the ArcMap model use in join database.

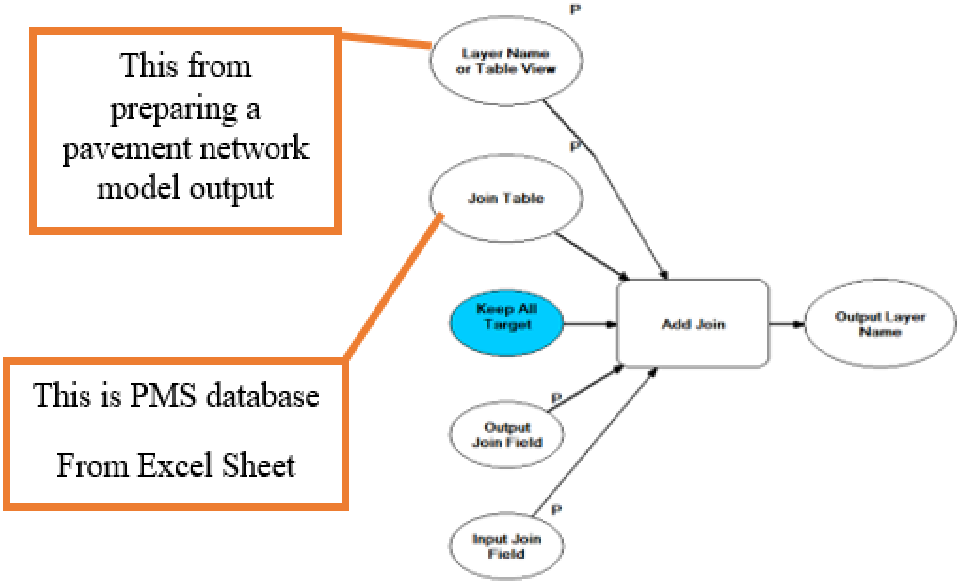


Figure 3.16 Join model

5-Sympology of output map

Finally, various reports, queries, charts, thematic maps with legends and symbols are produced by GIS and the main output is thematic maps. The method of representing the priority index is different from the method of representing the pavement condition index. Where in the PCI, the rates are divided into five categories: (0-20), (20-40), (40-60), (60-80), (80-100), and each value lies within any category gives them a certain color as in Table 3.4. And for the PI rating, one color is adopted and each PI value is given a degree of intensity to representing the amount of the need this road for maintenance, as shown in Figure 3.17.

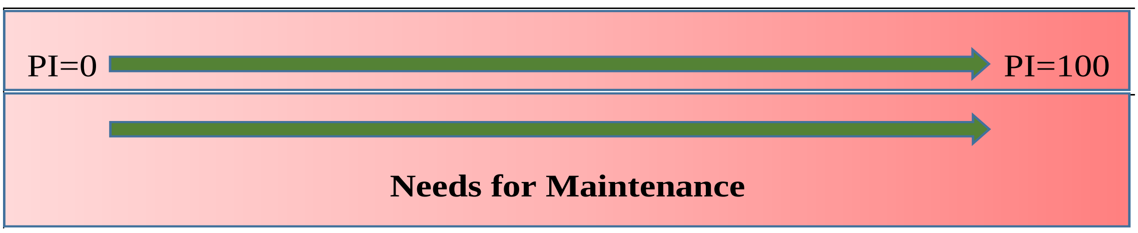


Figure 3.17: Symbology of Priority Index

Table 3.4: Pavement Condition Index (PCI) Rating

PCI value	Status	Color in map
80-100	Excellent	
60-80	Very Good	
40-60	Fair	
20-40	Poor	
0-20	Fail	

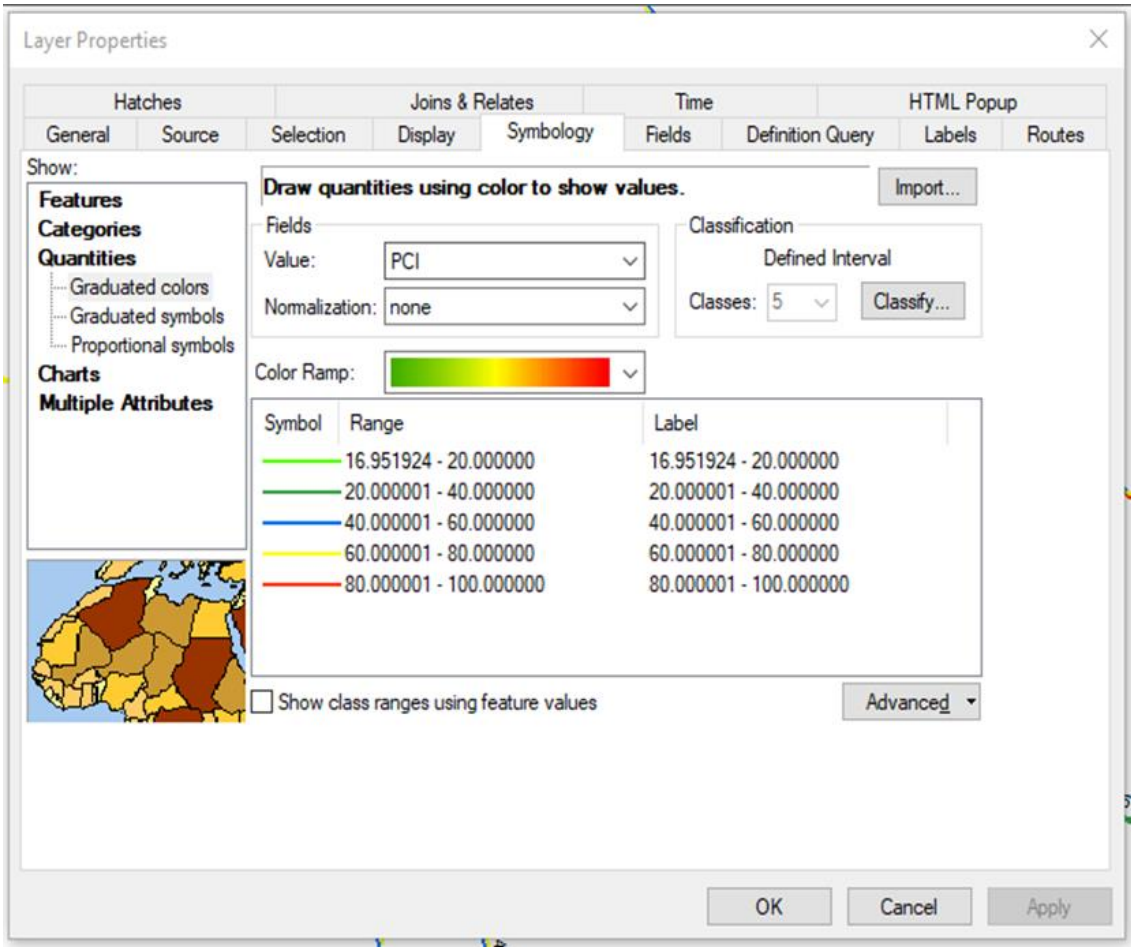


Figure 3.18: Pavement Condition Index symbology layer tools

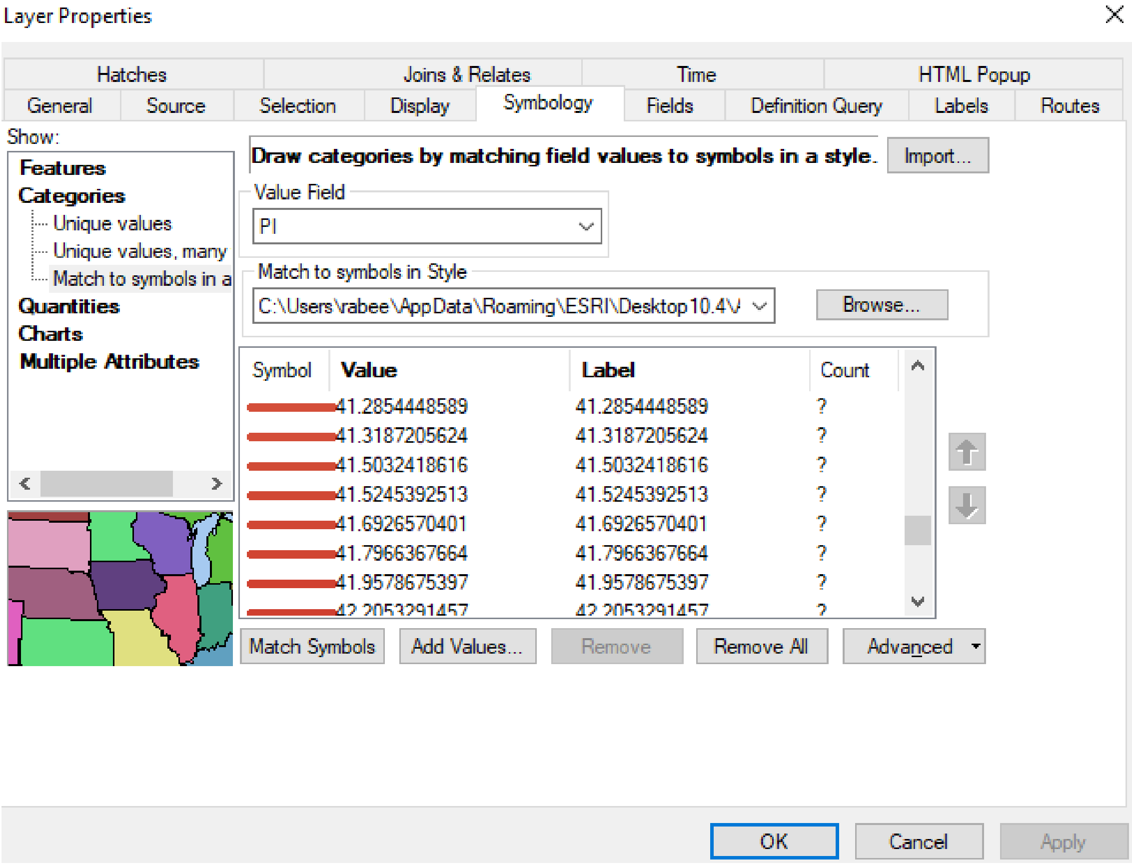


Figure 3.19: Priorty Index symbology layer tools

3.6 Summary

The manual uses of the existing PCI method provided by ASTM to a large number of road sections is time-consuming, costly and labor-intensive. Due to the need for large scale data analysis in this research study, it was necessary to develop an automated version of the ASTM PCI calculation procedure. The algorithm and mathematical functions used in the automated Excel template are the same as those provided by ASTM. The template, will serve as an efficient PCI calculation tool for the rest of the analysis in this research. In addition, the automated PCI calculation template can be utilized with any pavement performance database that is driven by pavement distresses data.

Chapter Four

Application: a Case from Nablus City

4.1 Introduction

In this research, a PMS-GIS model was developed on the basis of the systematic process. In this process, the two-main software's are utilized, these software's are Ms Excel and Geographic Information System (GIS). The first one is used for storing and evaluating the PMS data and the second one (GIS) has been used as an intelligent software for presenting PMS results on a geographic map. Figure 4.1 shows a proposed system that is explained in the following sections.

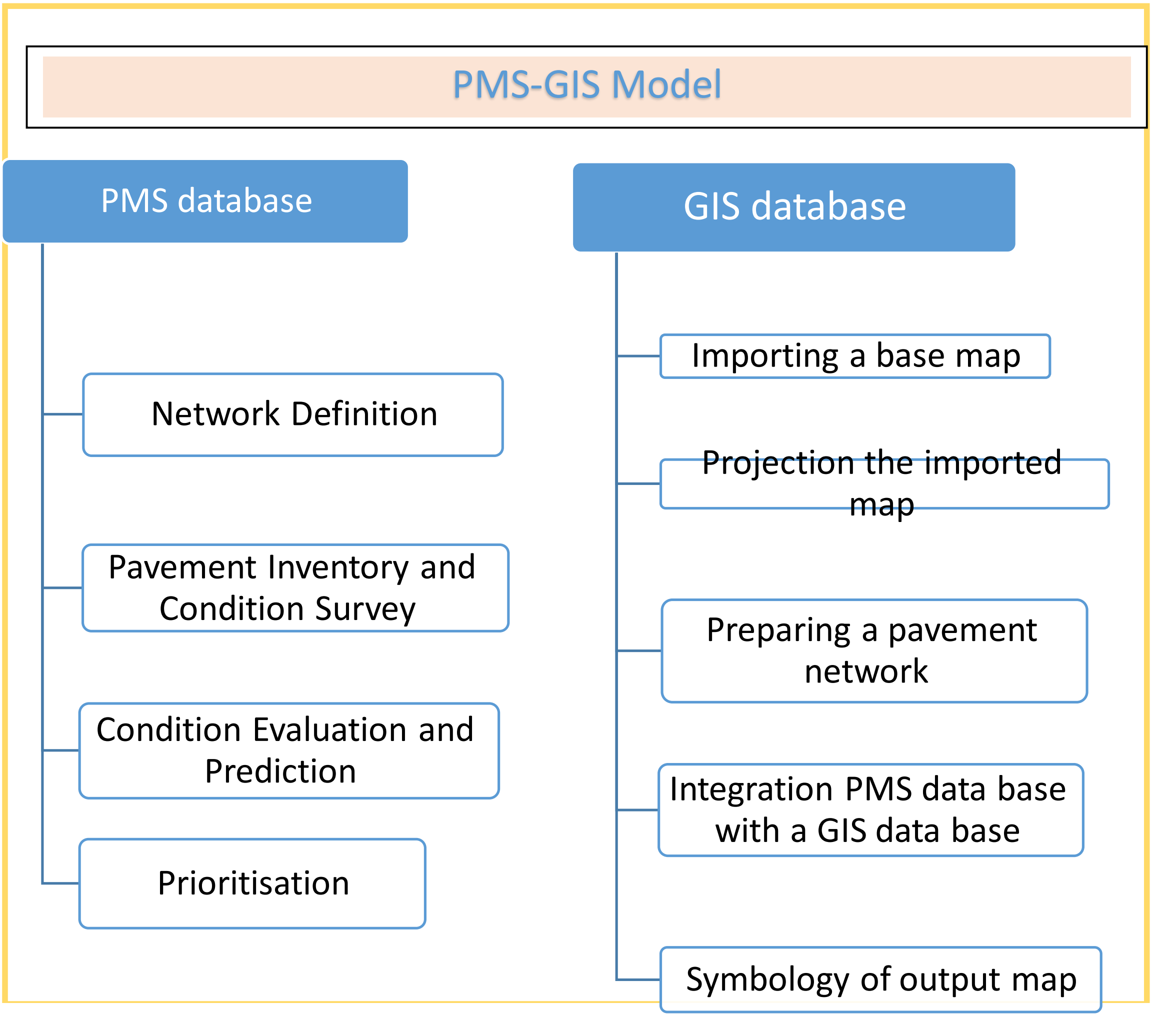


Figure 4.1: A proposed system uses to build PMS-GIS model

As mentioned above, the study area selected for apply the model is located around the new campus of An-Najah National University in Nablus city, that's to ensure the validity of the model and checking the desired goals are achieved and working to repair the problems designed to solve them. Figure 4.2 shows the systematic model for the PMS-GIS model and how the data move between the PMS and GIS databases.

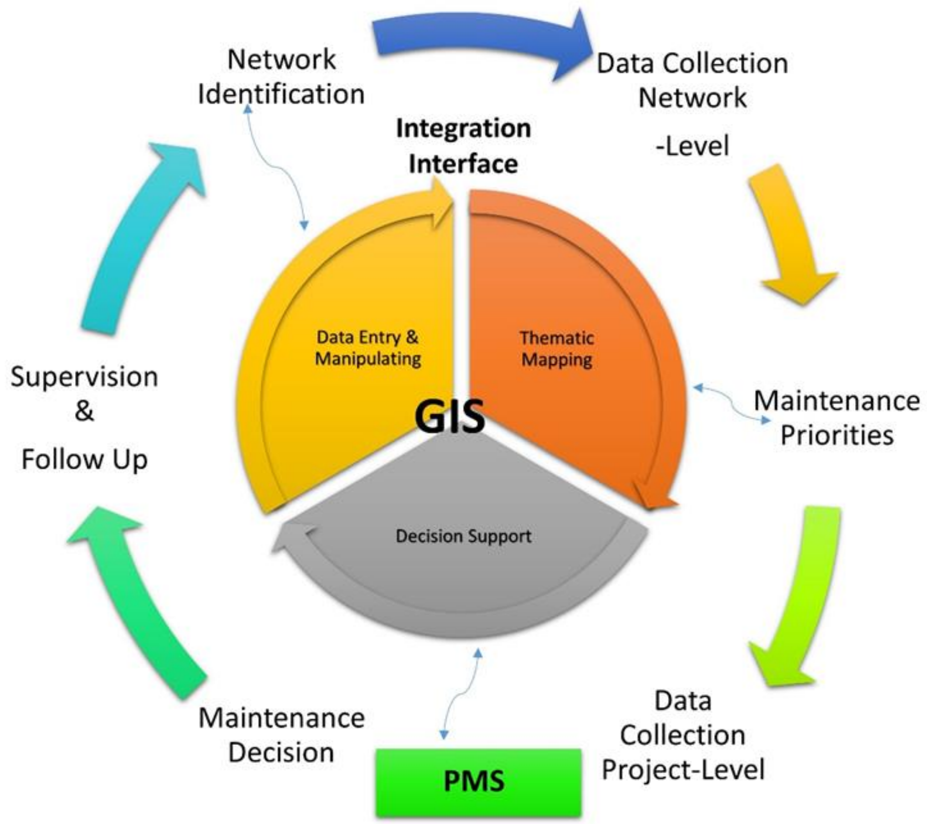


Figure 4.2: Systematic Model for PMS-GIS Model

4.2 Create PMS Database

In chapter three, all the foundations and methods for building the PMS database were developed, and Excel sheet has also been created to facilitate the data entry and automate calculations needed to obtain the value of the PCI & PI and to arrange the data in custom tables suitable for these values methods of use and ability to link with the GIS. Pavement management system database creation for the study area passing through four steps:

1- Network Definition

As mention earlier in chapter three, the method of coding road and road section that was used in the O&M manual of the municipalities in Palestine also adopted in this research with addition in some modifications. Figure 4.3 shows the study area road network.

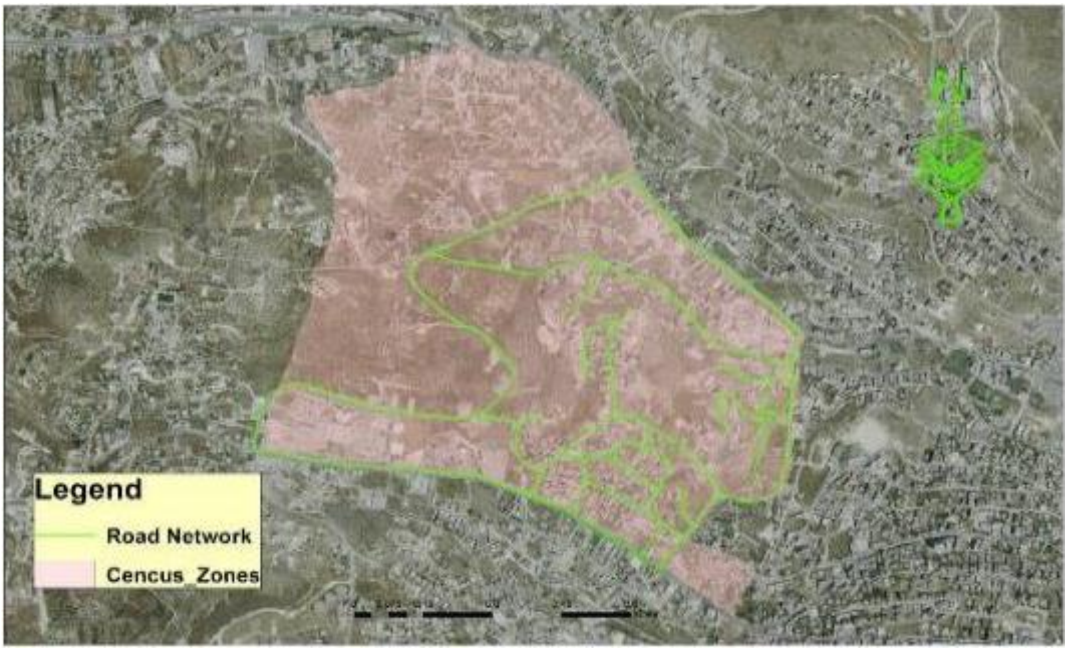


Figure 4.3: Study area road network

It is well known, for defining a pavement network, a suitable referencing system should be chosen. The main purpose of a referencing system is to delineate one pavement section in the network from other sections.

