Sudan University of Science and Technology

College of Graduate Studies

PREDICTION OF PAVEMENT CONDITION USING Micro PAVER
CASE STUDY: NORTHEREN KORDOFAN STATE ROADS

التنبؤ بحالة الرصف باستخدام المايكروبيفر

دراسة حالة: طرق ولاية شمال كردفان

By

Elfadil Adam Ali Ahmed

(B.Sc. IN Civil Engineering University of Nyala, 2010)

A thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

Supervisor

Dr. Kamal Masaoud Margi

August.2014

Dedication

To my mother

To My father

To My wife

To all my family and teachers

Acknowledgement

First my thanks must be to Allah who helps me to complete this dissertation.

I am also greatly indebt to all people far and near who have contributed in the making of this study in any way be it with academic input, moral support or encouragement. Special thank is due to supervisor, ***Dr. Kamal Masaoud Margi*** for his appreciable and valuable supervision, advices, guidance and assistance throughout the study. Considerable thanks are due to staff of civil Engineering Department, Sudan University of Science and Technology for their assistance and support. Thanks are extended to University of Nyala for the permission progress my post graduate education.

Finally, my most appreciations are to my parents, wife, daughters, brothers and sisters for their full support, encouragement and patience that give me the power all life.

المستخلص

تمثل الطرق بنية تحتية مهمة بالنسبة لجميع البلدان. ففي السودان، إستثمارات قليلة انفقت في بِناء طرق جديدة في شبكة الطرق القومية. وهذه الشبكة تتطلب عناية كبيرة وذلك من خلال اجراء التقييم الدوري والصيانة المستمرة وبذلك المحافظة على الشبكة في مستوى مقبول من الخدمة. فالتنبؤ بحالة الرصف وتطوير النماذج لها يمكن ان تحسن من قابلية اداء نظام ادارة الرصف. حيث تسمح النماذج للسطات بتحديد الحالة الحالية للرصف و التنبؤ بالحالة المستقبيلية لها، ممايساعدها في اتخاذ القرارات المناسبة للصيانات المطلوبة وانشطتها مع التنبؤ بالتوقيت المناسب لاعادة التأهيل ، كما يحدد متطلبات التمويل البعيدة المدى وذلك للحفاظ على أداء الشبكة.

في هذه الدراسة تم اختيار طرق قطاع شمال كردفان والتي تمثل جزء من الشبكة القومية للطرق في السودان و تم تقسيمها الى ستة قطاعات بطول كلي حوالي 626 كلم، حيث تم جمع البيانات لها وتصنيفها وتحليلها وذلك باستخدام برنامج المايكروبيفر المطور بواسطة سلاح المهندسين بالجيش الامريكي. حيث وجد ان معظم العيوب في الشبكة نتيجة مسببات اخرى (مثل الطفح والترقيع وهبوط الاكتاف) والتي ليس لها علاقة بالاحمال او المناخ حيث تمثل حوالي 69% من جملة العيوب.

كما ان نتائج تحليل وحساب قيم دليل حالة الرصف(PCI) للشبكة بواسطة برنامج المايكرو بيفر اظهرت ان الحالة العامة للشبكة في عام 2005 كافية وبمتوسط PCI=71، اما بنهاية العام 2014 فيتوقع ان تكون الشبكة في حالة رديئة وبمتوسط PCI=43، مما يستوجب عمليات صيانة واعادة تاهيل بصورة عاجلة.

والمعادلة المطورة بواسطة النظام للتنبؤ بحالة الرصف ، كعلاقة بين عمر الرصف وحالته هي PCI=100-3.08428x (حيث x تمثل عمر الرصف)، بمعامل ارتباط قدره 0.885.

ABSTRACT

Pavements represent an important infrastructure to all countries. In Sudan, little investments have been made in constructing of the new national road. This road network requires great care through conducting periodic evaluation and timely maintenance to keep the network operating under acceptable level of service.

Pavement condition prediction models can greatly enhance the capabilities of a pavement management system. These models allow Pavement authorities to know and predict the condition of the pavements and consequently determine the maintenance needs and activities, predicting the timing of maintenance or rehabilitation, and estimating the long range funding requirements for preserving the performance of the network.

In this study, historical data of pavement distress and pavement condition on the national road network of northern Kordofan state, Sudan were collected. These data were categorized, processed, and analyzed using Micro PAVER software which is successfully applied for calculating and predicting the pavement condition for the road under study. These data have been used to generate prediction of pavement condition models for Sudan National Road -Northern Kordofan state sector. This network composed of six pavement section with an overall length of 626 km.

According to micro PAVER classification method, The most distress observed on the pavement sections were due to other reasons are constitute 69 % (such as bleeding, patching, and slippage cracking), furthermore load related causes (such as rutting and alligator cracking) were constitute 22 % and environmental effects (such as weathering, longitudinal and transverse cracking, and block cracking) are constitute 19%.