In this research, the study area network is represented by using feature line for each road. This line is divided to equal segments with length of 100 meter by X tools to obtain road section, and each section have direction Right or Left. Figure 4.4 shows split method in X tools. Figure 4.5 illustrate road network sections, while Figure 4.6 depicts Two lane direction map

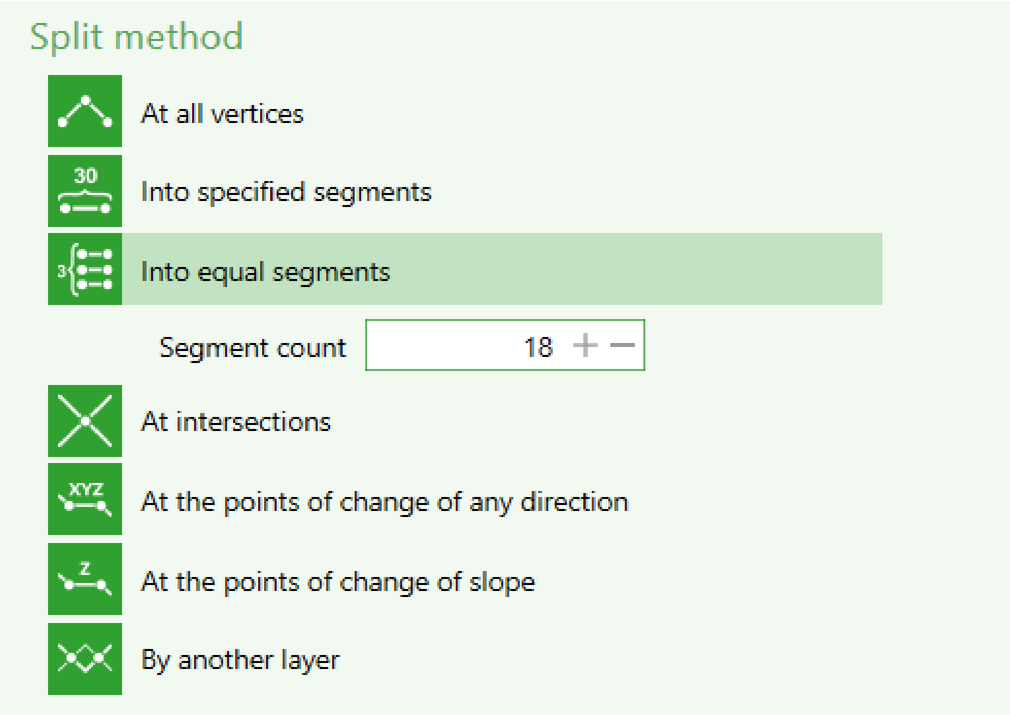


Figure 4.4: Split method in X tools

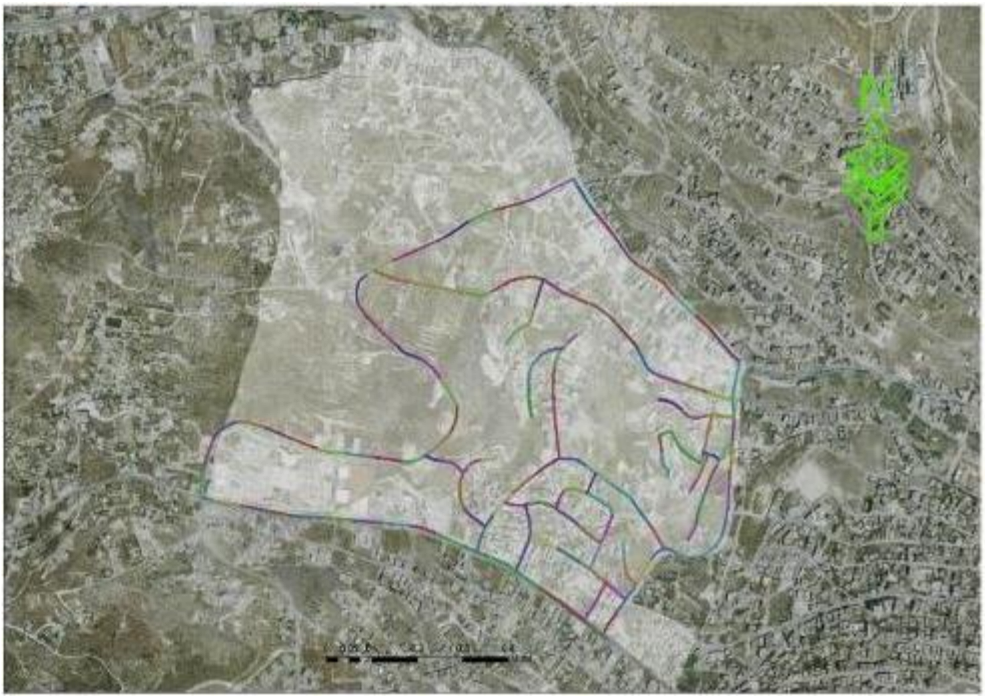


Figure 4.5: Road network sections

Figure 4.6: Two-lane direction map

2- Pavement Inventory and Condition Survey

In this study, about 45,000 square meters of asphalt surface have been surveyed. Firstly, inventory data were collected, then pavement condition inspected was applied considering section by section. Finally, special forms are used to record the collected data and presented.

Pavement Inventory

Pavement inventory is the basis of each pavement management system, and usually contains the physical properties of the pavements and normally these data do not change among maintenance actions. The primary function of the pavement inventory survey is to provide data to identify the pavement physical features, in this research the minimum information needs for establishing pavement inventory are listed below

- Pavement section ID and name.
- Functional classification.
- Lane direction.
- Citizen complaints.
- Road importance.
- Pavement width.
- Pavement length.
- Pavement surface area.
- Average Daily Traffic (ADT).

The road network in the study area are divided into four categories according to functionality of the road 1- Arterial road (AR) ,2- Collector road (CL) 3- Local road (LC) 4- Parking lot (PL). The value of ADT was assumed as 10000 pc for the arterial road, 2500 for collector road, and 200-500 for local road. Some of the collected inventory data are shown in the Figure 4.7.(Al-Sahili and Abu-Eisheh, 2002)

ROAD NAMI	N0100631R			DATE	24/04/2017
CITIZEN COMPLAINT	شكاوي متوسطة		LANE DIRECTION		R
ROAD NUM	006	ROAD CLASS	LC	SAMPLE NUM	31
ZONE	N01		ROAD IMPORTANCE	غير ذلك	
SURVEYED BY	GROUP 1		SAMPLE AREA	300	
ADT	500		AREA DESCRIPTION		
LENGTH	100		WIDTH	3	

Figure 4.7: Inventory data

A number of tools have been used for this purpose, such as a manual odometer (measuring wheel), three-meter straight-edge, tape measure, ruler and digital camera. The measuring wheel was used to measure the length of the road and also to measure the lengths or areas of existing distresses. The three-meter straight-edge and ruler were used to measure pothole depth and other depressions, and the digital camera was used for capturing. Figure 4.8 shows measurements tools.

Figure 4.8: Measurements tools.

The guide maps that were used in survey were obtained from GIS data base to recognize and facilitate the process.

Pavement Condition Survey

Field walking condition survey of the pavement sections was carried out in April 2017 to collect and assess the existing conditions of the pavement network. This survey was conducted by using “Paver Asphalt Distress Manual” which is evolved by the US Army Corps of Engineers (US Army Corps of Engineers, 1997). A range of distress types was measured and assessed according to their severity levels. Records from these measurements and assessments were registered in the survey sheet.

The most common distresses which were surveyed in the area of study pavement network are illustrated in Figures 4.9 to 4.16

Figure 4.9: Alligator Cracking

Figure 4.10: Pothole Cracking

Figure 4.11: Block Cracking

Figure 4.12: Corrugation Cracking

Figure 4.13: Depression Cracking

Figure 4.14: Edge Cracking

Figure 4.15: Longitudinal and Transverse Cracking

Figure 4.16: Patching and Utility Cut Patching Cracking

Condition Evaluation and Prediction

Once an inventory and condition survey are completed, the recorded results are entered to the Excel sheet database, this software calculates the Pavement Condition Index (PCI) for each individual section in the project level management and PCI for the road in the network level management. The PCI is derived from the critical score, from a combination of the quantities of different types of distress and their severity. Tables 4.1 & 4.2 show some of PCI results for different pavement section.

Table 4.1: Some of PCI and PI results for pavement section (project level)

	A	B	C	D	E	F	L	M
1	SURVEYID	ROADName	ROADNUM	SectionNUM	ZONE	LANE DIRECTIO	PI	PCI
2	1	N01034239L	034	239	N01	L	48	54
3	2	N0100739R	007	039	N01	R	30	94
4	3	N0100636R	006	036	N01	R	42	69
5	4	N01035240L	035	240	N01	L	40	73
6	5	N01044284R	044	284	N01	R	35	84
7	6	N01032230L	032	230	N01	L	28	100
8	7	N0100944R	009	044	N01	R	41	71
9	8	N0100944L	009	044	N01	L	43	65
10	9	N0100945R	009	045	N01	R	38	77
11	10	N01039264L	039	264	N01	L	30	96
12	11	N01043282L	043	282	N01	L	45	60
13	12	N0101994R	019	094	N01	R	32	90
14	13	N0101683R	016	083	N01	R	59	31
15	14	N0100207R	002	007	N01	R	44	64
16	15	N0101257R	012	057	N01	R	47	57
17	16	N01044283L	044	283	N01	L	54	41
18	17	N01042279L	042	279	N01	L	55	38
19	18	N01042278L	042	278	N01	L	44	63
20	19	N01042280L	042	280	N01	L	65	17
21	20	N01039263L	039	263	N01	L	42	67
22	21	N0101993R	019	093	N01	R	44	63
23	22	N01045289L	045	289	N01	L	28	100

Table 4.1 PCI and PI results for pavement road (network level)

ID	ROAD	COMPLAINTS	DIRECTION	ROAD_NUM	CLASS	ZONE	SectionNum	ROAD_IMPORTANCE	ADT	PCI	PI
1	N01034239L	شكاوي متوسطة	L	034	LC	N01	239	غير ذلك	500	54	42
2	N0100739R	شكاوي متوسطة	R	007	LC	N01	039	غير ذلك	500	93	24
3	N0100636R	شكاوي متوسطة	R	006	LC	N01	036	غير ذلك	455	65	37
4	N01035240L	شكاوي متوسطة	L	035	LC	N01	240	غير ذلك	83	73	33
5	N01032230L	شكاوي متوسطة	L	032	LC	N01	230	غير ذلك	133	84	28
6	N0100944R	شكاوي متوسطة	R	009	LC	N01	044	غير ذلك	111	79	30
7	N01039264L	شكاوي متوسطة	L	039	LC	N01	264	غير ذلك	500	83	28
8	N01043282L	شكاوي متوسطة	L	043	LC	N01	282	غير ذلك	250	60	39
9	N0101994R	شكاوي متوسطة	R	019	LC	N01	094	غير ذلك	333	77	32
10	N01044283L	شكاوي متوسطة	L	044	LC	N01	283	غير ذلك	300	57	40
11	N01042279L	شكاوي متوسطة	L	042	LC	N01	279	غير ذلك	278	43	47
12	N01045289L	شكاوي متوسطة	L	045	LC	N01	289	غير ذلك	500	82	29
13	N0102097R	شكاوي متوسطة	R	020	LC	N01	097	غير ذلك	300	66	36
14	N0101052R	شكاوي متوسطة	R	010	LC	N01	052	غير ذلك	500	68	35
15	N01033237L	شكاوي متوسطة	L	033	LC	N01	237	غير ذلك	278	69	35
16	N0101683R	شكاوي متوسطة	R	016	LC	N01	083	غير ذلك	500	73	33
17	N01027172L	شكاوي متوسطة	L	027	LC	N01	172	غير ذلك	500	60	39
18	N0101892R	شكاوي متوسطة	R	018	LC	N01	092	غير ذلك	500	48	44
19	N01031228L	شكاوي متوسطة	L	031	LC	N01	228	غير ذلك	300	46	45
20	N01030222L	شكاوي متوسطة	L	030	LC	N01	222	غير ذلك	500	85	28
21	N0101786R	شكاوي متوسطة	R	017	LC	N01	086	غير ذلك	286	57	40
22	N0100423R	شكاوي متوسطة	R	004	LC	N01	023	غير ذلك	500	42	47
23	N01021106R	شكاوي متوسطة	R	021	AR	N01	106	ي ويمر بالمنطقة التجارية او بالقرب من	10000	69	41
24	N01040273L	شكاوي متوسطة	L	040	AR	N01	273	ي ويمر بالمنطقة التجارية او بالقرب من	10000	58	47
25	N0101156R	شكاوي متوسطة	R	011	LC	N01	056	غير ذلك	500	53	42
26	N01048295L	شكاوي متوسطة	L	048	LC	N01	295	غير ذلك	500	70	35
27	N01037247L	شكاوي متوسطة	L	037	LC	N01	247	غير ذلك	500	58	40
28	N01022113R	شكاوي متوسطة	R	022	LC	N01	113	غير ذلك	500	58	40
29	N0100206R	شكاوي متوسطة	R	002	LC	N01	006	غير ذلك	500	69	35
30	N0101257R	شكاوي متوسطة	R	012	LC	N01	057	غير ذلك	500	62	38

According to the PCI rating method that was followed in this research, study area road section rating as in flowing Table 4.3

Table 4.3: Pavement Condition Index (PCI) Rating for Road Section

PCI value	Status	Color in map
80-100	Excellent	
60-80	Very Good	
40-60	Fair	
20-40	Poor	
0-20	Fail	

It is important to note that the PCI method deals with surface conditions only. Surface conditions are often symptoms of underlying problems, while in many cases possible distresses may well be hidden under the pavement without inevitably indicating any visual distress signs on the surface. Thus, the PCI reports should be considered for guidance and not conclusive information on the conditions of the pavement Maintenance Prioritization.

After generating the pavement condition for the road segments, Excel sheet also makes a prioritized listing of pavement sections on the basis of the PCI value as well as other parameters such as ADT, functional classification, road importance and citizen complaints. Table 4.4 shows the calculation of priority index and ranking in descending order for all roads in the study area considering segment by segment process.

Table 4.4: Prioritization value for road of study area.

Rank	LANE_DIRECTION	ROAD_NUM	PCI	PI
1	R	4	42	47.2
2	L	42	43	46.7
3	L	40	58	46.6
4	L	31	46	45.5
5	R	18	48	44.4
6	R	11	53	42.3
7	L	34	54	41.5
8	R	21	69	41.2
9	R	17	57	40.3
10	L	44	57	40.2
11	L	37	58	40.0
12	R	22	58	40.0
13	L	27	60	38.9
14	L	43	60	38.9
15	R	12	62	38.3
16	R	6	65	36.8
17	R	20	66	36.2
18	R	10	68	35.2
19	L	33	69	35.0
20	R	2	69	35.0
21	L	48	70	34.7
22	R	16	73	33.0
23	L	35	73	32.9
24	R	19	77	31.5
25	R	9	79	30.4
26	L	45	82	29.2
27	L	39	83	28.5
28	L	32	84	28.1
29	L	30	85	27.7
30	R	7	93	24.2

4.3 Create GIS Database

The process of creating the GIS database passing through five steps which will be mentioned later in this research and these steps are:

1. Importing a base map

In this process two main base map for the study area were obtained first of them is Orthophoto_2016_10cm and it was obtained from the GeoMolg data base server. The second base map is Cencus Zones and it was obtained from the PCBS, the base map is imported into the ArcMap by using add tool, as shows in Figure 4.17.

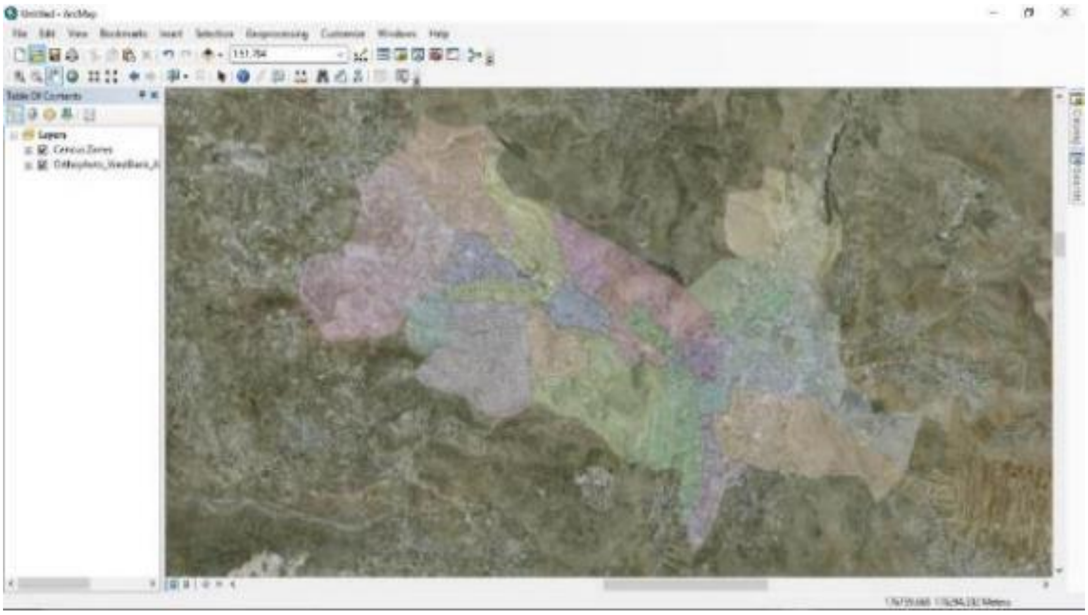


Figure 4.17: Base map imported

2. Define Projection Map

After adding the base map to ArcMap, the Cencus Zones map should be defined projection to Palestine_1923_Palestine_Grid Coordination System in ArcGIS as indicated in Figure 4.18.

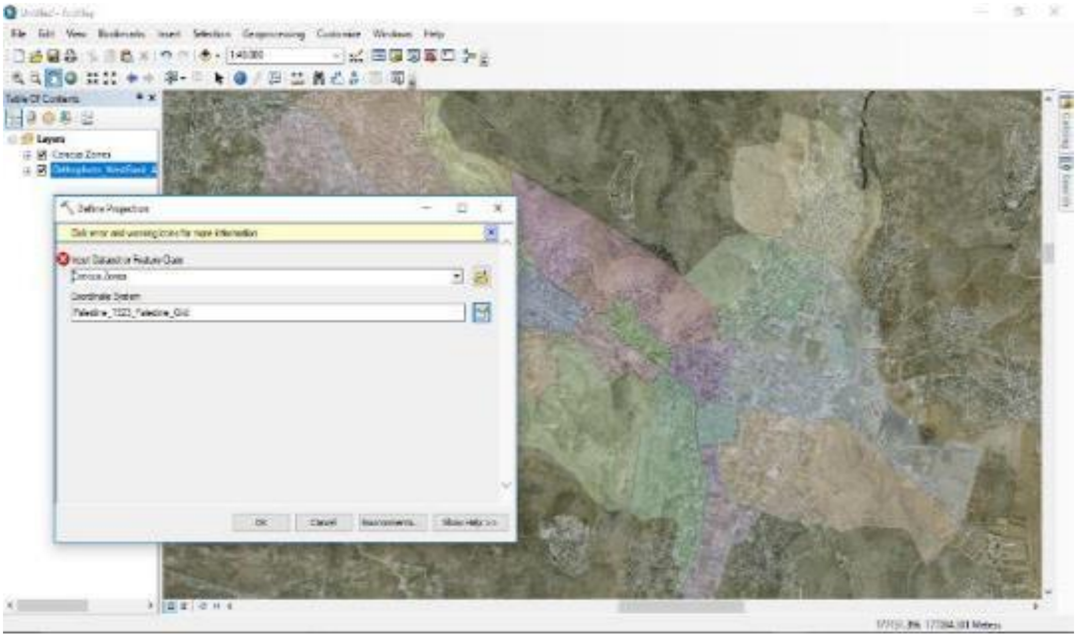


Figure 4.18: Projection of base map

3-preparing a pavement network

The process of preparation of a pavement network passes through eight steps as was mentioned in Section 3.5 and these steps are:

1- Obtaining road network map from a reliable source or creating it manually by GIS. The map of the road network in Nablus city was obtained from the Ministry of Local Government. Where, this map is one of the outputs of the naming and coding project. The map contains a unique number for each road. Figure 4.19 shows Nablus city roads network.

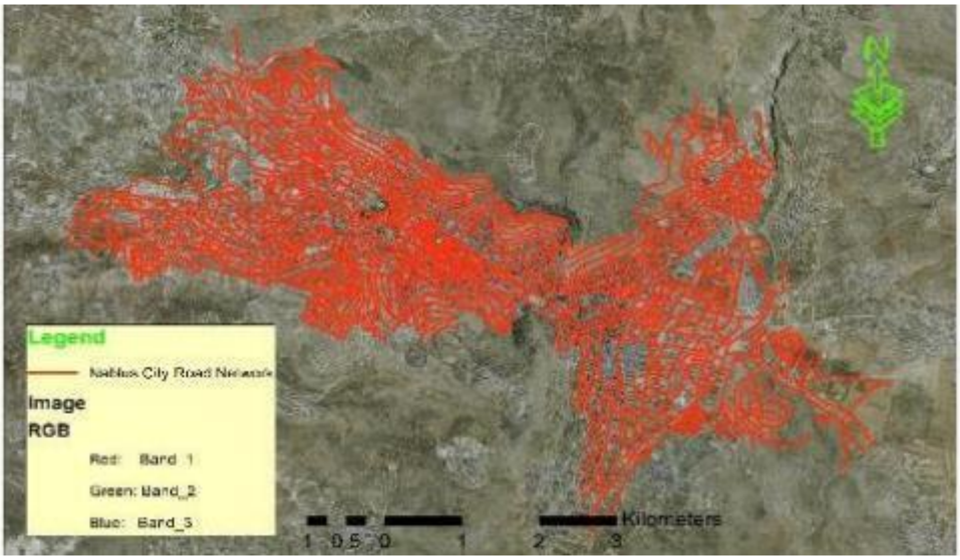


Figure 4.19: Nablus city roads network

2- Checking and treating the road network and repairing any defect or recurrence. At this stage, the start point and the end point of each road are determined, mainly, the intersection points between the roads were used to determine starting and ending points. As illustrated in Figure 4.20.

Figure 4.20: Example of Start point and End point

3- Dividing the roads network into sections with a length of 100 meters using the X tool. As presented in Figure 4.21.

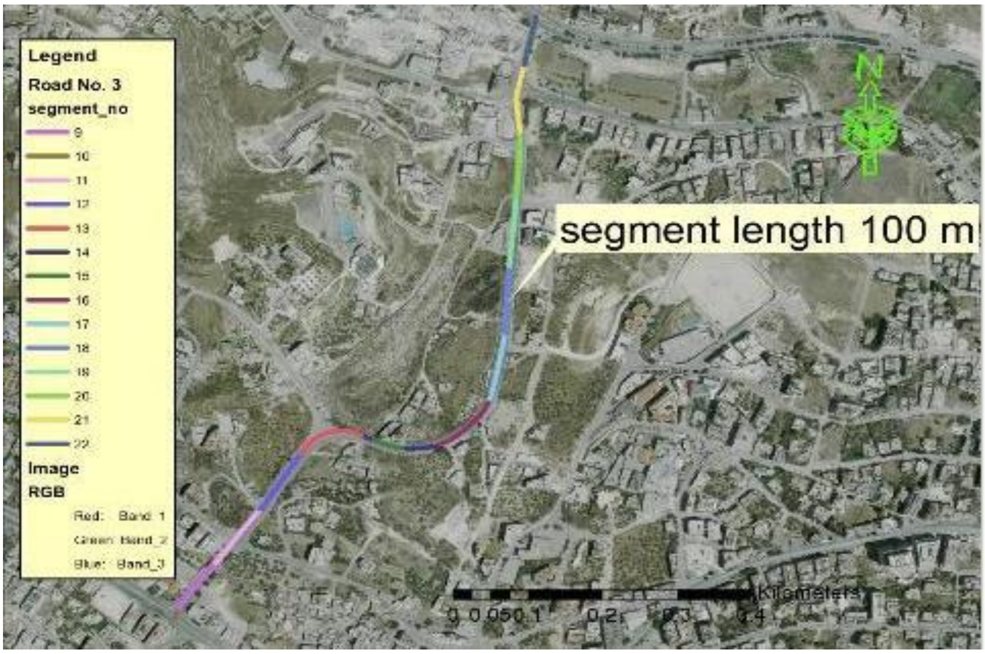


Figure 4.21: Example Road No. 3 segments

4- After the implementation of the previous three steps a new layer was extracted from the road network, then the direction is reversed by using Flip tools.

In the Figure 4.22 below, the original digitized direction is left to right (since the red vertex indicates the last vertex). The flipped digitized direction is right to left, as its noted from the new position of the red vertex.

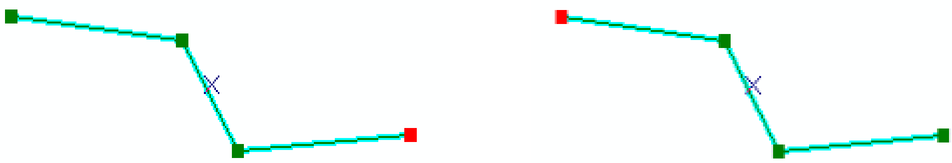


Figure 4.22: Flip tools output

5- Adding a new field with name lane direction to the tow roads network layer, in the first layer the value of new filed is "R" letter and its refer to Right direction and in the second layer the value is "L" letter and its refer to left direction. This process was implemented to obtain a representation of both direction of movement and it's one of the PMS coding requirements.

6- Merging between the two-road networks by merge tool to get one road network layer represent the two directions. As presented in Figure 4.23.

7- Intersect between the final road network layer and zone layer with tolerance 1 meter to get new field in road network considering the location of the road. Also, it's one of the PMS coding requirements.

Figure 4.23 Two lane direction map

8- Finally, all components of the PMS coding system are available in the same layer. As explained earlier in this study, the following table shows the components of the coding process to be used.

Table 4.5: Road Network Attributes

Table

Road Network

Dairection	ROAD_NM	segment_no	zone	PCI_NAME
R	1	1	N01	N0100101R
R	1	2	N08	N0800102R
R	1	3	N01	N0100103R
R	2	4	N01	N0100204R
R	2	5	N01	N0100205R
R	2	6	N01	N0100206R
R	2	7	N01	N0100207R
R	2	8	N01	N0100208R
R	3	9	N01	N0100309R
R	3	10	N08	N0800310R

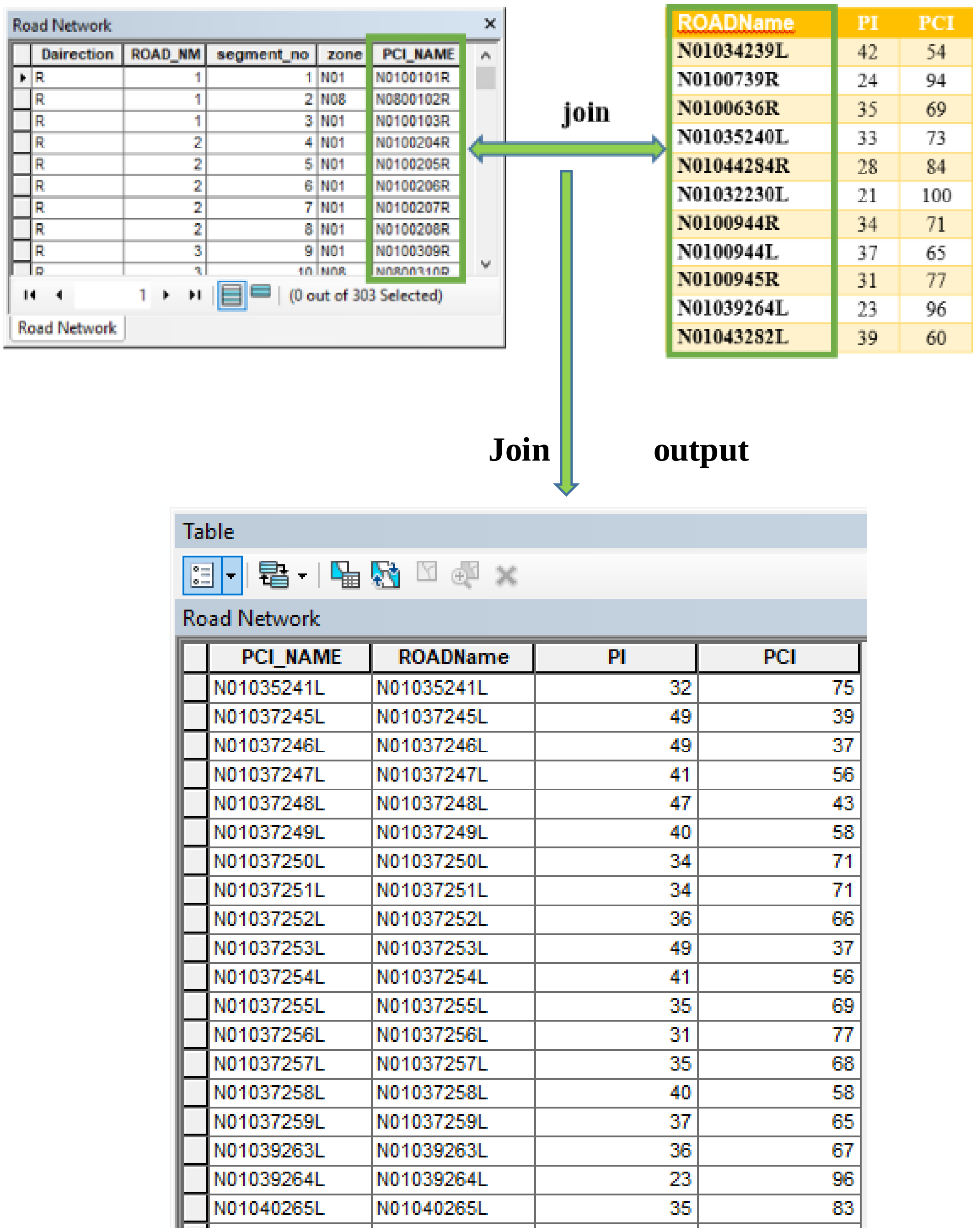
1 (0 out of 303 Selected)

Road Network

PCI Name is the key field will used in connection between PCI database and GIS database

4-Integration PMS database with a GIS database

As explained earlier, the integration of the PMS database and the GIS database will be performed by connecting a unique and non-repeating field that is identical between the two databases by joining process. Figures 4.24 & 4.25 show the joining process between the two databases.



	Dairection	ROAD_NM	segment_no	zone	PCI_NAME
▸	R	1	1	N01	N0100101R
	R	1	2	N08	N0800102R
	R	1	3	N01	N0100103R
	R	2	4	N01	N0100204R
	R	2	5	N01	N0100205R
	R	2	6	N01	N0100206R
	R	2	7	N01	N0100207R
	R	2	8	N01	N0100208R
	R	3	9	N01	N0100309R

ROADName	PI	PCI
N01034239L	42	54
N0100739R	24	94
N0100636R	35	69
N01035240L	33	73
N01044284R	28	84
N01032230L	21	100
N0100944R	34	71
N0100944L	37	65
N0100945R	31	77
N01039264L	23	96
N01043282L	39	60

PCI_NAME	ROADName	PI	PCI
N01035241L	N01035241L	32	75
N01037245L	N01037245L	49	39
N01037246L	N01037246L	49	37
N01037247L	N01037247L	41	56
N01037248L	N01037248L	47	43
N01037249L	N01037249L	40	58
N01037250L	N01037250L	34	71
N01037251L	N01037251L	34	71
N01037252L	N01037252L	36	66
N01037253L	N01037253L	49	37
N01037254L	N01037254L	41	56
N01037255L	N01037255L	35	69
N01037256L	N01037256L	31	77
N01037257L	N01037257L	35	68
N01037258L	N01037258L	40	58
N01037259L	N01037259L	37	65
N01039263L	N01039263L	36	67
N01039264L	N01039264L	23	96
N01040265L	N01040265L	35	83

Figure 4.24 Join process between GIS & PMS databases in project level.

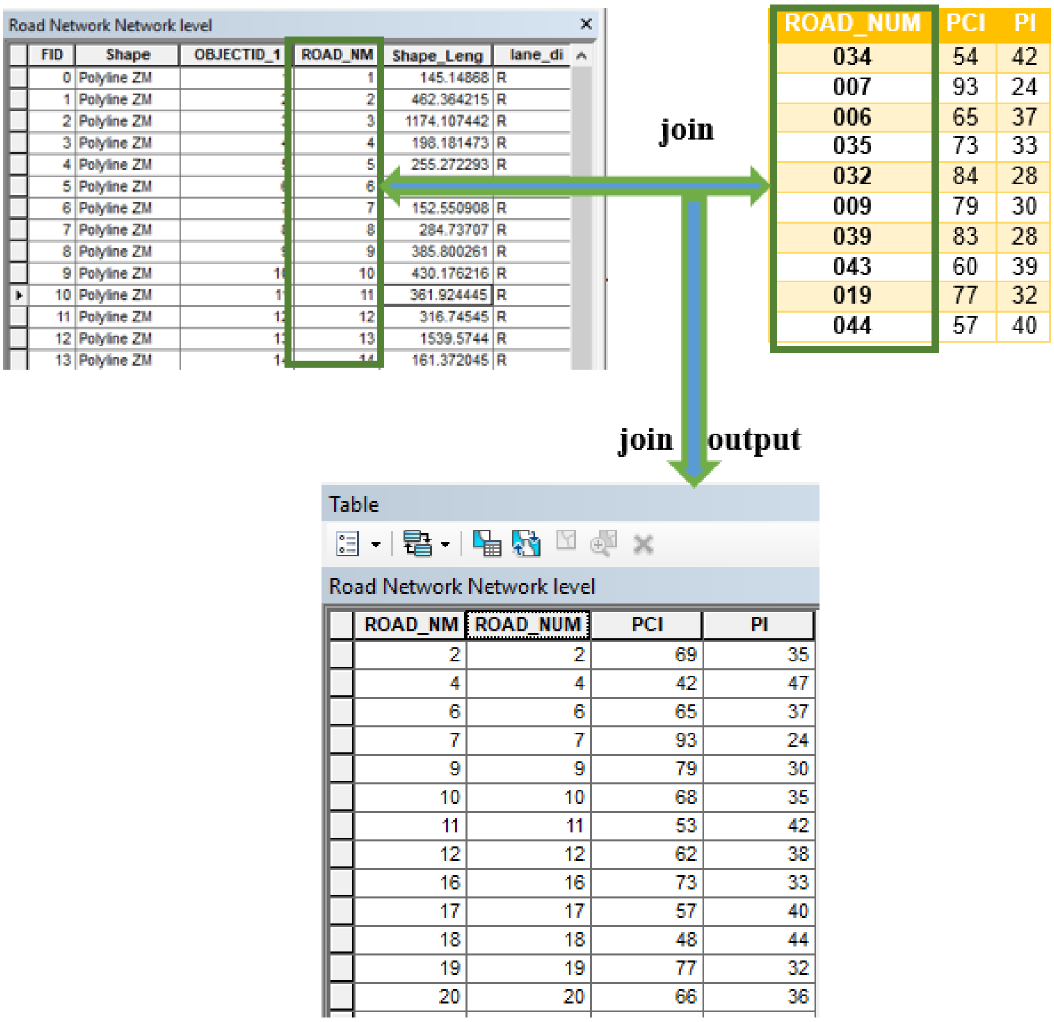


Figure 4.25 Join process between GIS & PMS databases in Network level.

Integration between GIS and PMS is the core of this research. Where the integration process is the main objective of this research. The integration process aims at finding a practical and simplified model that helps in making maintenance decisions, preparing plans and archiving data for the road network based on the results of field surveys.

5-Symbology of Output Maps

Output maps are one of the most important results of the integration process between GIS and PMS because these maps help effectively in the decision-making process including management and maintenance of pavement section. Moreover, the results help decision makers who are not specialized in the field of road and pavement in taking the right decisions. The output maps reflect the results of the road assessment and the maintenance prioritization in the form of colored lines, where each color reflects the condition of the road and the priority of maintenance in the two management levels; project and network levels. The next Figures (4.26-4.29) show the output maps that can be generated from GIS and PMS integration model.

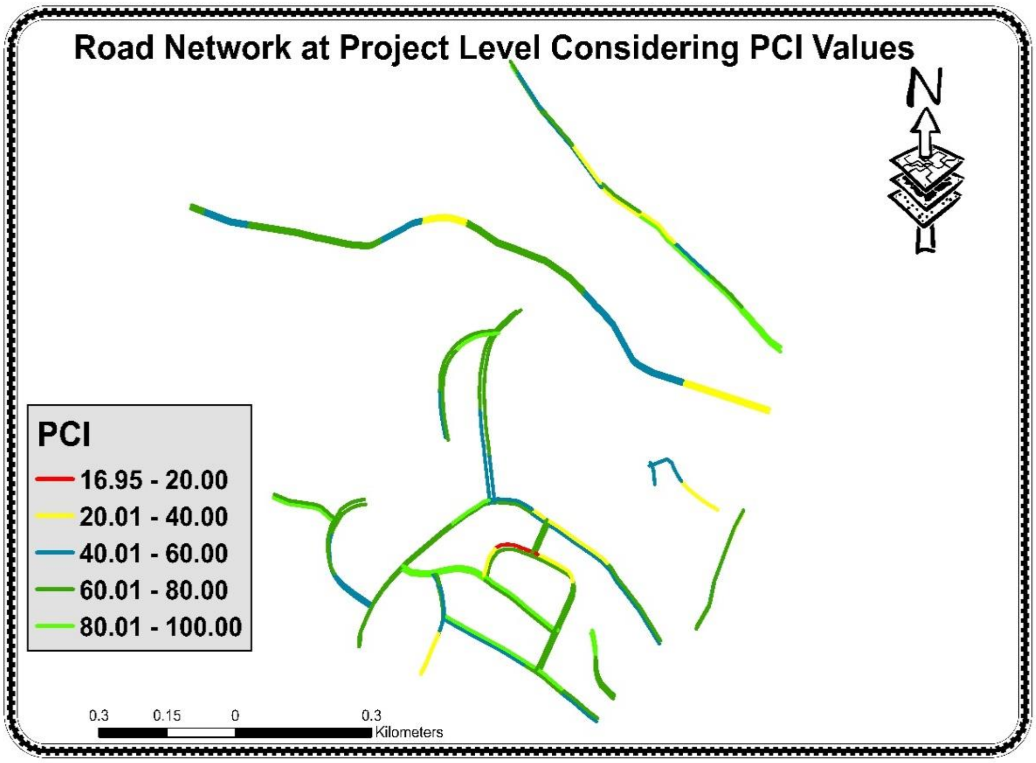


Figure 4.26: Pavement condition index map at project level

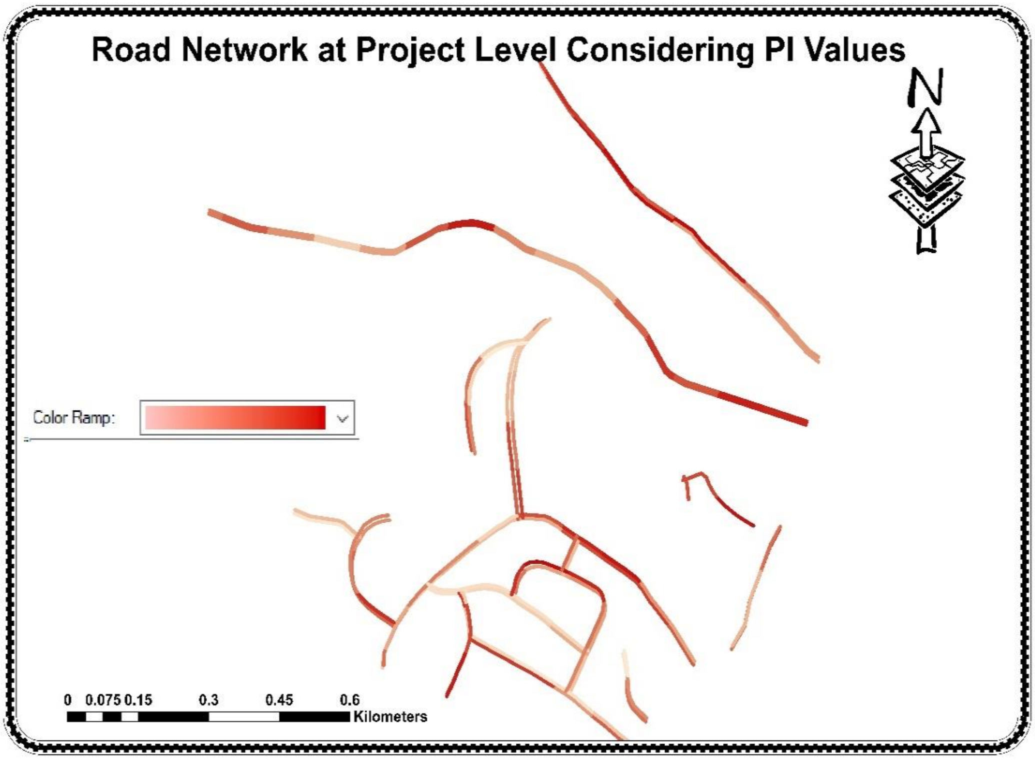


Figure 4.27: Priority index map at project level

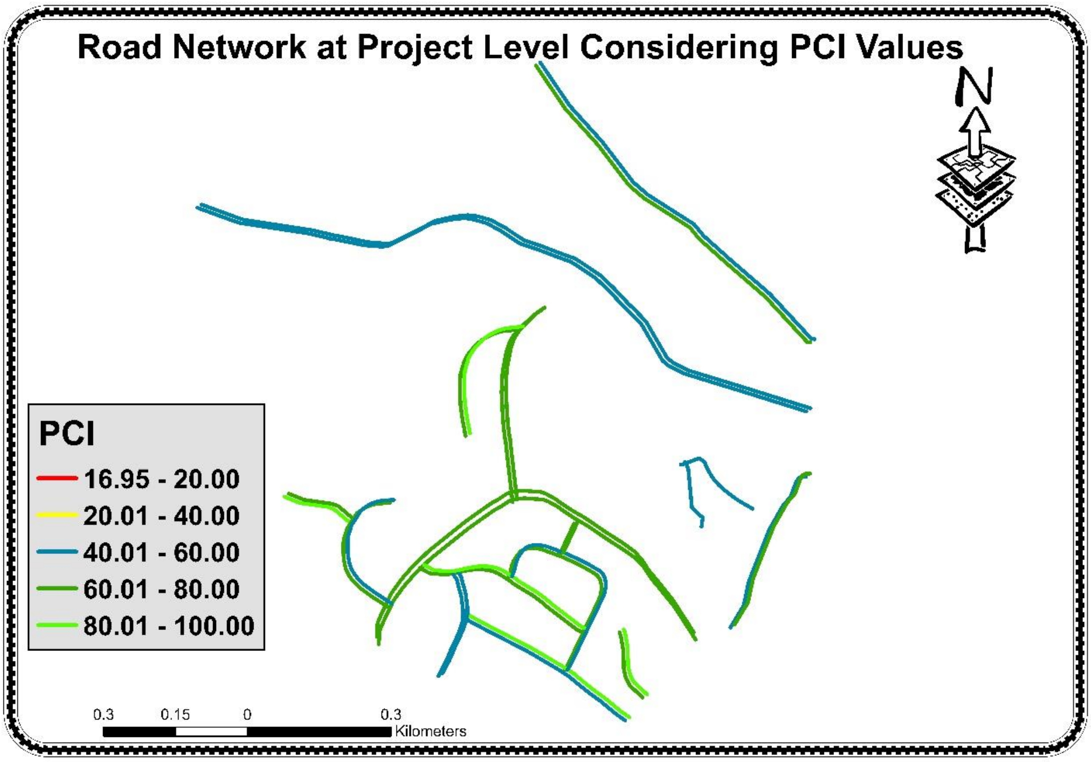


Figure 4.28: Pavement condition index map at network level

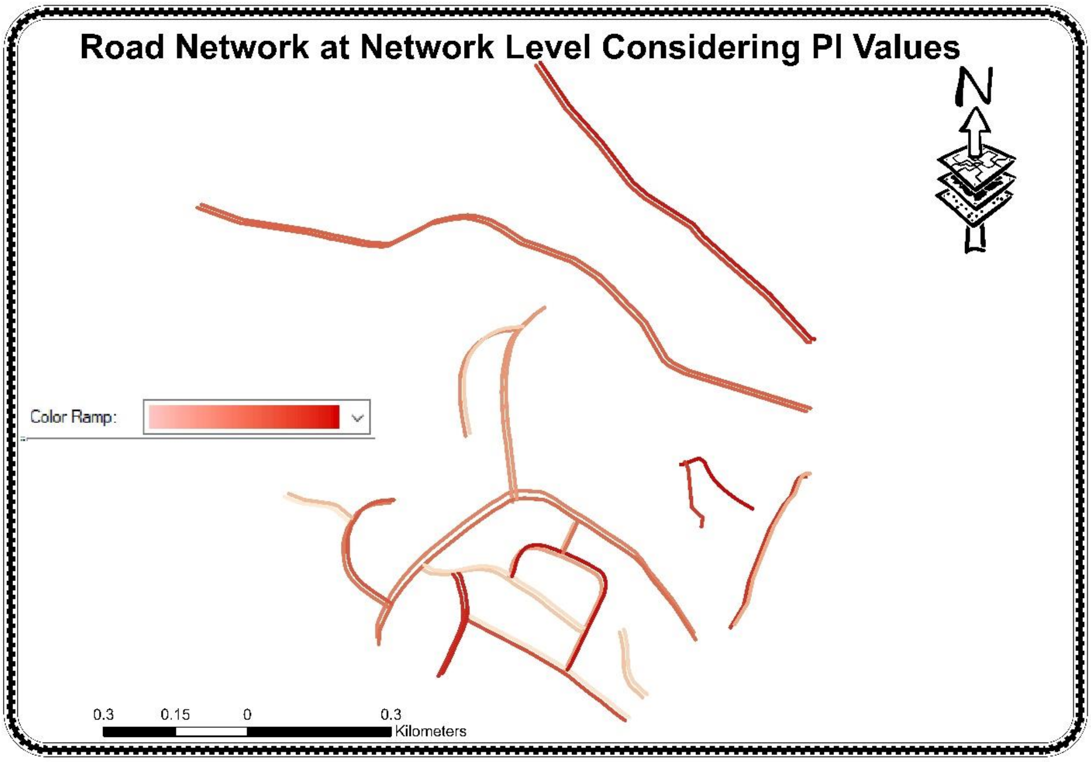


Figure 4.29: Priority Index map at network level

4.4 Results and Discussion

The percentages of paved surface area are classified based on the present year (2017) condition at the project level, it can be seen that 14.2 % of the pavement surfaced area are in (Excellent) condition, 48.2 % are in (Very Good), 24.8 % are ranked as (Fair), 12.1 % are ranked as (Poor), and 0.7% are ranked as (Fail) condition, as shown in Figure 4.30. At network level, it is noticed that 17 % of the pavement surfaced area are in (Excellent) condition, 40 % are in (Very Good), 43 % are classed as (Fair), finally there are no (Poor) and (Fail) conditions, as shown in Figure 4.31.

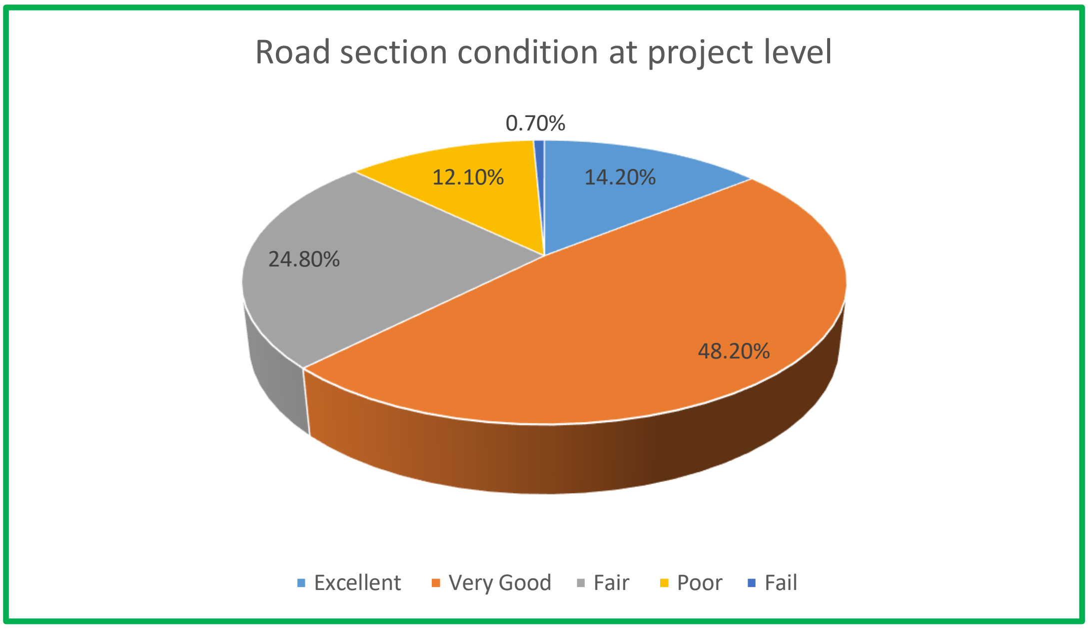


Figure 4.30: Road section condition at project level

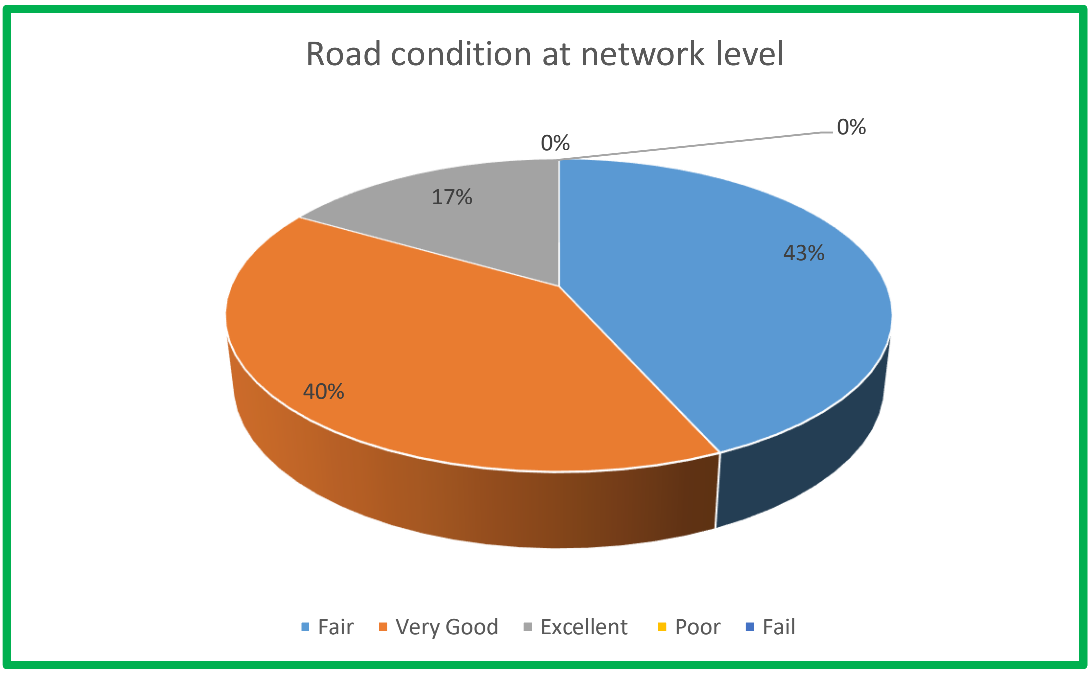


Figure 4.31: Road section condition at network level

The importance of these results lies in line with its ability to assist decision-makers in the process of determining the need for maintenance considering this area. The results are also contributed in maintaining the level of road network at an acceptable condition to maintaining good level of service.

Accordingly, through the data resulted from the model, it was noted that there were some sections of roads that suffer from poor condition and that means these sections need quick maintenance to improve their status and performance.

However, the pavement condition index alone is insufficient to determine whether the road section needs maintenance or not. Where, the process of prioritizing the maintenance of road sections is subjected to a specific methodology explained in the previous stage of this research. This methodology is based mainly on assessing the pavement condition of the section and other factors are included such as citizens' complaints, road classification, road importance, and average daily traffic. The PMS-GIS model calculates the value of the priority index for each road and for each section of the road as an evidence of the priority of maintenance.

For example, to determine the maintenance priorities of the road, four roads are taken to compare them and to determine the proper maintenance considering PMS-GIS maps and results. The input data for the example is presented in Table 4.6.

Table 4.6: An example of roads data

ROAD_NM	LANE_DIREC	ROAD_CLASS	PCI	PI
18	R	LC	48	44.4
31	L	LC	46	45.5
40	L	AR	58	46.6
42	L	LC	43	46.7

The example is resulted in different values for PCI, PI, considering the direction, classification, and the road number, all example roads are in fair condition. The PCI values are represented in Figure 4.32

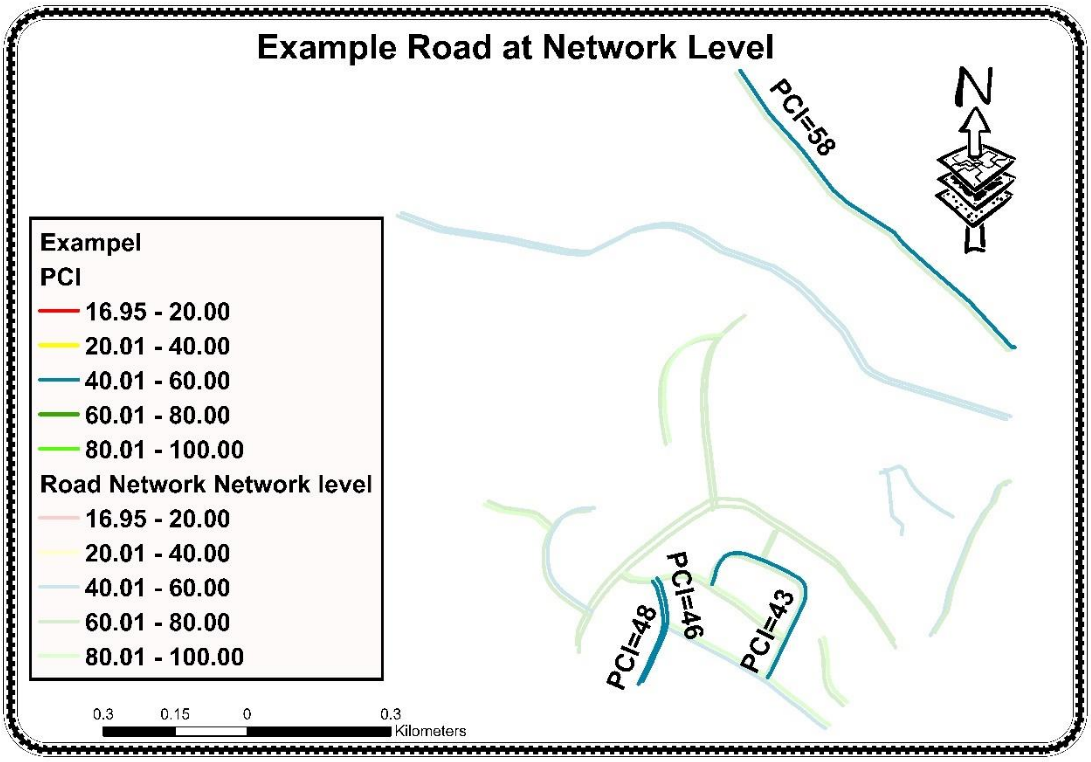


Figure 4.32: Graphical map represent PCI value for the road example

From the output result, its seen that road number 40 which is classified as an arterial has the highest PCI value. While the remaining 18, 31, 42 have a PCI value of 48, 46, and 43, respectively.

The priority of maintenance need for each road is represented by PI value, in the example, the PI value are shown in Figure 4.33 its observed that the road condition index is not the only measure to determine the priority of the need for maintenance. The highest value of the PCI of the road is for the road number 40, but the PI values indicates that the priority of maintenance is for the road number 42 which has less PCI value, then road number 40, then road number 31, and finally road number 18.

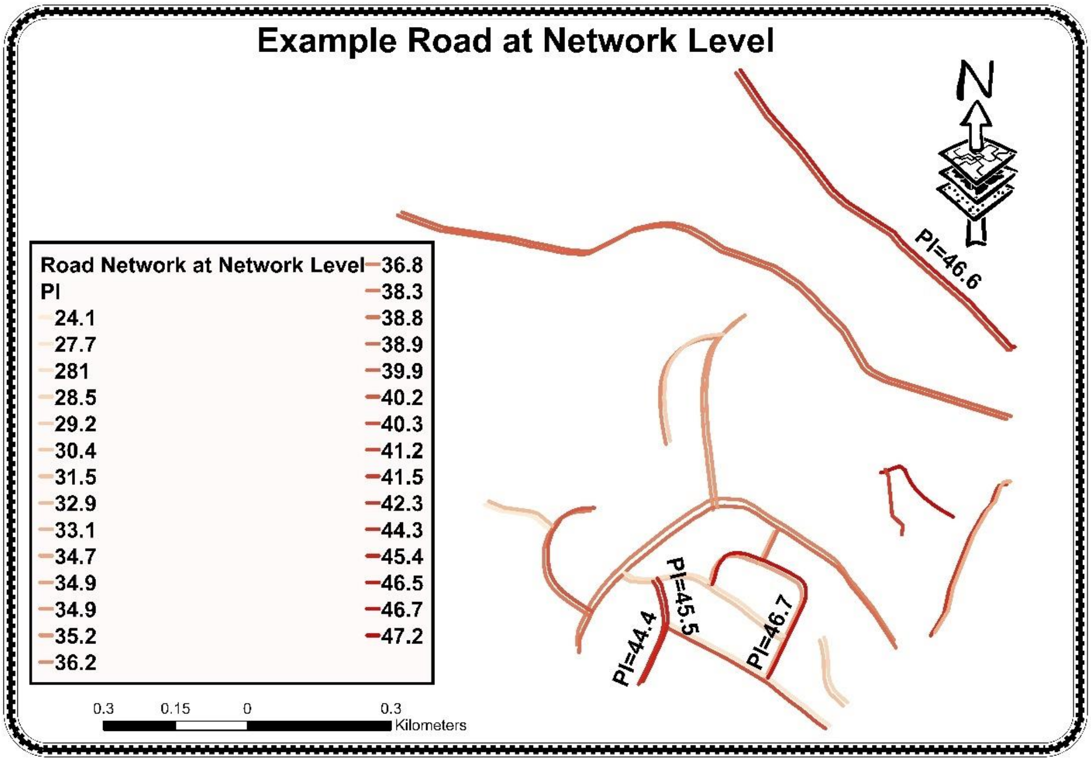


Figure 4.33 : Graphical map represent PCI value for the road example

Also, the results from the PMS-GIS model in the study area show that the defect types in the road network are distributed as 22.1 % are Longitudinal and Transverse cracks, 17.7 % are Patching and Utility cut patching,20.8 % are Alligator (Fatigue) cracks, 11.1% are Corrugation,6.2 % are Depression,1.9 % are Rutting,14.4 % are Shoving, 2.1% are Edge cracks,0.1% are Joint reflection cracking, 0.5% are Block cracks, 0.6 % are Slippage cracks, and 1.7 % Swell, also 0.8 % for Weathering and Raveling. Figure 4.34 shows the percentage of pavement defects by type.

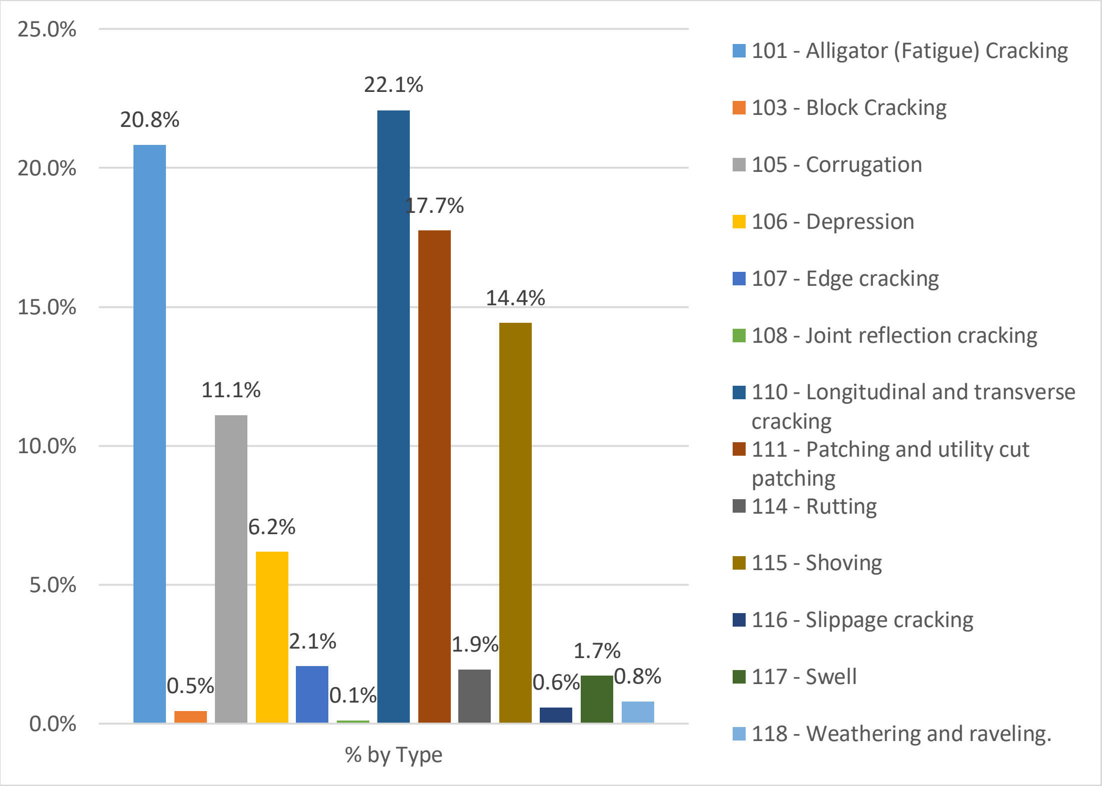


Figure 4.34: Percentage of defects by type

The percentage of each defect helps decision-makers in the process of determining the causes of the defect and thus identifying the proper type of maintenance to be conducted in each road section. For example, the alligator cracks present 20.8% from all defects in the study area, the main cause of this defect is the repetition of the traffic load that stresses the pavement to the fatigue life limit. Also, due to heavy loads on the pavement structure the crack formation is accelerated. The alligator cracks can also be occurred due to insufficient drainage of the pavement which affects the strength of pavement structure due to saturation. Finally, the poor design and inadequate paving thickness or quality during construction phase combined with loading repetition can also be contributing in generating alligator cracking.

Repair strategies for alligator cracks depend on the severity of the distresses. If cracks occur frequently in a particular section, the patching process can be performed. The overlays are used to mitigate the problems of alligator cracks that cover an extensive area, but the thickness of the overlay must be sufficiently designed to convey the expected loads. If poor subgrade drainage is the main cause, drainage improvements are to be carried. Finally, If the pavement structure is fatigued due to repetitive loading alone, a stronger pavement structure is required to carry the anticipated traffic.

Chapter Five

Conclusions and Recommendations

5.1 Introduction

Constructing a PMS is a necessary step that most agencies around the world apply to help the decision makers in identifying the proper treatment for the proper section at the proper time. The weakness of the pavement management system in Palestine and the need for optimum utilization of resources by making the appropriate decision for proper maintenance actions was the idea behind this research. Geographic Information Systems (GIS) based Pavement Management System (PMS) is the future for managing pavement in all countries.

5.2 Conclusions

The results and the analysis discussed early shows that the GIS based application is reliable, precise and can be used for an effective monitoring and evaluation of the road network. The results from the case study show that the percentages of paved surface area are classified based on the present 2017-year conditions. At the project level, it can be seen that 14.2 % of the pavement surfaced area are in (Excellent) condition, 48.2 % are in (Very Good), 24.8 % are ranked as (Fair), 12.1 % are ranked as (Poor), 0.7% are ranked as (Fail) condition. At network level, it is noticed that 17 % of the pavement surfaced area are in (Excellent) condition, 40 % are in (Very

Good), 43 % are classed as (Fair), finally there are no (Poor) and (Fail) conditions.

Establishing and checking the applicable the PMS-GIS model is the main objective for this research and the result shown that model is user friendly, cheap and one need not to be a database expert or an expert in GIS before he/she can operate it. If implemented, it will help decision-makers in taking decisions interactively with the aid of visualization of data in GIS without requiring any specialized technical skills.

5.3 Recommendations

The main recommendations for this research are:

1- The transportation agencies concerned with the pavement management in Palestine are recommended to use the integrated PMS-GIS model. This research proved that it is a practical system. Which, enables decision makers to apply the maintenance strategies for them assets such as roads and considering the existing of comprehensive spatial data and making the right decision in prioritization of maintenance activities.

2- Its recommended to establish a specialized unit in each municipality to manage the pavement maintenance process in all relevant Palestinian agencies responsible for the management and maintenance of the roads.

3- Its recommended to build the capacity for relevant engineers, administrators, decision makers, and road workers to familiarize themselves with the PMS-GIS. This can be achieved through conducting periodic training workshops.

4- The Integration between GIS software and the PMS database in this study was achieved through exchanging of files (Loose Coupling integration), this procedure is time consuming and prone to error. It would be more feasible to achieve that through a common user interface, which is taking care of the data sharing between the two components (Close Coupling integration). It is recommended that future research effort to be directed toward optimizing the spatial results of maintenance prioritization models. More research concerning the spatial operational management of maintenance activities is needed. This can result in a better understanding of spatial distribution of the maintenance activities. In addition that can also result in scheduling of maintenance activities, which considered to be an important matter for the decision making process.

5- Additionally, more work should be done to explore additional uses of GIS within the framework of PMS. Sophisticated queries and spatial analysis are two of the many tools available within GIS. These types of analysis should be further developed to increase the usefulness of this tool to road engineers. Some examples of possible studies include; the effect of soil type and water table height on pavement condition, the relationship between pavement condition and surrounding land usage, studies on the affect of different weather parameters, and the study of the relationship between topography/ground slope and pavement condition. Analysis of all these types of variables can be performed within GIS. Future research should be considered in studying how these types of analysis could be useful to road engineer, as well as, how to best implement them into the PMS-GIS model.

References

1. AASHTO. (1993). **Guide for Design of Pavement Structures (2nd ed.).** Washington DC: American Association of State Highway and Transportation Officials.
2. AASHTO. (2001). **Pavement management guide.** Washington DC: American Association of State Highway and Transportation Officials.
3. Abo-Hashema, M. A. and Sharaf, E. A. (2000). **A simplified pavement maintenance decision tree for use in developing countries**. Al-Azhar University Engineering Journal, Volume 4, pp. 308-339.
4. Abo-Hashema, M. A. and Sharaf, E. A. (2004). **A simplified maintenance decision system for flexible pavements in developing countries**. Sixth International Conference on Managing Pavements, Brisbane, Australia.
5. Abo-Hashema, M. A., Abdel Samad, A. M. and Al-Zaroni, Y. (2006). **Pavement maintenance management practices and GIS inAl-Ain.** Availableat:http://www.gisdevelopment.net/magazine/middleeast/2006/ mav-iune/34 1 .htm [Accessed: 2 Feb 2016].
6. Acquah, P. C. and Fosu, C. (2017) '**Implementation of Geographic Information System Application in the Maintenance Management of Roads in Ghana : A Case Study of Roads in Kumasi Metropolis**', 6(3), pp. 90–102. doi: 10.5923/j.ajgis.20170603.02.
7. Adeleke, O. O., Kolo, S. S., Odumosu, J. O., Abdulrahman H. S. and Atilola, B. Y. (2015). **Application of GIS as Support Tool for**

Pavement Maintenance Strategy Selection. Nbrri International Conference Theme: Roadmap To Safe, Efficient And Sustainable Road Transportation In Nigeria

8. Agarwal, P., Animesh, D. & Chakroborty, P. (2004). **A Rational Approach for Prioritisation of Highway Sections for Maintenance.** Paper presented at the Sixth International Conference on Managing Pavements, India, pp. 1-12.
9. Ali, G., & Al-Qatabi, K. (1995). **Efforts in road maintenance management in Oman: development and sensitivity analysis**. Proceedings International Conference on New Horizons in Roads and Road Transport**,** Vol. 1, ICORT.
10. Al-Swailmi, S., & Al-Mulhem, M. (1998). **Integrating GIS with Riyadh PMMS.** Paper presented at the Fourth International Conference on Managing Pavements, King Abdalaziz City for Science and Technology, Saudi Arabia.
11. Al-Sahili, K. and Abu-Eisheh, S. (2002) '**Traffic systems management studies for Palestinian cities**: Implementation assessment', Proceedings of the Conference on Traffic and Transportation Studies, ICTT*S*, 40630(January). doi: 10.1061/40630(255)29.
12. Bemanian, S. (2007). **Financial consequence based pavement management system**. Paper presented at the National Pavement Management Conference, Virginia.
13. Bham, G. H., Gharaibeh, N. G., & Darter M. I. (2001). **Development of GIS-Based Illinois Highway Pavement Management System**. Paper

presented at the ESRI User 2001 Conference, San Diego, California. Available at: http://proceedings.esri.com/library/userconf/proc01/professional/papers/pap511/p511 .htm [Accessed: 2 Feb 2016].

14. Bryman, A. 2012. **Social research methods**, Oxford University press.
15. Burrough, P. A. (1986). **Principles of Geographical Information Systems for Land Resources Assessment**. Oxford: Clarendon Press.
16. Coppock, J. T. and Rhind, D. W. (1991). **The history of GIS**. In P. A. Longley, M. F. Goodchild, D. J. Maguire and D. W. Rhind (eds). Geographical Information Systems: Principles and Applications. Wiley.
17. Collis, J. & Hussey, R. (2009). **Business Research: A Practical Guide for Undergraduate and Postgraduate Students 3rd ed.** Basingstoke: Palgrave Macmillan Press Ltd.
18. Denscombe, M. (1998). **The Good Research Guide for Small-Scale Social Research Projects.** Maidenhead, Berkshire, Open University Press.
19. de Vaus, D. (2001). **Research Design in Social Research,** London, SAGE Publications.
20. Elhadi, H. (2009). **GIS, a tool for pavement management**. Master's of Science Thesis in Geoinformatics, Royal Institute of Technology (KTH), Stockholm.
21. ESRI. (2012). **ESRI Software Website**. Available at: http://www.esri.com/ [Accessed: 13 May 2012].
22. Flintsch, G., Dymond, R., Collura, J. and Kuttesch, J. (2004). **Review of**

state practices on the use of GIS for pavement management applications.

23. Flintsch, G. and Chen, C. (2007). **Soft computing applications in infrastructure management**. Journal of Infrastructure Systems, Volume 10, Number 4, pp. 157-166.
24. Fwa, T., & Shanmugan R. (1998). **Fuzzy logic technique for pavement condition rating and maintenance needs assessment.** Paper presented at the Fourth International Conference on Managing Pavements, South Africa, pp. 465-476.
25. Golabi, K., & Pereira, P. (2003). **Innovative pavement management and planning system for road network of Portugal**. Journal of Transport Engineering ASCE, 9(2), pp. 75-80.
26. Goodchild, M. F. and Longley, P. A. (1999). **The future of GIS and spatial analysis**. In: P. A. Longley, M. F. Goodchild, D. J. Maguire and D. W. Rhind (eds). Geographical Information Systems: Principles, Techniques, Management and Applications. Wiley.
27. Graeff, C. & Loui, M. (2008). **Ethical implications of technical limitations in geographic information systems**. Proceedings, IEEE International Symposium on Technology and Society, ISTAS 2008 (pp. 1- 20), New York.
28. Gray, J. (2006). **GIS Visualization for a Performance-Based Road Maintenance Rating Program Trend Analysis.** MS project and report, Virginia Polytechnic Institute and State University.

29.Haas, R., Hudson, W. and Zaniewski, J. (1994). **Modern Pavement Management.** Florida: Krieger Publishing Company.

30.Hudson, E. G. F. and W. R. (1983) '**Development of a prioritization procedure for the network level pavement management system** .,.', (2), p. 121.

31.Hammersley, M. (1993) Social Research: **Philosophy, Politics and Practice**, London, SAGE Publication in association with The Open University

32.Harper, W., & Majidzadeh, K. (1991). **Use of expert opinion in two pavement management systems**. in transportation research record, Journal of transportation research board, No 1311 TRB Washington, pp. 242-247.

33.Heywood, I., Cornelius, S. and Carver, S. (2011). **An Introduction to Geographical Information Systems** (4th ed.). Pearson Education Limited.

34.Housner, G., & Thiel, C. (1995). Continuing challenge: **report on the performance of state bridges in the Northridge earthquake**. Earthquake Spectra, pp. 607-636.

35.-Heggie, Ian. G, and Vickers, P. (1998). "**Commercial Management and Financing of Roads.** Technical Paper No. 409. World Bank, Washington, D.C.

36.Ibraheem, A. and Atia, N. (2012). New Methods in Pavement Maintenance Strategy Selection: **Coupling of Decision Making with Analytical Hierarchy Process.** Lambert Academic Publishing.

37. Ibraheem, A. and Falih, D. (2012). **Applying geographic information system (GIS) for maintenance strategy selection. Engineering,** Volume 4, Number 1, pp. 44-54. Jankowicz, A. D. (2005) Business Research Projects, London, Thomson Learning.
38. -Issa, A. and Abu-Eisheh, S. (2017) '**Evaluation of implementation of municipal roads' maintenance plans in Palestine: A pilot case study'**, International Journal of Pavement Research and Technology. Chinese Society of Pavement Engineering, 10(5), pp. 454–463. doi: 10.1016/j.ijprt.2017.07.006.
39. Jendia, S. and Al Hallaq, M. (2005). **Development of a pavement maintenance management system (PMMS) for Gaza City**. Journal of the Islamic University of Gaza**,** Volume 13, Number 1, pp. 119-138.
40. Johnson, R.B. and Onwuegbuzie, A.J., (2004). **Mixed methods research: A research paradigm whose time has come**. Educational researcher, 33(7), pp.14-26.
41. Johnson, A. & Snopl, P. J. (2000). **Best practices handbook on asphalt pavement maintenance.** http://ntl.bts.gov/lib/! 1000/11500/11596/2000-04.pdf [Accessed: 21 Dec 2015].
42. Jones, C. (2004). Quantitative and qualitative research: **Conflicting paradigms or perfect partners**, Proceedings of the fourth international conference on networked learning: 106-12. Lancaster: Lancaster University and University of Sheffield.
43. Kennedy, M. (2009). **Introducing Geographic Information Systems with ArcGIS** (2nd ed.). New Jersey: John Wiley & Sons Inc.

44. Keenan, P. (2007) '**Using a GIS as a DSS Generator', Geographic Information System**, pp. 97–113.

45. Kmetz, R. (2011). **GIS Based Pavement Maintenance: A Systematic Approach**. Purdue University, Indiana.

46. Kunka, M., Polak, M., Krishnamurthy, B. and Abou-Seif, M. (2005). **Municipal GIS: The Abu Dhabi experience**. Map Middle East, UAE.

47. Lewis, S., & Sutton, J. (1993). **Demonstration Project No. 85; GIS/ Video Imagery Applications.** Washington DC: Federal Highway Administration.

48. **Mansour, K. (2005).** GIS Implementation in Operation and Maintenance Department Jeddah Municipality. **First National GIS Symposium in Saudi Arabia.**

49. Miles, S. and Ho, C. (1999). Applications and issues of GIS as a tool for civil engineering modeling. **Journal of Computing in Civil Engineering,** Volume 13, Number 3, pp. 144-152.

50. Miles, M. B. & Huberman, M. (1994) **Qualitative Data Analysis: An Expanded Sourcebook,** Thousand Oaks, California, USA, Sage Publications, Inc.

51. MPWH (2015) '**Road Sector In Palestine Achievements, Needs, and Challenges**'.

52. Moazami, D., Muniandy, R., Hamid, H. and Yousoff, Z. MD. (2011). **The use of Analytical Hierarchy Process in Priority Rating of Pavement Maintenance**. Scientific Research and Essays. Vol. 6(12), pp. 2447-2456.

53. Moore, D. (1998). **Roughness.** Report No.UMTRI-98-2, University of Michigan Transportation Research Institute, Michigan.

54. National Cooperative Highway Research Program (2011). **Sustainable Pavement Maintenance Practices**. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp rrd 365.pdf [Accessed: 3 Dec 2015].

55. Neuman, W. L. (2003). Social Research Methods: **Qualitative and Quantitative Approaches. 5th edition. Pearson Education,** Inc. USA

56. NHI (1997). Application of Geographic Information Systems for transportation. National Highway Institute course 151029, Arlington, Virginia.

57. NCHRP-335 (2004) **Pavement Management Applications Using Geographic Information Systems**, Transportation Research Board. doi: 10.17226/23344.

58. OMB (2010). **Geospatial line of business: OMB Circular** A-16 Supplemental Guidance, Office of Management and Budget, The Executive Office of the President. Available at: http://www.whitehouse.gov/sites/default/files/omb/memoranda/2011/m 11-03.pdf [Accessed: 23 Feb 2016].

59. Orabi, W. (2010). **Optimising highway reconstruction and rehabilitation projects.** PhD research project, University of Illinois at Urbana-Champaign.

60. Pantha, B.R., Yatabe, R. and Bhandary, N.P., 2010. **GIS-based highway maintenance prioritization mode**l: an integrated approach for highway

maintenance in Nepal Mountains. Journal of Transport Geography**,** 18(3), pp.426-433.

61. Parida, M. (2005). **Enhancing pavement management systems using GIS. Proceedings of the Institution of Civil Engineers** - Transport, Volume 158, Number 2, pp. 107-113.
62. Phillips, S. J. (1994). **Development of United Kingdom Pavement Management System.** Paper presented at the Third International Conference on managing pavement, Department of Transport, England.
63. Pinard, M. (1987). **Factors affecting the development and implementation of pavement management systems in developing countries**. In Proceedings of Second North American Conference on Managing Pavements, Toronto, Ontario, Canada, Volume 1, pp. 300-310.
64. Radopoulou, S. C. & Brilakis, I. (2015). **Detection of multiple road defects for pavement condition assessment.** Conference Paper: International Workshop of Intelligent Computing in Engineering, pp. 1-10.
65. Rhind, D. W. (1989). Why GIS? ARC News (Summer): pp. 28-29
66. Robinson, R., Danielson, U., & Snaith, M. (1998). **Road Maintenance Management: Concepts and Systems**. New York: Palgrave.
67. Robson, C. (2011). Real World Research. 3rd edition. Wiley. UK.
68. Roy, B. 2005. An overview of MCDA techniques today: **Paradigms and challenges. In: FIGUEIRA, J., GRECO, S. & EHRGOTT, M. (eds.) Multiple Criteria Decision Analysis:** State of the art surveys. New York: Springer.

69. Saaty, T. L. (1980). **The analytic hierarchy process.** McGraw-Hill, New York.

70. Saaty, T. L. (2008). **Decision making with the analytic hierarchy process.** International Journal of Services Sciences, 1, 83-98.

71. Saunders J. (2005). Real-time pavement management. **Farallon Geographies Directions Magazine,** U.S.A.

72. Shahin M., and Kohn, S. (1981). **Pavement maintenance management for roads and parking lots**. United States Army Corps of Engineers, Technical Report M-294.

73. Shahin, M. and Walther, J. (1990). **Pavement maintenance management for roads and street using the PAVER system**. US Army Corps of Engineers.

74. Shahin, M. (2005), **Pavement for airports, roads, and parking lots**. Springer, New York, USA.

75. Shrestha, P. P. and Pradhananga, N. (2009). **GIS-based Road Maintenance Management.** Proceedings of 2009 ASCE International Conference on Computing in Civil Engineering, Austin, Texas, June 24-27, 2009, ISBN 978-0-7844-1052-3, pp. 472484.

76. Simkowitz, H. J. (1990) '**Using geographic information system technology to enhance the pavement management process**', *Transportation Research Record*, (1261).

77. Surrey County Council (2015). **Maintaining our roads and pavements.** Available at:http://www.surreycc.gov.uk/roads-and-transport/road-

maintenance-and-cleaning/maintaining-our-roads-and-pavements [Accessed: 17 Nov 2015].

78. -Tavakoli, A., Lapin, M. and Figueroa, J. (1992) '**PMSC: Pavement Management System for Small Communities',** *Journal of Transportation Engineering*. American Society of Civil Engineers, 118(2), pp. 270–280. doi: 10.1061/(ASCE)0733-947X(1992)118:2(270).
79. Tsai, Y. and Lai, J. (2001). **A framework and strategy for implementing an IT-based pavement management system**. Transportation Research Record, Number 1816, Washington DC, pp. 56-64.
80. Wang, K., Zaniewski, P. and Delton, J. (1994). **Analysis of Arizona Department of Transportation's new pavement network optimisation system**. Transportation Research Record**,** Number 1455, Transportation Research Board, Washington DC, pp. 91-100.
81. Williams, J. and Schuman, W. G. (1995). **Dynamic Segmentation using Intergraph's MGE Segment Manager.** Intergraph Corporation White Paper.
82. WSDT. (1994). Washington State Department of Transportation. **A guide for local agency pavement managers.** TransAid Service Center, Olympia.
83. Yin, R.K. (2009). **Case study research: Design and methods**. Sage publications.

84. Yunus, M.Z.B.M. and Hassan, H.B. (2010). **Managing road maintenance using geographic information system application**. Journal of Geographic Information System, 2(4), p.215.

85. Zhang, Z. and Hudson, W. R. (1998). **Development of an integrated infrastructure management system.** In Proceedings of the Fourth International Conference on Managing Pavements, Durban, South Africa, Volume 4, pp. 1348-1362.

86. Ziad, T. (2009). **Bridge Asset Management: A Framework for Best Practice and Artificial Intelligence Models to Aid Multi-Criteria Decision Making.** PhD research thesis, University of Manchester, UK.

87. Zietlow, G. (2004) **Road Funds in Latin America.**

Appendices

Appendix (A): Distress types and details.

Appendix (B): Deduct value formulas tables and charts

Appendix (C): Visual Basic (VB) codes

Appendix (A)

Distress Types and Details

Longitudinal Cracks

Longitudinal cracks are individual cracks which form parallel to traffic direction or the roadway centerline. These are occurred most frequently at the joint between adjacent lanes or at the edges of the wheel paths in a pavement and can start as hairline cracks and widen with time and traffic.

Figure A.1 Longitudinal Cracks

Longitudinal cracks create a water seepage to enter the subsurface layers and subgrade resulting in the development of fatigue cracking at the joint between lanes and raveling.

Causes

The lower density of the asphalt concrete results in lower tensile strengths. Longitudinal cracking develops as surface temperatures drop to a level such that the thermally induced shrinkage stresses exceed the tensile strength of the asphalt concrete at the joints. Longitudinal cracking can develop at any place in the pavement if shrinkage stresses exceed the tensile strength of the pavement; however, it will usually first occur at a construction joint due to the lower tensile strength.

The other causes for this distress is the higher voids in the asphalt pavement at the joint which increases the hardening due to oxidation, which makes the pavement more susceptible to cracking and raveling.

Repair

In general, longitudinal crack repair typically involves a variety of maintenance techniques, depending on the severity of the crack (Roberts, et al, 96). In the early stages of crack development, sealing can repair longitudinal cracks. If the cracks are less than ¼ inch wide, fog seals can be used. Fog seals is a light application of a slow setting emulsion on the distresses. Cracks wider than ¼ inch are to be filled with crack sealant. When the distress is severe and raveling develops at the crack edges, the repair would be more extensive, sometimes requiring an overlay TRANSVERSE.

Cracks

Transverse cracks are generally observed on the pavement surface perpendicular to the direction of the traffic and roadway centerline. This type of cracking is also referred to as low temperature or thermal cracking.

Figure A.2 Transverse Cracks

Causes

Transverse cracks are developed when the surface temperature drops to a level such that thermally induced shrinkage stresses exceed the tensile strength of the asphalt concrete.

Repair

Transverse crack repair is similar to longitudinal crack repair. If the distress level is low, cracks can be fog sealed and crack sealant can be used for high distress levels. If the sides of the cracks are at different elevations, milling can eliminate the difference in elevation of the road surface. In advanced stages of transverse crack development, overlays may be required.

Fatigue CRACKS

Fatigue cracking is also known as αlligator crαcking because of the visual look of the distress. Fatigue cracking starts with individual longitudinal cracks developing in wheel paths. With time and traffic, additional longitudinal and transverse cracks develop and the cracks become interconnected. This results in a closely spaced crack pattern that resembles the pattern on an alligator’s back. If pavement areas with alligator cracking are not treated, potholes eventually develop.

Figure A.3 Fatigue Crack

Causes

The tensile stresses are the greatest at the bottom of the asphalt pavement layer from where the cracking starts and with eventual increase in traffic loading, the cracks migrate to the surface.

The main cause of this defect in the pavements is the repetition of the traffic load that stresses the pavement to the fatigue life limit. Also due to heavy loads on the pavement structure the crack formation is accelerated. The fatigue crack can also occur due to insufficient drainage of the pavement because pavement layers lose their strength due to saturation. Due to poor design and inadequate paving thickness or quality during construction combined with repetitive loading can also induce alligator cracking.

Repair

Repair strategies for alligator crack depend on the severity of the distress. Patching, overlays or reconstruction techniques. If cracks occur frequently in a particular section, the patching process can be performed. The Overlays are used to mitigate the problems of alligator cracks that cover an extensive area, but the thickness of the overlay must be sufficiently designed to convey the expected loads. If poor subgrade drainage is the root cause, drainage improvements are to be carried. If the pavement structure is fatigued due to repetitive loading alone, a stronger pavement structure is required to carry the anticipated traffic.

Block Cracks

Block cracking is an interconnected series of longitudinal and transverse cracks, which divides the pavement into approximate square pieces.

Figure A.4 Block Cracks

Causes

Block cracking is caused by the shrinkage of the asphalt pavement due to thermal stresses, hardening of the asphalt. Once the severity of the cracks increases, water starts infiltrating through the cracks into the subsurface.

Repair

A surface seal can be used to reduce surface water infiltration in the early stages of block cracking. But at the advanced stages of distress, either a thick overlay is placed on the existing surface or the old material is removed and replaced with a new asphalt concrete surface.

Edge Cracks

Edge cracking is similar to the longitudinal cracking but occurs along the shoulders of the pavement.

Figure A.5 Edge Cracks

Causes

Edge cracking can occur as a result of poor shoulder support, excessive traffic loads, or a high percentage of heavy trucks on an insufficiently designed road.

Repair

The rehab techniques for the edge cracking depends on severity and extent. These cracks are usually repaired with either thin overlays, chip seal, patching, thick overlay, or reconstruction techniques. If the problem is lack of edge support, material must be added to the shoulders to bring it up to the road level and the material should be properly compacted.

Rutting

Rutting is a depression of asphalt concrete in vehicle wheel paths. The surface depressions created in the wheel paths result from either continued consolidation or lateral displacement of the asphalt concrete under traffic

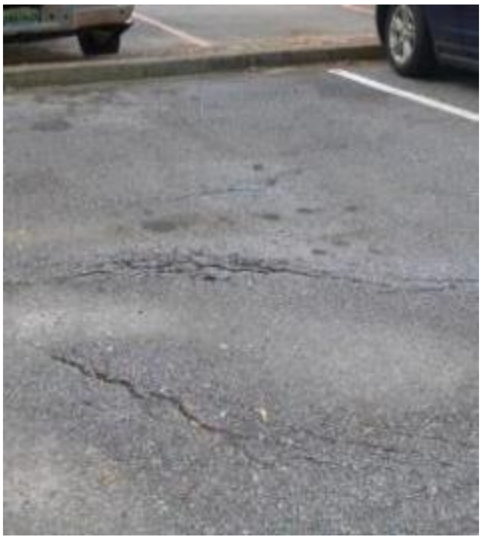


Figure A.6 Rutting

Causes

Some of the factors that because rutting is insufficient compaction during construction, poor mix design (high asphalt content, excessive mineral filler, rounded aggregate, etc.), inadequate drainage, and poor subgrade strength.

Repair

The pavement section must be carefully examined to determine the cause of the rutting before a specific treatment is selected. Minor rutting can be repaired with surface milling and preventive maintenance techniques, such as rut filling with micro surfacing major rutting requires surface milling and rehabilitation (thick overlay). Sections with poor drainage conditions also require drainage improvements to increase subgrade strength.

Raveling

Raveling is the loss aggregate from the asphalt concrete matrix as a result of a bond loss between the aggregate and the asphalt binder.

Figure A.7 Raveling

Causes

The loss of bond between the aggregate and binder can occur as a result of asphalt cement oxidation, poor compaction, or insufficient asphalt content. A poor aggregate/binder bond can also occur when aggregate containing external dust material is used in the asphalt concrete mix. When raveling occurs at the pavement surface, the asphalt concrete layer progressively disintegrates downward.

Repair

Minor raveling can be repaired with preventive maintenance treatments, while major raveling requires thick overlays or recycling of the pavement surface.

Patches

Patches are sections of pavement that have been removed and replaced. Patches are typically used to repair localized pavement defects or to cover utility trenches. A patch failure can lead to widespread pavement distress problems. Patches are defects relative to the original pavement. Even patches in good condition can accelerate the rate of pavement distress development because it can permit the intrusion of water into the subsurface layers and subgrade if the patch is not constructed and sealed properly.

Causes

Patch cracking and distortions typically occur when the root cause of a pavement defect was not properly corrected before the patch was placed. Patches over utility trenches typically fail when the trench was not adequately back-filled and compacted.

Figure A.8 Patches

Repair

Patches that have minor cracking can be repaired with preventive maintenance techniques so that surface water does not enter the subsurface. Pavement sections with a high extent of severely cracked and distorted patches will need reconstruction. Extensive settlement in utility trenches may require additional repair to the utility trench prior to pavement repairs.

Potholes

Potholes allow water to collect and are a hazard to motorists. They are considered a progressive failure. At first, small fragments of the top layer become dislodged from the road surface. Over time, the distress progresses downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage.

Figure A.9 Potholes

Causes

Potholes are formed when the pavement disintegrates under heavy traffic loading. This is due to inadequate strength in one or more layers of the pavement structure, usually accompanied by the presence of water.

Repair

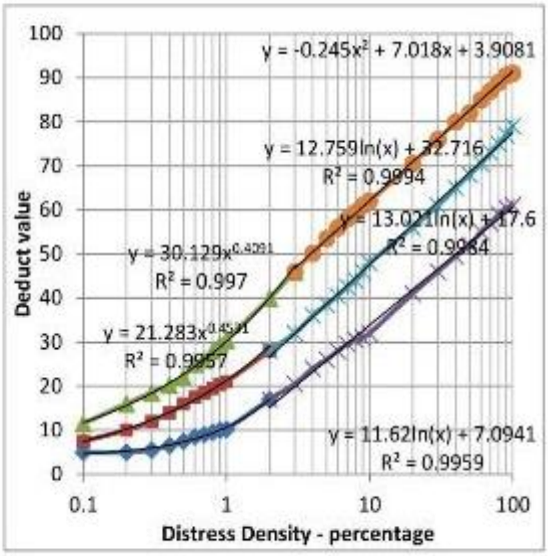
Potholes usually do not develop if the root cause was repaired before it developed into a pothole. Excavating localized areas and replacing the base and surface materials repairs potholes. The removal of external dust materials and proper compaction of the new materials can help reduce the pothole formation. Improvements in drainage may be required if the intrusion of water is causing the subgrade to weaken the pavement surface.

APPENDIX (B)

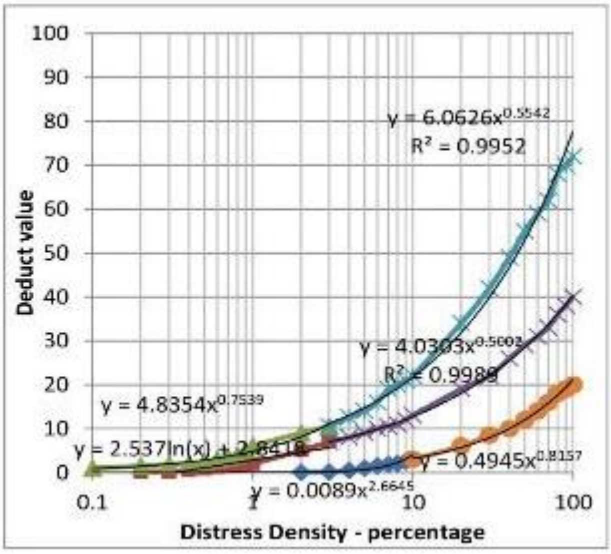
Deduct Value Formulas Tables and Charts

Appendix contains all the deduct value charts and summarized formulas used for calculating the corrected deduct value and total deduct value.

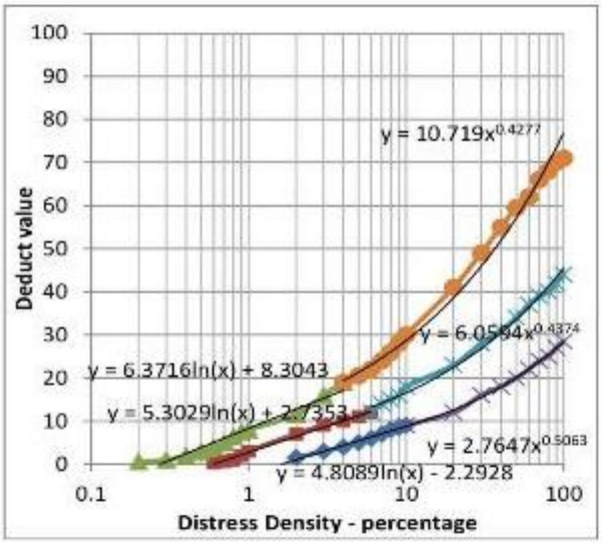
Fatigue Cracking		
	X	Y
Low	0.1	4.61
Medium	0.1	7.50
high	0.1	11.75



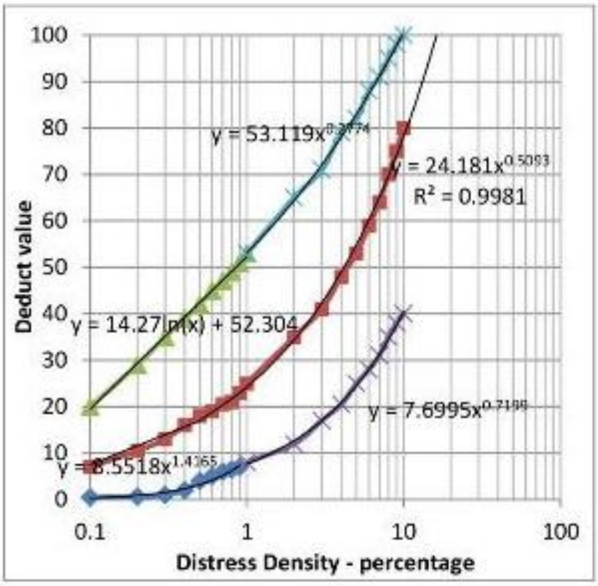
Bleeding		
	X	Y
Low	0.1	1.92704E-05
Medium	0.1	-2.999858381
high	0.1	0.852182097
Note: IF otained Y less than 0, give Y = 0		



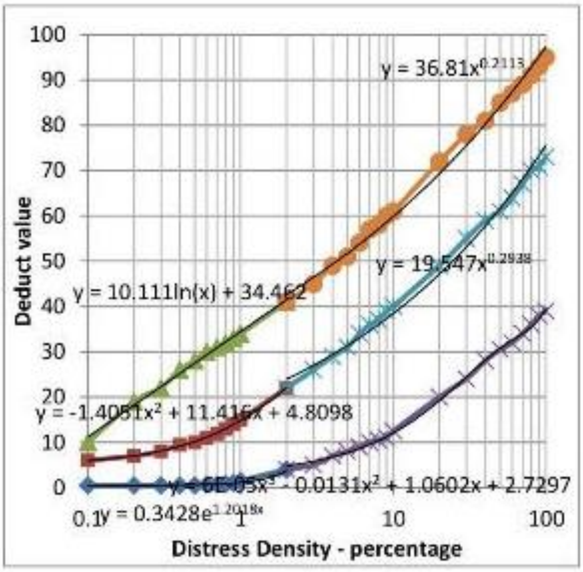
Block Cracking		
	X	Y
Low	0.1	-13.36570145
Medium	0.1	-9.47507849
high	0.1	-6.366851179
Note: IF otained Y less than 0, give Y = 0		



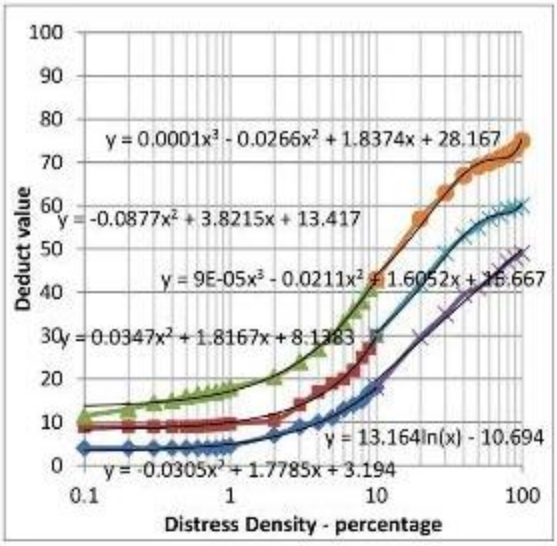
Bumps and Sags		
	X	Y
Low	0.1	0.327761196
Medium	0.1	7.484697575
high	0.1	19.44611072
Note: IF otained Y less than 0, give Y = 0		
X less than 10		



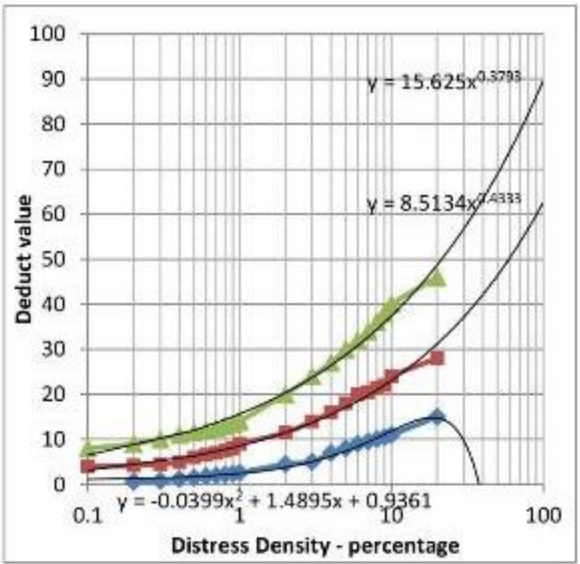
Corrugation		
	X	Y
Low	0.1	0.386575809
Medium	0.1	5.937349
high	0.1	11.18056212



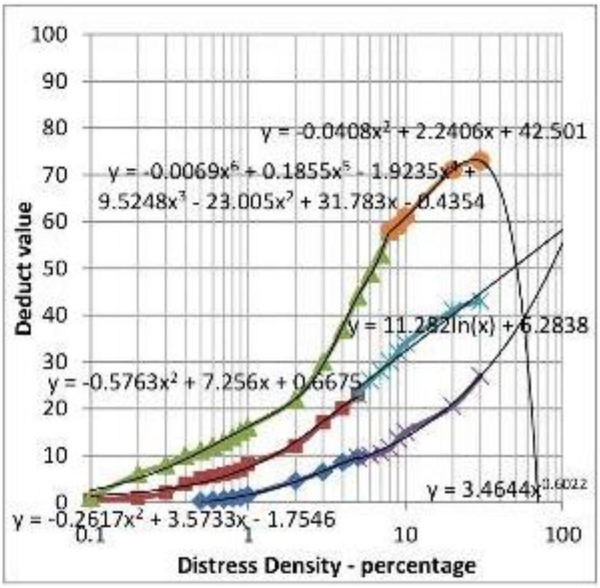
Depression		
	X	Y
Low	0.1	3.371545
Medium	0.1	8.320317
high	0.1	13.798273



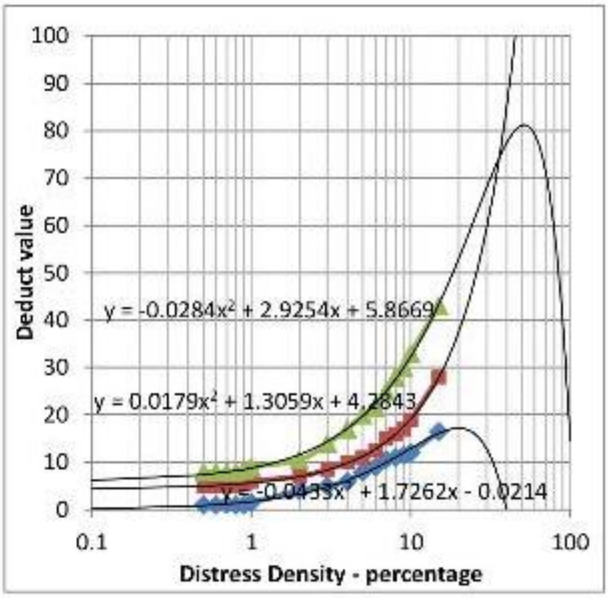
Edge Cracking		
	X	Y
Low	0.1	1.084651
Medium	0.1	3.139084736
high	0.1	6.524091239
Note:	X<20	



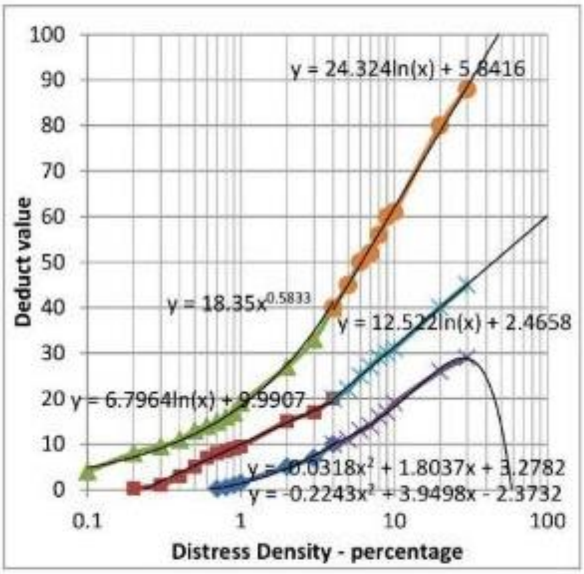
Joint reflection Cracking		
	X	Y
Low	0.36	-0.50212832
Medium	0.1	1.387337
high	0.1	6.114913
Note: IF otained Y less than 0, give Y = 0		
X<30		



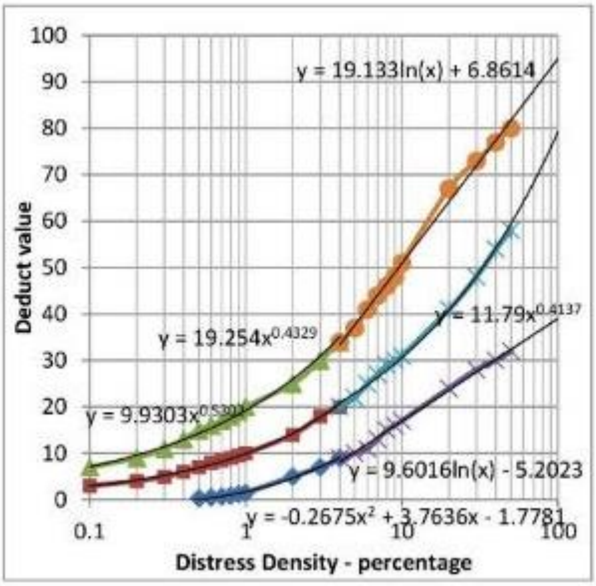
Lane/Shoulder Drop off		
	X	Y
Low	0.1	0.150787
Medium	0.1	4.415069
high	0.1	6.159156
Note:	0.4<X<20	



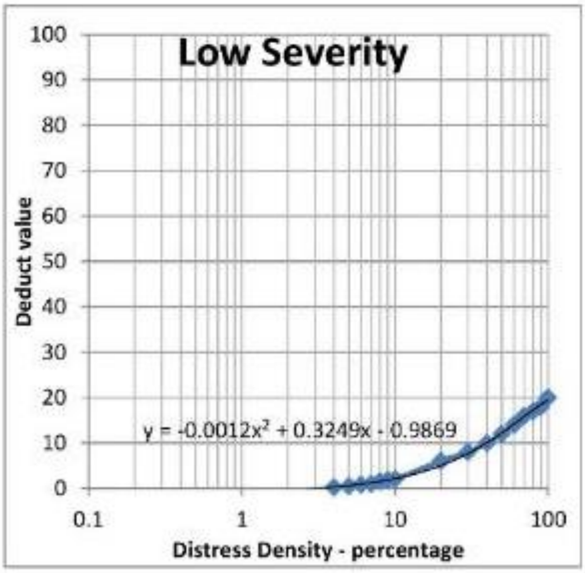
Longitudinal/transverse Cracking		
	X	Y
Low	0.1	-1.980463
Medium	0.3	1.808019233
high	0.1	4.790006123
Note: IF otained Y less than 0, give Y = 0		
X<30		



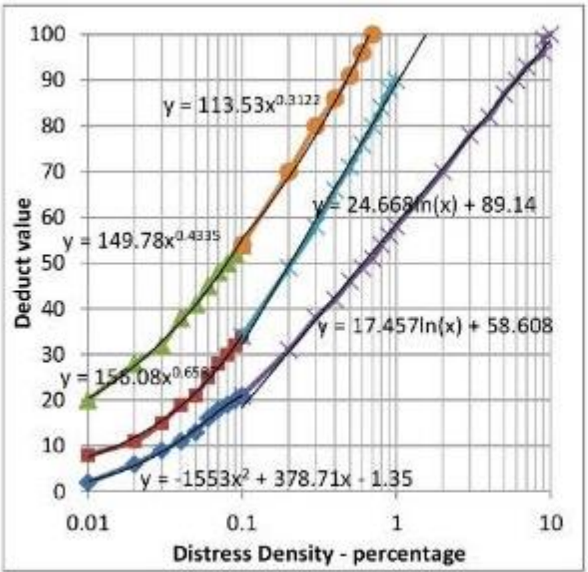
Patching and Utility Cut Patching		
	X	Y
Low	0.1	-1.404415
Medium	0.1	2.92929
high	0.1	7.105930696
Note: IF otained Y less than 0, give Y = 0		



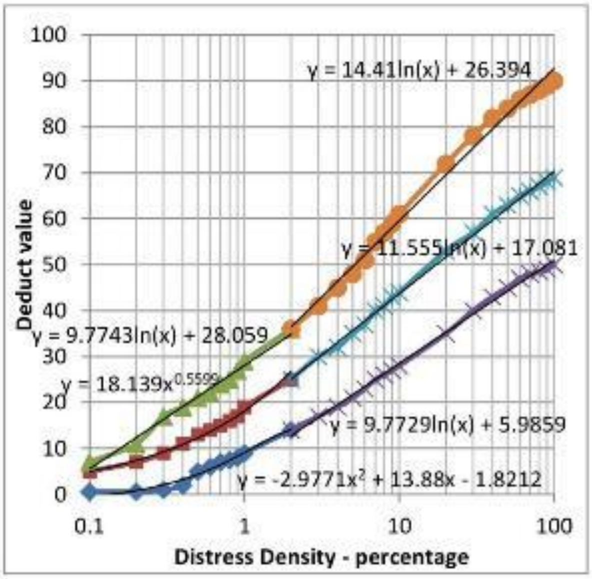
Polished Aggregate		
	X	Y
Low	0.1	-0.95442



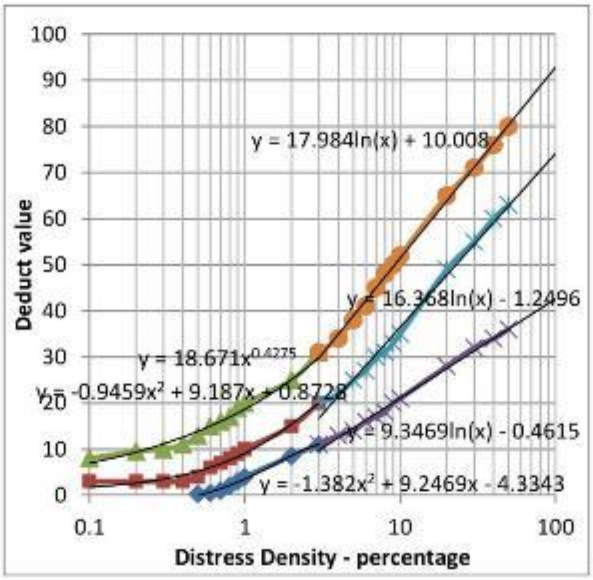
Potholes		
	X	Y
Low	0.01	2.2818
Medium	0.01	7.546529193
high	0.01	20.3448188



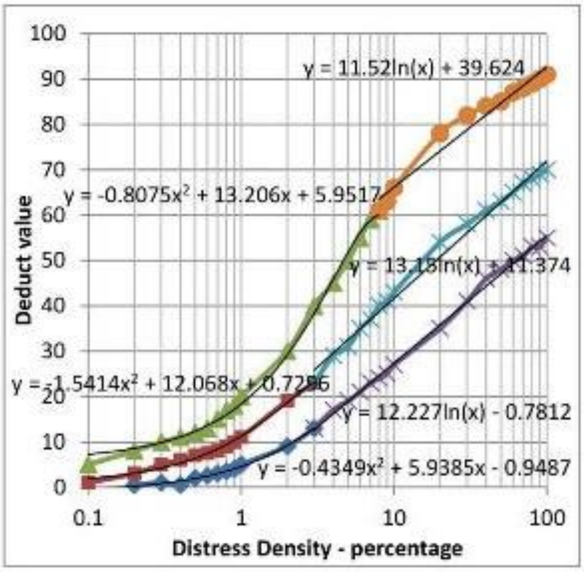
Rutting		
	X	Y
Low	0.1	-0.462971
Medium	0.1	4.997045925
high	0.1	5.552842526
Note: IF otained Y less than 0, give Y = 0		



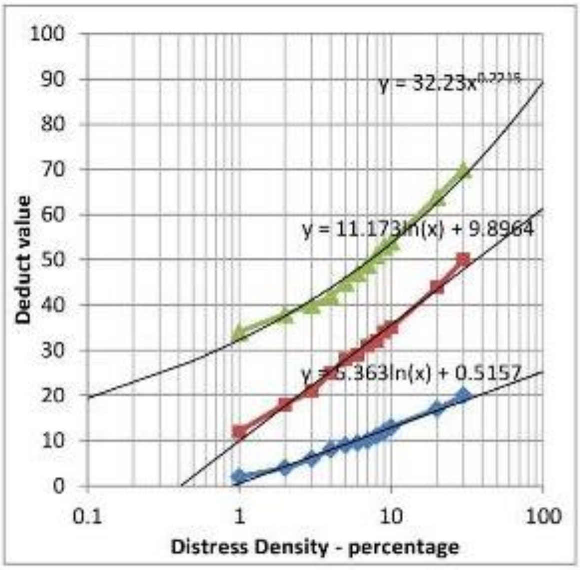
Shoving		
	X	Y
Low	0.1	-3.42343
Medium	0.1	1.782041
high	0.1	6.976981621
Note: IF otained Y less than 0, give Y = 0		
X<50		



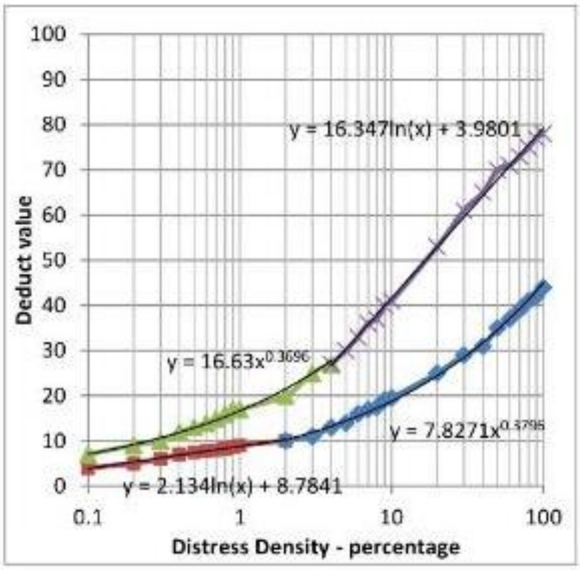
Slippage Cracking		
	X	Y
Low	0.1	-0.359199
Medium	0.1	1.951814
high	0.1	7.264225
Note: IF otained Y less than 0, give Y = 0		



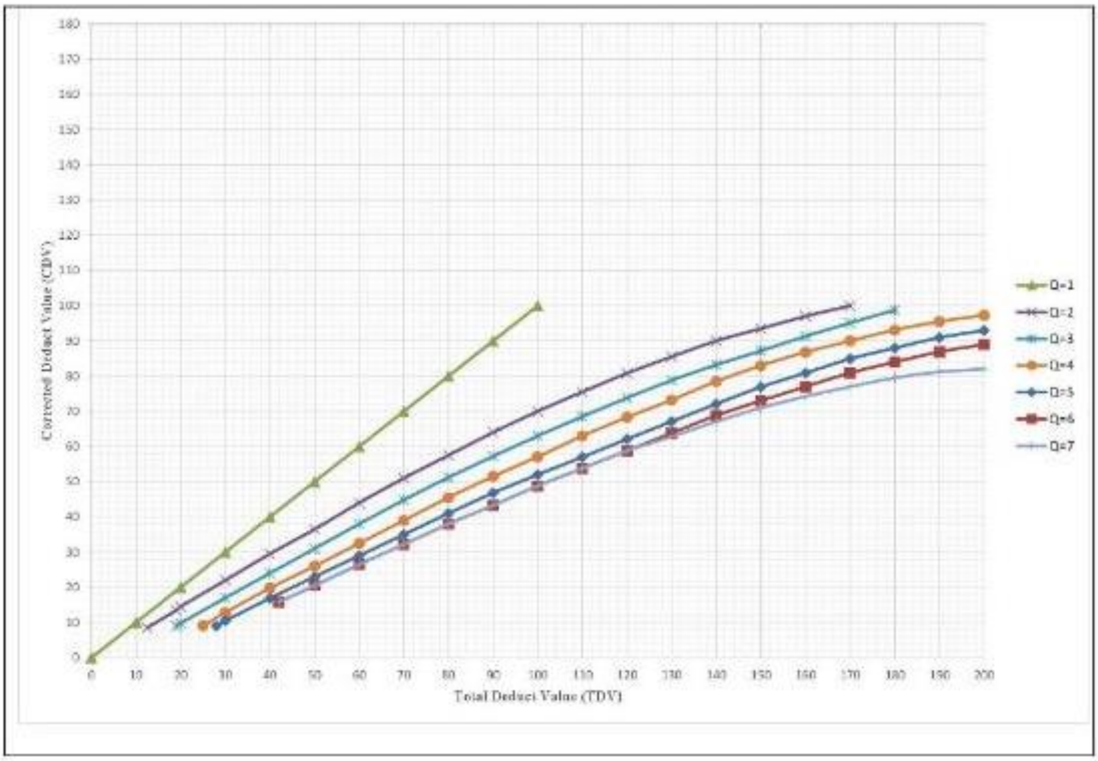
Swell		
	X	Y
Low	1	0.5157
Medium	1	9.8964
high	1	32.23
Note:	1<X<30	



Raveling		
	X	Y
Medium	0.1	3.870
high	0.1	7.101



The corrected deduct value is obtained from the graph mentioned below.



If	Eq
Q=1	y = x
Q=2	y = 0.5994x + 5.7421
Q=3	y = 0.5681x + 2.5118
Q=4	y = 0.5218x + 1.5156
Q=5	y = 0.5039x - 1.1146
Q=6	y = 0.4757x - 0.6059
Q=7	y = 0.4353x + 2.5678

q=1	X	
	Y	0
q=2	X	
	Y	5.7421
q=3	X	
	Y	2.5118
q=4	X	
	Y	1.5156
q=5	X	
	Y	-1.1146
q=6	X	
	Y	-0.6059

Appendix (C)

Visual Basic (VB) codes

1. Field Sheet Code

• Clear Selected data

```
Private Sub ClearButton_Click()

   'This button opens a form that will

   'let you select records to clear...

   '

   Dim ListLength As Long

   Dim SourceText As String

   ListLength = 0

   Do While
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(ListLeng
th + 1, 0).Value <> ""

      ListLength = ListLength + 1

   Loop


   If ListLength > 0 Then

     SourceText = "SurveyArchive!" &
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1,
0).Resize(ListLength, 8).Address

      'Call MsgBox(SourceText, vbOKOnly, "No Saved Surveys")

      ClearForm.ClearList.RowSource = SourceText

      ClearForm.ClearList.ColumnWidths = "80,50,60,60,60,60,60,60"

      ClearForm.Show

   Else

      Call MsgBox("No Saved Surveys", vbOKOnly, "No Saved
Surveys")

   End If
```

```
End Sub

Private Sub ClearSelectedButton_Click()

    'This button will clear selected

    'survey results...

    '

    Dim SurveyID As Long

    Dim i As Long

    Dim b As Integer

    ClearForm.Hide

     b = 0

    For i = 0 To ClearList.ListCount - 1


        If ClearList.Selected(i) Then

            b = b + 1

            SurveyID = Range(ClearList.RowSource).Item(i + 1, 1).Value

            Call DeleteSurvey(SurveyID)

        End If

    Next i

   ' Call MsgBox(b, vbOKOnly, "sumPCI")

End Sub

Public Sub DeleteSurvey(SurveyID As Long)

    'This function deletes a survey from the hidden database.
```

```
    Dim FoundIt As Boolean

    Dim ListRange As Range

    Dim DistressRange As Range

   Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1, 0)

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

    'Remove it from the survey list...

    Do While ListRange.Value <> ""

        If ListRange.Value = SurveyID Then

            'move down one row and delete the one

            'that was active...

            Set ListRange = ListRange.Offset(1, 0)

            ListRange.Offset(-1, 0).Resize(1, 19).Delete (xlShiftUp)

            FoundIt = True

        Else

            'if it isn't found go to next line...

            Set ListRange = ListRange.Offset(1, 0)

            'Once you are done deleting a section,

            'stop the loop to save time...  This

            'assumes the sections are clumped.

            If FoundIt Then Exit Do
```

```
        End If

    Loop



    'Remove it from the distresses list...

    FoundIt = False

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

   ' Call MsgBox(DistressRange, vbOKOnly, "distressrange")

    Do While DistressRange.Value <> ""

        If DistressRange.Value = SurveyID Then

            'move down one row and delete the one

            'that was active...

            Set DistressRange = DistressRange.Offset(1, 0)

            DistressRange.Offset(-1, 0).Resize(1, 9).Delete (xlShiftUp)

            FoundIt = True

        Else

            'if it isn't found go to next line...

            Set DistressRange = DistressRange.Offset(1, 0)

            'Once you are done deleting a section,

            'stop the loop to save time...  This

            'assumes the sections are clumped.

            If FoundIt Then Exit Do
```

```
        End If

    Loop

    Call PI_Calculate

    Call RestoreFinalSurvey


    ' Call PIPCI_Calculate

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

End Sub

Public Sub FinalDeleteSurvey(SurveyID As Long)

    'This function deletes a survey from the hidden database.

    Dim FoundIt As Boolean

    Dim ListRange As Range

    Dim DistressRange As Range

    Set ListRange =
Worksheets("Networklevel").Range("FinalSurveyList").Offset(1, 0)

    'Remove it from the survey list...

    Do While ListRange.Value <> ""

        If ListRange.Value = SurveyID Then

            'move down one row and delete the one

            'that was active...

            Set ListRange = ListRange.Offset(1, 0)

            ListRange.Offset(-1, 0).Resize(1, 17).Delete (xlShiftUp)
```

```
            FoundIt = True
        Else
            'if it isn't found go to next line...
            Set ListRange = ListRange.Offset(1, 0)

            'Once you are done deleting a section,
            'stop the loop to save time...  This
            'assumes the sections are clumped.
            If FoundIt Then Exit Do
        End If
    Loop
End Sub
Public Sub FinalDeletePI(SurveyID As Long)
    'This function deletes a survey from the hidden database.
    '
    Dim FoundIt As Boolean
    Dim ListRange As Range
    Set ListRange = Worksheets("Project
level").Range("PIVALUESCALCID").Offset(1, 0)
    'Remove it from the survey list...
    Do While ListRange.Value <> ""
        If ListRange.Value = SurveyID Then
            'move down one row and delete the one
```

```
            'that was active...
            Set ListRange = ListRange.Offset(1, 0)
            ListRange.Offset(-1, 0).Resize(1, 17).Delete (xlShiftUp)
            FoundIt = True
        Else
            'if it isn't found go to next line...
            Set ListRange = ListRange.Offset(1, 0)
            'Once you are done deleting a section,
            'stop the loop to save time...  This
            'assumes the sections are clumped.
            If FoundIt Then Exit Do
        End If
    Loop
End Sub
```

- **Clear All Data**

```
Private Sub ClearAllButton_Click()

    'This button will clear all

    'survey results...

    '

    Dim Response As Variant


    ClearForm.Hide

    Response = MsgBox("Are you sure you want to delete all survey
results?", vbYesNo, "Delete All Results")

    If Response = vbYes Then

        Call DeleteAllSurveys

    End If

End Sub

Public Sub DeleteSurvey(SurveyID As Long)

    'This function deletes a survey from the hidden database.

    Dim FoundIt As Boolean

    Dim ListRange As Range

    Dim DistressRange As Range

   Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1, 0)

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)
```

```
    'Remove it from the survey list...

    Do While ListRange.Value <> ""

        If ListRange.Value = SurveyID Then

            'move down one row and delete the one

            'that was active...

            Set ListRange = ListRange.Offset(1, 0)

            ListRange.Offset(-1, 0).Resize(1, 19).Delete (xlShiftUp)

            FoundIt = True

        Else

            'if it isn't found go to next line...

            Set ListRange = ListRange.Offset(1, 0)

            'Once you are done deleting a section,

            'stop the loop to save time...  This

            'assumes the sections are clumped.

            If FoundIt Then Exit Do

        End If

    Loop


    'Remove it from the distresses list...

    FoundIt = False

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)
```

```
' Call MsgBox(DistressRange, vbOKOnly, "distressrange")

 Do While DistressRange.Value <> ""

    If DistressRange.Value = SurveyID Then

        'move down one row and delete the one

        'that was active...

        Set DistressRange = DistressRange.Offset(1, 0)

        DistressRange.Offset(-1, 0).Resize(1, 9).Delete (xlShiftUp)

        FoundIt = True

    Else

        'if it isn't found go to next line...

        Set DistressRange = DistressRange.Offset(1, 0)

        'Once you are done deleting a section,

        'stop the loop to save time...  This

        'assumes the sections are clumped.

        If FoundIt Then Exit Do

    End If

 Loop

 Call PI_Calculate

 Call RestoreFinalSurvey


 ' Call PIPCI_Calculate
```

```
    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

End Sub

Public Sub FinalDeleteAllSurveys()

    'This function deletes all surveys from the hidden database.

    Dim MaxSurveyID As Long

    'This reads the the survey IDs in sequence and deletes them

    'individually.

    Do While
Worksheets("Networklevel").Range("FinalSurveyList").Offset(1,
0).Value <> ""

        'To make this quicker, we will start deleting from the

        'bottom and work our way up.  The records should increase

        'with the SurveyID

        MaxSurveyID =
WorksheetFunction.Max(Worksheets("Networklevel").Range("FinalSur
veyList").EntireColumn)

        Call FinalDeleteSurvey(MaxSurveyID)

    Loop

End Sub

Public Sub FinalDeleteAllPI()

    'This function deletes all surveys from the hidden database.



    Dim MaxSurveyID As Long
```

```
    'This reads the the survey IDs in sequence and deletes them

    'individually.

    Do While Worksheets("Project level").Range("PIVALUESCALCID").Offset(1, 0).Value <> ""

        'To make this quicker, we will start deleting from the

        'bottom and work our way up.  The records should increase

        'with the SurveyID

        MaxSurveyID = WorksheetFunction.Max(Worksheets("Project level").Range("PIVALUESCALCID").EntireColumn)

        Call FinalDeletePI(MaxSurveyID)

    Loop

End Sub
```

- **Load Data**

```
Private Sub LoadButton_Click()

    'This button opens a form that will

    'let you select records to clear...

    '

    Dim ListLength As Long

    Dim SourceText As String

    ListLength = 0

    Do While Worksheets("SurveyArchive").Range("OurSurveyList").Offset(ListLength + 1, 0).Value <> ""
```

```
    ListLength = ListLength + 1

  Loop

  If ListLength = 0 Then

   Call MsgBox("No Saved Surveys", vbOKOnly, "No Saved Surveys")

  Else

  SourceText = "SurveyArchive!" &
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1,
0).Resize(ListLength, 9).Address

  LoadForm.LoadList.RowSource = SourceText

  LoadForm.LoadList.ColumnWidths = "80,50,60,60,60,60,60,60,60"

  LoadForm.Show

  End If

End Sub Private Sub LoadSelectedButton_Click()

  'This button will load selected

  'survey results...

  '

  Dim SurveyID As Long

  Dim i As Long

  LoadForm.Hide

  For i = 0 To LoadList.ListCount - 1

    If LoadList.Selected(i) Then

      SurveyID = Range(LoadList.RowSource).Item(i + 1, 1).Value

      Call RestoreSurvey(SurveyID)
```

```
        End If

    Next i

End Sub

Public Sub RestoreSurvey(SurveyID As Long)

    'This function takes the survey from the hidden database,

    'and restores it to the form...

    Dim ListRange As Range

    Dim DistressRange As Range

    Dim i As Long

    Dim k As Long

    Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1, 0)

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

    'Find the SurveyID or end...

    Do While ListRange.Value <> "" And ListRange.Value <> SurveyID

        Set ListRange = ListRange.Offset(1, 0)

    Loop


    'If the SurveyID isn't found, do nothing...

    If ListRange.Value = "" Then Exit Sub
```

```
   Do While DistressRange.Value <> "" And DistressRange.Value <> SurveyID

       Set DistressRange = DistressRange.Offset(1, 0)

   Loop

   'go through the spreadsheet and restore all entries...

   'do the survey headers...

  ' Worksheets("Field Sheet").Range("B12").Formula = ListRange.Offset(0, 17).Formula 'road name

   Worksheets("Field Sheet").Range("B14").Formula = ListRange.Offset(0, 2).Formula 'ROADNUM

   Worksheets("Field Sheet").Range("C13").Formula = ListRange.Offset(0, 3).Formula 'CITIZEN COMPLAINTS

   Worksheets("Field Sheet").Range("G13").Formula = ListRange.Offset(0, 4).Formula 'LANE DIRECTION

   Worksheets("Field Sheet").Range("I14").Formula = ListRange.Offset(0, 5).Formula 'Sample Num

   Worksheets("Field Sheet").Range("E14").Formula = ListRange.Offset(0, 6).Formula 'road class

   Worksheets("Field Sheet").Range("B15").Formula = ListRange.Offset(0, 7).Formula 'zone

   Worksheets("Field Sheet").Range("G15").Formula = ListRange.Offset(0, 8).Formula 'ROAD IMPORTANCE

   Worksheets("Field Sheet").Range("B18").Formula = ListRange.Offset(0, 9).Formula 'ADT

   'Worksheets("Field Sheet").Range("G16").Formula = ListRange.Offset(0, 18).Formula 'Area

   Worksheets("Field Sheet").Range("B20").Formula = ListRange.Offset(0, 11).Formula
```

```
    Worksheets("Field Sheet").Range("F20").Formula =
ListRange.Offset(0, 12).Formula

    'Worksheets("Field Sheet").Range("K54").Formula =
ListRange.Offset(0, 14).Formula ' PCI

    Worksheets("Field Sheet").Range("H12").Formula =
ListRange.Offset(0, 15).Formula

    Worksheets("Field Sheet").Range("C16").Formula =
ListRange.Offset(0, 16).Formula

    'restore the distresses...

    i = 0

    Do While DistressRange.Value = SurveyID

        i = i + 1

        Worksheets("Field Sheet").Range("A31").Offset(i, 0).Formula =
DistressRange.Offset(0, 1).Formula

        For k = 1 To 7

            Worksheets("Field Sheet").Range("B31").Offset(i, k).Formula =
DistressRange.Offset(0, 1 + k).Formula

        Next k

        Set DistressRange = DistressRange.Offset(1, 0)

    Loop

End Sub
```

- **Save Data**

```
Private Sub SaveButton_Click()

    'This button saves the record...

    Call StoreSurvey

End Sub
```

2. Survey Archive

- **Save Data**

```
 Public Sub StoreSurvey()

    'This function takes the survey presented in the

    'field form and stores it in the hidden database.

    Dim ListRange As Range

    Dim DistressRange As Range

    Dim SurveyID As Long

    Dim i As Long

    Dim k As Long

    Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyList").Offset(1, 0)

    Set DistressRange =
Worksheets("SurveyArchive").Range("OurSurveyDistresses").Offset(1,
0)

    'Find the first blank space...

    Do While ListRange.Value <> ""

        Set ListRange = ListRange.Offset(1, 0)
```

```
    Loop

    Do While DistressRange.Value <> ""

        Set DistressRange = DistressRange.Offset(1, 0)

    Loop

    SurveyID = WorksheetFunction.Max(ListRange.EntireColumn) + 1

    'go through the spreadsheet and store any entries...

    ListRange.Offset(0, 0).Formula = SurveyID

    ListRange.Offset(0, 1).Formula = Worksheets("Field
Sheet").Range("B12").Value 'road name

    ListRange.Offset(0, 2).Formula = Worksheets("Field
Sheet").Range("B100").Value 'ROADNUM

    ListRange.Offset(0, 3).Formula = Worksheets("Field
Sheet").Range("C13").Formula 'CITIZEN COMPLAINTS

    ListRange.Offset(0, 4).Formula = Worksheets("Field
Sheet").Range("G13").Formula 'LANE DIRECTION

    ListRange.Offset(0, 5).Formula = Worksheets("Field
Sheet").Range("I14").Formula 'Sample Num

    ListRange.Offset(0, 6).Formula = Worksheets("Field
Sheet").Range("E14").Formula 'road class

    ListRange.Offset(0, 7).Formula = Worksheets("Field
Sheet").Range("B15").Formula 'zone

    ListRange.Offset(0, 8).Formula = Worksheets("Field
Sheet").Range("G15").Formula 'ROAD IMPORTANCE

    ListRange.Offset(0, 9).Formula = Worksheets("Field
Sheet").Range("B18").Formula 'ADT

    ListRange.Offset(0, 10).Formula = Worksheets("Field
Sheet").Range("G16").Value
```

```
    ListRange.Offset(0, 11).Formula = Worksheets("Field
Sheet").Range("B20").Formula

    ListRange.Offset(0, 12).Formula = Worksheets("Field
Sheet").Range("F20").Formula

    ListRange.Offset(0, 13).Value = Worksheets("Field
Sheet").Range("K54").Value

    ListRange.Offset(0, 14).Formula = Worksheets("Field
Sheet").Range("K54").Formula

    ListRange.Offset(0, 15).Formula = Worksheets("Field
Sheet").Range("H12").Formula

     ListRange.Offset(0, 16).Formula = Worksheets("Field
Sheet").Range("C16").Formula 'SURVEYED BY

    ListRange.Offset(0, 18).Formula = Worksheets("Field
Sheet").Range("G16").Formula

    ListRange.Offset(0, 17).Formula = Worksheets("Field
Sheet").Range("B12").Formula 'road name

   ' ListRange.Offset(0, 2).Formula = Worksheets("Field
Sheet").Range("B101").Formula 'ROADNUM

    For i = 1 To 20

        'do the survey headers...

        'Insert 1 distress...

        DistressRange.Offset(0, 0).Formula = SurveyID

        DistressRange.Offset(0, 1).Formula = Worksheets("Field
Sheet").Range("A31").Offset(i, 0).Formula

        For k = 1 To 7

            DistressRange.Offset(0, 1 + k).Formula = Worksheets("Field
Sheet").Range("B31").Offset(i, k).Formula

        Next k
```

```
        Set DistressRange = DistressRange.Offset(1, 0)

    Next i

    Call PI_Calculate

    Call RestoreFinalSurvey

    ' Call PIPCI_Calculate

End Sub
```

3. Network Level

- **Save Data**

```
Public Sub RestoreFinalSurvey()

    'This function takes the survey from the hidden database,

    'and restores it to the form...

    Dim ListRange As Range

    Dim FListRange As Range

    Dim DistressRange As Range

    Dim PCIRange As Range

    Dim FPCIRange As Range

    Dim FinalRoadNumRange As Range

    Dim RoadNumRange As Range

    Dim SegLengthRange As Range

    Dim SegAreaRange As Range

    Dim FinalRoadClassRange As Range

    Dim RoadClassRange As Range

    Dim FinalRoadADTRange As Range

    Dim RoadADTRange As Range

    Dim FinalCitizenComplaintsRange As Range

    Dim CitizenComplaintsRange As Range

    Dim FinalLaneDirectionRange As Range
```

```
Dim LaneDirectionRange As Range

Dim FinalZoneRange As Range

Dim ZoneRange As Range

Dim FinalRoadImportanceRange As Range

Dim RoadImportanceRange As Range

Dim FinalSectionNumRange As Range

Dim SectionNumRange As Range

Dim FinalPIRange As Range

Dim PIRange As Range

Dim i As Long

 Dim cc As Long

Dim k As Long

Dim Found As Long

Dim j As Long

Dim NotFound As Boolean

Dim Repeated As Boolean

Dim Sum_PCI As Double

Dim Sum_PI As Double

Dim Sum_ADT As Double

Dim Sum_Seg  As Double

Dim resultpci As Double

Dim resultpi As Double
```

```
    Dim MaxSurveyID As Long

    Dim FSurveyID As Long

    Dim PCI_LOCAL_STORGE As Object

    Dim PI_LOCAL_STORGE As Object

    Dim ROAD_LOCAL_STORGE As Object

    Dim ROADNUM_LOCAL_STORGE As Object

    Dim ROADCLASS_LOCAL_STORGE As Object

    Dim ROADADT_LOCAL_STORGE As Object

    Dim CitizenComplaints_LOCAL_STORGE As Object

    Dim LaneDirection_LOCAL_STORGE As Object

    Dim Zone_LOCAL_STORGE As Object

    Dim RoadImportance_LOCAL_STORGE As Object

    Dim SectionNum_LOCAL_STORGE As Object

    Call FinalDeleteAllSurveys

    Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyRoad").Offset(1, 0)

    Set FListRange =
Worksheets("Networklevel").Range("FinalSurveyList").Offset(1, 0)

    Set PCIRange =
Worksheets("SurveyArchive").Range("OurSurveyPCI").Offset(1, 0)

    Set FPCIRange =
Worksheets("Networklevel").Range("FinalPCIList").Offset(1, 0)

    Set FinalRange =
Worksheets("Networklevel").Range("FinalSurveyRoad").Offset(1, 0)
```

```
    Set FinalRoadNumRange =
Worksheets("Networklevel").Range("FinalSurveyROAD_NUM").Offset
(1, 0)

    Set RoadNumRange =
Worksheets("SurveyArchive").Range("OurSurveyROAD_NUM").Offset
(1, 0)

    Set RoadClassRange =
Worksheets("SurveyArchive").Range("OurSurveyROAD_CLASS").Offs
et(1, 0)

    Set FinalRoadClassRange =
Worksheets("Networklevel").Range("FinalSurveyROAD_CLASS").Offs
et(1, 0)

    Set RoadADTRange =
Worksheets("SurveyArchive").Range("OurSurveyADT").Offset(1, 0)

    Set FinalRoadADTRange =
Worksheets("Networklevel").Range("FinalSurveyADT").Offset(1, 0)

    'Set SegLengthRange =
Worksheets("SurveyArchive").Range("OurSurveyLENGTH").Offset(1,
0)

    Set SegAreaRange =
Worksheets("SurveyArchive").Range("OurSurveyArea").Offset(1, 0)

    Set FinalCitizenComplaintsRange =
Worksheets("Networklevel").Range("FinalCitizenComplaints").Offset(1,
0)

    Set CitizenComplaintsRange =
Worksheets("SurveyArchive").Range("OurSurveyCitizen_Complaints").
Offset(1, 0)

    Set FinalLaneDirectionRange =
Worksheets("Networklevel").Range("FinalLaneDirection").Offset(1, 0)

    Set LaneDirectionRange =
Worksheets("SurveyArchive").Range("OurSurveyLaneDirection").Offse
t(1, 0)

    Set FinalZoneRange =
Worksheets("Networklevel").Range("FinalZone").Offset(1, 0)
```

```
    Set ZoneRange =
Worksheets("SurveyArchive").Range("OurSurveyZone").Offset(1, 0)

    Set FinalRoadImportanceRange =
Worksheets("Networklevel").Range("FinalRoadImportance").Offset(1,
0)

    Set RoadImportanceRange =
Worksheets("SurveyArchive").Range("OurSurveyRoadImportance").Off
set(1, 0)

    Set FinalSectionNumRange =
Worksheets("Networklevel").Range("FinalSurveySectionNum").Offset(1
, 0)

    Set SectionNumRange =
Worksheets("SurveyArchive").Range("OurSurveySectionNUM").Offset(
1, 0)

    Set PIRange = Worksheets("Project
level").Range("PIVALUESCALCPi").Offset(1, 0)

    Set FinalPIRange =
Worksheets("Networklevel").Range("FinalSurveyArchivePI").Offset(1,
0)

    Set PCI_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

    Set ROAD_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

    Set ROADNUM_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

    Set ROADCLASS_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

    Set ROADADT_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

    Set CitizenComplaints_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")
```

```
   Set LaneDirection_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

   Set Zone_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

   Set RoadImportance_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

   Set SectionNum_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

   Set PI_LOCAL_STORGE =
CreateObject("System.Collections.ArrayList")

   MaxSurveyID =
WorksheetFunction.Max(Worksheets("SurveyArchive").Range("OurSur
veyList").EntireColumn)

  cc = 0

    For i = 0 To MaxSurveyID - 1

          NotFound = True

        Sum_PCI = PCIRange.Offset(i, 0).Value *
SegAreaRange.Offset(i, 0).Value

        Sum_ADT = RoadADTRange.Offset(i, 0).Value

        Sum_PI = PIRange.Offset(i, 0).Value * SegAreaRange.Offset(i,
0).Value

        Sum_Seg = SegAreaRange.Offset(i, 0).Value

        For l = 0 To ROADNUM_LOCAL_STORGE.Count - 1

         If RoadNumRange.Offset(i, 0).Value =
ROADNUM_LOCAL_STORGE.Item(l) Then

            NotFound = False

            j = 1
```

```
End If

Next l

If NotFound Then

'Call MsgBox(RoadNumRange.Offset(i, 0).Value, vbOKOnly,
"netcc")

cc = cc + 1

For k = (i + 1) To (MaxSurveyID)

If RoadNumRange.Offset(i, 0).Value =
RoadNumRange.Offset(k, 0).Value Then

Sum_PCI = Sum_PCI + (PCIRange.Offset(k, 0).Value *
SegAreaRange.Offset(k, 0).Value)     ' calculat pci commullative

Sum_Seg = Sum_Seg + SegAreaRange.Offset(k, 0).Value

Sum_ADT = Sum_ADT + RoadADTRange.Offset(k,
0).Value

Sum_PI = Sum_PI + (PIRange.Offset(k, 0).Value *
SegAreaRange.Offset(k, 0).Value)

j = j + 1

End If

Next k

If Sum_Seg = 0 Then

Sum_Seg = 1

End If

If j = 0 Then

j = 1
```

```
End If

resultpci = CDec(Sum_PCI) / Sum_Seg

resultpi = CDec(Sum_PI) / Sum_Seg

' Repeated = False



'If Not Repeated Then

' Sum_Seg = SegLengthRangeRange.Offset(i, 0).Value

' Sum_PCI=PCIRange.Offset(i, 0).Value *
SegLengthRangeRange.Offset(i, 0).Value

' End If

'Call MsgBox(MaxSurveyID, vbOKOnly, "Countddd")

' Call MsgBox(Sum_PI, vbOKOnly, "Sum PI")

' Call MsgBox(Sum_Seg, vbOKOnly, "Sum Seg")

PCI_LOCAL_STORGE.Add (resultpci)  ' store pci name
locally

PI_LOCAL_STORGE.Add (resultpi)

ROAD_LOCAL_STORGE.Add (ListRange.Offset(i, 0).Value)
' store road name locally

ROADNUM_LOCAL_STORGE.Add
(RoadNumRange.Offset(i, 0).Value) ' store road number locally

ROADCLASS_LOCAL_STORGE.Add
(RoadClassRange.Offset(i, 0).Value) ' store road class locally

ROADADT_LOCAL_STORGE.Add (Sum_ADT / j) ' store
road adt locally

CitizenComplaints_LOCAL_STORGE.Add
(CitizenComplaintsRange.Offset(i, 0).Value) 'store CitizenComplaints
```

```
            LaneDirection_LOCAL_STORGE.Add
(LaneDirectionRange.Offset(i, 0).Value) 'store LaneDirection

            Zone_LOCAL_STORGE.Add (ZoneRange.Offset(i, 0).Value)
'store Zone

            RoadImportance_LOCAL_STORGE.Add
(RoadImportanceRange.Offset(i, 0).Value) 'store RoadImportance

            SectionNum_LOCAL_STORGE.Add
(SectionNumRange.Offset(i, 0).Value) 'Store section num

        End If

         Next i

    'Call MsgBox(cc, vbOKOnly, "netcc")

    ' retrive values from loacl to final sheet

      For l = 0 To ROADNUM_LOCAL_STORGE.Count - 1

                If ROADNUM_LOCAL_STORGE(l) <> "" Then

                FListRange.Offset(l, 0).Formula = l + 1 ' id

                FPCIRange.Offset(l, 0).Formula =
PCI_LOCAL_STORGE(l) ' pci

                FinalRoadNumRange.Offset(l, 0).Formula =
ROADNUM_LOCAL_STORGE(l) ' road number

                FinalRoadClassRange.Offset(l, 0).Formula =
ROADCLASS_LOCAL_STORGE(l) ' road class

                 FinalRoadADTRange.Offset(l, 0).Formula =
ROADADT_LOCAL_STORGE(l) ' road adt

                FinalRange.Offset(l, 0).Formula =
ROAD_LOCAL_STORGE(l) ' road name

                FinalCitizenComplaintsRange.Offset(l, 0).Formula =
CitizenComplaints_LOCAL_STORGE(l) ' CitizenComplaints
```

```
                FinalLaneDirectionRange.Offset(l, 0).Formula =
LaneDirection_LOCAL_STORGE(l) ' LaneDirection

                FinalZoneRange.Offset(l, 0).Formula =
Zone_LOCAL_STORGE(l) ' zone

                FinalRoadImportanceRange.Offset(l, 0).Formula =
RoadImportance_LOCAL_STORGE(l) ' RoadImportance

                FinalSectionNumRange.Offset(l, 0).Formula =
SectionNum_LOCAL_STORGE(l)

                FinalPIRange.Offset(l, 0).Formula =
PI_LOCAL_STORGE(l)

               ' Call MsgBox(PCI_LOCAL_STORGE(l), vbOKOnly,
"sumPCI")

                End If



          Next l



   'end
```

4. Project Level

- **Save data**

```
Public Sub PI_Calculate()

    'This function takes the survey from the hidden database,

    'and restores it to the form...

    Dim ListRange As Range

    Dim PIListRange As Range

    Dim DistressRange As Range

    Dim PCIRange As Range

    Dim PIPCIRange As Range

    Dim PCIVRange As Range

    Dim PIPCIVRange As Range

    Dim PIRoadNumRange As Range

    Dim RoadNumRange As Range

    Dim SegLengthRange As Range

    Dim PIRoadClassRange As Range

    Dim RoadClassRange As Range

    Dim PIRoadADTRange As Range

    Dim RoadADTRange As Range

    Dim PICitizenComplaintsRange As Range

    Dim CitizenComplaintsRange As Range
```

```
Dim PILaneDirectionRange As Range

Dim LaneDirectionRange As Range

Dim PIZoneRange As Range

Dim ZoneRange As Range

Dim PISectionRange As Range

Dim SectionRange As Range

Dim PIDirectionRange As Range

Dim DirectionRange As Range

Dim PIRoadImportanceRange As Range

Dim RoadImportanceRange As Range

Dim PIVALUESCALCPiRange As Range


Dim i As Long

Dim k As Long

Dim Found As Long

Dim j As Long

Dim NotFound As Boolean

Dim Repeated As Boolean

Dim Sum_PCI As Double

Dim Sum_Seg  As Double

Dim MAx_ADT As Double

Dim resultpci As Double
```

```
    Dim MaxSurveyID As Long

    Dim PISurveyID As Long

    Dim PCI_LOCAL_STORGE As Object

    Dim PCIV_LOCAL_STORGE As Object

    Dim ROAD_LOCAL_STORGE As Object

    Dim ROADNUM_LOCAL_STORGE As Object

    Dim ROADCLASS_LOCAL_STORGE As Object

    Dim ROADADT_LOCAL_STORGE As Object

    Dim CitizenComplaints_LOCAL_STORGE As Object

    Dim LaneDirection_LOCAL_STORGE As Object

    Dim Zone_LOCAL_STORGE As Object

    Dim Section_LOCAL_STORGE As Object

    Dim Direction_LOCAL_STORGE As Object

    Dim RoadImportance_LOCAL_STORGE As Object

    Call FinalDeleteAllPI

    Set PIListRange = Worksheets("Project
level").Range("PIVALUESCALCID").Offset(1, 0)   'PI_id

    Set PIRange = Worksheets("Project
level").Range("PIVALUESCALCROADName").Offset(1, 0) '
PI_roadname

    Set ListRange =
Worksheets("SurveyArchive").Range("OurSurveyRoad").Offset(1, 0) '
survey_roadname

    Set PIRoadNumRange = Worksheets("Project
level").Range("PIVALUESCALCROADNUM").Offset(1, 0) '
PI_roadnum
```

```
    Set RoadNumRange =
Worksheets("SurveyArchive").Range("OurSurveyROAD_NUM").Offset
(1, 0) ' survey_roadnum

    Set PIZoneRange = Worksheets("Project
level").Range("PIVALUESCALCZone").Offset(1, 0) ' PI_zone

    Set ZoneRange =
Worksheets("SurveyArchive").Range("OurSurveyZone").Offset(1, 0)
'survey_zone

    Set PISectionRange = Worksheets("Project
level").Range("PIVALUESCALCSection").Offset(1, 0) ' PI_section

    Set SectionRange =
Worksheets("SurveyArchive").Range("OurSurveySectionNUM").Offset(
1, 0)  'survey_section

    Set PIDirectionRange = Worksheets("Project
level").Range("PIVALUESCALCDirection").Offset(1, 0) ' PI_direction

    Set DirectionRange =
Worksheets("SurveyArchive").Range("OurSurveyLaneDirection").Offse
t(1, 0)  'survey_direction

    Set RoadADTRange =
Worksheets("SurveyArchive").Range("OurSurveyADT").Offset(1, 0)

    Set PIRoadADTRange = Worksheets("Project
level").Range("PIVALUESCALCFiADT").Offset(1, 0)



     Set PCIRange =
Worksheets("SurveyArchive").Range("OurSurveyPCI").Offset(1, 0)

     Set PIPCIRange = Worksheets("Project
level").Range("PIVALUESCALCFiPCI").Offset(1, 0)




     Set RoadClassRange =
Worksheets("SurveyArchive").Range("OurSurveyROAD_CLASS").Offs
et(1, 0)
```

```
    Set PIRoadClassRange = Worksheets("Project level").Range("PIVALUESCALCFiRoadClass").Offset(1, 0)



    Set PICitizenComplaintsRange = Worksheets("Project level").Range("PIVALUESCALCFiCITIZENCOMPLAINTS").Offset(1, 0)

    Set CitizenComplaintsRange = Worksheets("SurveyArchive").Range("OurSurveyCitizen_Complaints").Offset(1, 0)

    Set PIRoadImportanceRange = Worksheets("Project level").Range("PIVALUESCALCFiROADIMPORTANCE").Offset(1, 0)

    Set RoadImportanceRange = Worksheets("SurveyArchive").Range("OurSurveyRoadImportance").Offset(1, 0)



    Set PIVALUESCALCPiRange = Worksheets("Project level").Range("PIVALUESCALCPi").Offset(1, 0)

   Set PCIVRange = Worksheets("SurveyArchive").Range("OurSurveyPCI").Offset(1, 0)

   Set PIPCIVRange = Worksheets("Project level").Range("PIVALUESCALCPCI").Offset(1, 0)



   Set PCI_LOCAL_STORGE = CreateObject("System.Collections.ArrayList")

   Set PCIV_LOCAL_STORGE = CreateObject("System.Collections.ArrayList")

   Set ROAD_LOCAL_STORGE = CreateObject("System.Collections.ArrayList")

   Set ROADNUM_LOCAL_STORGE = CreateObject("System.Collections.ArrayList")
```

```
    Set ROADCLASS_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set ROADADT_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set CitizenComplaints_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set Zone_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set Section_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set Direction_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

    Set RoadImportance_LOCAL_STORGE = 
CreateObject("System.Collections.ArrayList")

   ' MaxSurveyID = 
WorksheetFunction.Max(Worksheets("SurveyArchive").Range("OurSur
veyList").EntireColumn)

    MaxSurveyID = 
WorksheetFunction.CountA(Worksheets("SurveyArchive").Range("Our
SurveyList").EntireColumn)

     For i = 0 To MaxSurveyID - 1

          ROADNUM_LOCAL_STORGE.Add (RoadNumRange.Offset(i, 
0).Value) ' store road number locally ok

               NotFound = True

               MAx_ADT = RoadADTRange.Offset(i, 0).Value

               For l = 0 To ROADNUM_LOCAL_STORGE.Count - 1

                    If RoadNumRange.Offset(i, 0).Value = 
ROADNUM_LOCAL_STORGE.Item(l) Then

                       NotFound = False 'repeated
```

```
Exit For

End If

Next l

For k = 0 To (MaxSurveyID) - 1

If RoadNumRange.Offset(i, 0).Value =
RoadNumRange.Offset(k, 0).Value Then

If MAx_ADT <= RoadADTRange.Offset(k, 0).Value Then

MAx_ADT = RoadADTRange.Offset(k, 0).Value

End If

End If

Next k

'   Call MsgBox(MAx_ADT, vbOKOnly, "Max ADT")

ROAD_LOCAL_STORGE.Add (ListRange.Offset(i, 0).Value)
' store road name locally ok

Zone_LOCAL_STORGE.Add (ZoneRange.Offset(i, 0).Value)
'store Zone

Section_LOCAL_STORGE.Add (SectionRange.Offset(i,
0).Value) 'store Section

Direction_LOCAL_STORGE.Add (DirectionRange.Offset(i,
0).Value) 'store Direction

PCIV_LOCAL_STORGE.Add (PCIVRange.Offset(i,
0).Value) ' store PCI

If RoadClassRange.Offset(i, 0).Value = "AR" Then

ROADCLASS_LOCAL_STORGE.Add (100)  ' store Firoad
class locally
```

```
ElseIf RoadClassRange.Offset(i, 0).Value = "CL" Then

ROADCLASS_LOCAL_STORGE.Add (75)  ' store Firoad class locally

ElseIf RoadClassRange.Offset(i, 0).Value = "LC" Then

ROADCLASS_LOCAL_STORGE.Add (50)  ' store Firoad class locally

ElseIf RoadClassRange.Offset(i, 0).Value = "PL" Then

ROADCLASS_LOCAL_STORGE.Add (25)  ' store Firoad class locally

Else

 ROADCLASS_LOCAL_STORGE.Add (25)  ' store Firoad class locally

End If

If RoadImportanceRange.Offset(i, 0).Value = "ØÑíÞ ÔÑíÇäí æíãÑ ÈÇáããØÞÉ ÇáÊÌÇÑíÉ Çæ ÈÇáÞÑÈ ãä ÇãÇßä åÇãÉ" Then

RoadImportance_LOCAL_STORGE.Add (100)  ' store FiroadImportance locally



ElseIf RoadImportanceRange.Offset(i, 0).Value = "ØÑíÞ ÊÌãíÚí æíãÑ ÈÇáããØÞÉ ÇáÊÌÇÑíÉ Çæ ÈÇáÞÑÈ ãä ÇãÇßä åÇãÉ" Then

RoadImportance_LOCAL_STORGE.Add (75)  ' store FiroadImportance locally

ElseIf RoadImportanceRange.Offset(i, 0).Value = "ØÑíÞ ãÍáí æíãÑ ÈÇáããØÞÉ ÇáÊÌÇÑíÉ Çæ ÈÇáÞÑÈ ãä ÇãÇßä åÇãÉ" Then

RoadImportance_LOCAL_STORGE.Add (50)  ' store FiroadImportance locally
```

```
ElseIf RoadImportanceRange.Offset(i, 0).Value = "ÛíÑ Ðáß" 
Then

RoadImportance_LOCAL_STORGE.Add (25)  ' store 
FiroadImportance locally

Else

 RoadImportance_LOCAL_STORGE.Add (25)

End If

If CitizenComplaintsRange.Offset(i, 0).Value = "ÔßÇæí 
ßËíÑÉ" Then

CitizenComplaints_LOCAL_STORGE.Add (100)  ' store 
FiCitizenComplaints



ElseIf CitizenComplaintsRange.Offset(i, 0).Value = "ÔßÇæí 
ãÊæÓØÉ" Then

CitizenComplaints_LOCAL_STORGE.Add (66)  ' store 
FiCitizenComplaints

ElseIf CitizenComplaintsRange.Offset(i, 0).Value = "ÔßÇæí 
ÞáíáÉ" Then

CitizenComplaints_LOCAL_STORGE.Add (33)  ' store 
FiCitizenComplaints

ElseIf CitizenComplaintsRange.Offset(i, 0).Value = "áÇ ÊæÌÏ 
ÔßÇæí" Then

CitizenComplaints_LOCAL_STORGE.Add (0)  ' store 
FiCitizenComplaints

Else

 CitizenComplaints_LOCAL_STORGE.Add (0)  ' store 
FiCitizenComplaints
```

```
            End If

            If PCIRange.Offset(i, 0).Value <= 10 And PCIRange.Offset(i,
0).Value >= 0 Then

            'PCI_LOCAL_STORGE.Add (10)  ' store FiPCI

             PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i,
0).Value) ' store FiPC

            ElseIf PCIRange.Offset(i, 0).Value <= 20 And
PCIRange.Offset(i, 0).Value > 10 Then

            'PCI_LOCAL_STORGE.Add (9)  ' store FiPCI

             PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i,
0).Value) ' store FiPC

            ElseIf PCIRange.Offset(i, 0).Value <= 30 And
PCIRange.Offset(i, 0).Value > 20 Then

            'PCI_LOCAL_STORGE.Add (8)  ' store FiPCI

             PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i,
0).Value) ' store FiPC

            ElseIf PCIRange.Offset(i, 0).Value <= 40 And
PCIRange.Offset(i, 0).Value > 30 Then

            'PCI_LOCAL_STORGE.Add (7)  ' store FiPCI

            PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i,
0).Value) ' store FiPC

            ElseIf PCIRange.Offset(i, 0).Value <= 50 And
PCIRange.Offset(i, 0).Value > 40 Then

            'PCI_LOCAL_STORGE.Add (6)  ' store FiPCI

            PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i,
0).Value) ' store FiPC

            ElseIf PCIRange.Offset(i, 0).Value <= 60 And
PCIRange.Offset(i, 0).Value > 50 Then
```

```
'PCI_LOCAL_STORGE.Add (5)  ' store FiPCI

PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i, 0).Value) ' store FiPC

ElseIf PCIRange.Offset(i, 0).Value <= 70 And PCIRange.Offset(i, 0).Value > 60 Then

'PCI_LOCAL_STORGE.Add (4)  ' store FiPCI

PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i, 0).Value) ' store FiPC

ElseIf PCIRange.Offset(i, 0).Value <= 80 And PCIRange.Offset(i, 0).Value > 70 Then

'PCI_LOCAL_STORGE.Add (3)  ' store FiPCI

PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i, 0).Value) ' store FiPC

ElseIf PCIRange.Offset(i, 0).Value <= 90 And PCIRange.Offset(i, 0).Value > 80 Then

'PCI_LOCAL_STORGE.Add (2)  ' store FiPCI

PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i, 0).Value) ' store FiPC

ElseIf PCIRange.Offset(i, 0).Value <= 100 And PCIRange.Offset(i, 0).Value > 90 Then

'PCI_LOCAL_STORGE.Add (1)  ' store FiPCI

PCI_LOCAL_STORGE.Add (100 - PCIRange.Offset(i, 0).Value) ' store FiPC

Else

 PCI_LOCAL_STORGE.Add (0)

End If

If MAx_ADT = 0 Then
```

```
            MAx_ADT = 1

            End If

            ROADADT_LOCAL_STORGE.Add (100 *
(RoadADTRange.Offset(i, 0).Value / MAx_ADT)) ' store road adt
locally

            ' ROADADT_LOCAL_STORGE.Add (MAx_ADT) ' store
road adt locally

        Next i

    ' retrive values from loacl to final sheet

     'For l = 0 To ROADNUM_LOCAL_STORGE.Count - 1

      For m = 0 To MaxSurveyID - 2

                PIListRange.Offset(m, 0).Formula = m + 1 ' id

                PIRange.Offset(m, 0).Formula =
ROAD_LOCAL_STORGE(m) ' road name

                PIRoadNumRange.Offset(m, 0).Formula =
ROADNUM_LOCAL_STORGE(m) ' road number

                PIZoneRange.Offset(m, 0).Formula =
Zone_LOCAL_STORGE(m) ' zone

                PISectionRange.Offset(m, 0).Formula =
Section_LOCAL_STORGE(m) ' section

                PIDirectionRange.Offset(m, 0).Formula =
Direction_LOCAL_STORGE(m) ' direction

                PIRoadClassRange.Offset(m, 0).Formula =
ROADCLASS_LOCAL_STORGE(m) ' road class

                PIRoadADTRange.Offset(m, 0).Formula =
ROADADT_LOCAL_STORGE(m) ' road adt

                PIPCIRange.Offset(m, 0).Formula =
PCI_LOCAL_STORGE(m) ' pci
```

```
            PICitizenComplaintsRange.Offset(m, 0).Formula =
CitizenComplaints_LOCAL_STORGE(m) ' CitizenComplaints

            PIRoadImportanceRange.Offset(m, 0).Formula =
RoadImportance_LOCAL_STORGE(m) ' RoadImportance

            PIVALUESCALCPiRange.Offset(m, 0).Formula =
((RoadImportance_LOCAL_STORGE(m) * 0.1) +
(CitizenComplaints_LOCAL_STORGE(m) * 0.1) +
(PCI_LOCAL_STORGE(m) * 0.45) +
(ROADADT_LOCAL_STORGE(m) * 0.12) +
(ROADCLASS_LOCAL_STORGE(m) * 0.13)) ' RoadPi

            PIPCIVRange.Offset(m, 0).Formula =
PCIV_LOCAL_STORGE(m) ' pci

           ' Call MsgBox(PCI_LOCAL_STORGE(l), vbOKOnly,
"sumPCI")

        Next m

  'end



End Sub
```

5. Delete Blank Row from Excel

```
Sub Delete Blank Rows()

'Update 20131107

Dim Rng As Range

Dim WorkRng As Range

On Error Resume Next

xTitleId = "KutoolsforExcel"

Set WorkRng = Application.Selection

Set WorkRng = Application.InputBox("Range", xTitleId, WorkRng.Address,
Type:=8)

xRows = WorkRng.Rows.Count

Application.ScreenUpdating = False

For i = xRows To 1 Step -1

   If Application.WorksheetFunction.CountA(WorkRng.Rows(i)) = 0 Then

      WorkRng.Rows(i).EntireRow.Delete XlDeleteShiftDirection.xlShiftUp

   End If

Next

Application.ScreenUpdating = True

End Sub
```

جامعة النجاح الوطنية
كلية الدراسات العليا

تصميم تكاملي لنظم إدارة الرصفات مع نظم المعلومات الجغرافية

إعداد
ربيع حسام انيس ربايعة

إشراف
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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطرق والمواصلات بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

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تصميم تكاملي لنظم إدارة الرصفات مع نظم المعلومات الجغرافية

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الملخص

تواجه هيئات المواصلات في فلسطين تحديًا كبيرا في التعامل مع البنية التحتية القديمة.وخصوصا البنية التحتية الخاصة بالرصفات , حيث ان اعمار اغلب الطرق في فلسطين تتراوح ما بين 20-30 سنة وهذا العمر يعتبر العمر الافتراضي للطرق اما باقي الطرق فهي تعاني من نقص في المتابعة والإدارة لعمليات الصيانة .ان التوجه القائم والمستقبلي هو الحفاظ على الرصفات لكي توفر الأمان والراحة لنقل الناس والبضائع علاوة على ذلك ، تكشف الإدارة الحالية أن النظام المستخدم غير مرن بما يكفي ليعكس الظروف المتغيرة ويبين أيضا ضعف المساعدة في اتخاذ قرارات الصيانة المناسبة. تهدف هذه الدراسة الى تصميم نموذج تكاملي بين نظم إدارة الرصفات ونظم المعلومات الجغرافية (PMS-GIS) حيث يتبع هذا النموذج منهج علمي في إدارة الرصفات .

كما يشتمل النظام على مجموعة من الأدوات لتسهيل منهجية أكثر مرونة من شأنها تمكين المستخدمين من عملية صنع القرارات على نحو أكثر اقتصادية وفعالية أعلى. حيث يستند النموذج إلى التكامل المباشر بين قاعدة بيانات نظام إدارة الرصيف (PMS) المستوعبة في برنامج Microsoft Excel ونظم المعلومات الجغرافية (GIS) لاستغلال كامل القدرات لكل حزمة على حدة.

تم اختبار نموذج PMS-GIS بواسطة حالة دراسية تم فيها تغذية النظام بطرق معبدة بطول 15 كم من شبكة الطرق المحيطة بحرم جامعة النجاح الجديد في مدينة نابلس. وأخيرًا، تم إجراء تحليلات الحالة الدراسية وتحديد الأولويات بنجاح لتحديد وترتيب احتياجات الصيانة