The result of pavement condition index in 2005 shows that one section total out of six, its pavement condition is “good” rating with average PCI =90, and three sections have pavement condition “satisfactory” rating with an average PCI of 78, and one section in fair condition with an average PCI of 64, and finally poor condition occurs in one section with an average PCI of 53. In the overall, the network had an average weighted PCI of 71, which was considered “satisfactory” rating.

The prediction condition for November 2014 shows that the overall predicted condition of the network had an average weighted PCI of 43, which was considered “poor” rating. In details four road section having 77% from the pavement area are lies in poor condition with an average PCI of 49. And one section having 14% the pavement area is in very poor condition with an average PCI of 36. The remaining 9% is in serious condition with an average PCI of 25 which is simulating one section from network under study.

The prediction equation generated by the software for the family road network is PCI=100-3.08428x (x=age sine last construction or rehabilitation). The equation is having coefficient of correlation =0.885 which acceptable.

List of Tables

List of Figures

Table of Contents

Chapter One

Introduction

Introduction

1.1 Background

Pavements represent an important infrastructure to all countries. In Sudan, little investments have been made in constructing of the national road network. This road network requires great care through conducting periodic evaluation and timely maintenance to keep the network operating under acceptable level of service.

Pavement condition prediction models can greatly enhance the capabilities of a pavement management system. These models allow Pavement authorities to predict the condition of the pavements and consequently determine the maintenance needs and activities, predicting the timing of maintenance or rehabilitation, and estimating the long range funding requirements for preserving the performance of the network.

The accurate prediction of pavement performance is important for efficient management of road infrastructure. At the network level, pavement performance prediction is essential for rational budget and resource allocation. At programming level, pavement performance prediction is needed for adequate activity planning and project prioritization while at project level it is needed for establishing and designing the necessary corrective actions such as maintenance and rehabilitation.

Several performance prediction models have been proposed over the years. The models vary greatly in their comprehensiveness, their ability to predict performance with reasonable accuracy, and input data requirement. Most of these models are empirical and were developed for use under particular traffic and climatic conditions. Few of the models are of mechanistic empirical type in which some of the input parameters are calculated using mechanistic models.

This study presents the different aspects of pavement condition prediction modeling, the techniques for Developing prediction models, and a description of the prediction models used in the Micro PAVER pavement management system.

The National Highway Authority (NHA) in Sudan has carried out field survey of the functional condition of project road network in November 2005, compiled roadway inventory, pavement condition history, and construction activities data. To fully benefit from this database to support decisions regarding future repair strategies, it is necessary to predict future conditions and determine the remaining service life of pavement sections.

The main purpose of this study was to use the data available in the NHA pavement database to develop a pavement prediction model to predict future pavement conditions and to estimate the remaining service life of pavements

1.2 Research problem

Pavement in Sudan undergoes a process of deterioration directly after opening to traffic. This process under the effects of traffic and environmental conditions begin very slowly so that it may not be noticeable. Over time, the pavement deterioration has different mechanisms and faster rate of deterioration.

Models of road deterioration help to improve management, planning techniques, and give economic justification of expenditure and standards in the highways sector. Without adequate data, the road needs can't be quantified or evaluated accurately, and planning decisions tend to become short-term.

1.3 Research objectives

The ultimate objective of the development models is to use them within an integrated Pavement Management System. The models can provide predictions condition to support MR&R planning at both the project and network levels.

Reviewing the concept of pavement deterioration and condition models, and the factors associated with their performance at network level for urban roads,

The main objective to predict the pavement condition at any time and how to implement these models into a PMS,

The primary objectives of this study were to apply models to predict future pavement conditions and to determine remaining service life of pavements based on the predicted conditions,

Based on available data in the NHA pavement database, which contains the condition history of each pavement section, along with its location, year of construction, thickness, materials used, climate, and rehabilitation records the pavement condition models for the Sudan National Highway northern Kordofan state part are been develop.

1.4 Research Limitations

The study area is limited in National Highway Road in Sudan Northern Kordofan State part. The local network are not include

All data use in this study depending on the field survey data for the pavement distress survey in November 2005 carried out by the National Highway Authority in Sudan (NHA)

1.5 Research Methodology

Field survey data will be obtaining from the National Highway Authority (NHA) in Sudan

Building of the required databases will be subjected individually to two major steps.

The first major step is that each database will be analyzed in terms of normality; the second major step is to build the models

The “Family models” in Micro PAVER were used in this study. This method provides the ability to analyze groups of data, and consists of the following steps:

1. Pavement family definition,
2. Data filtering,
3. Data outlier analysis,
4. Family model development, and
5. Pavement model development.

1.6 Research Structure

The research is structured into six chapters. **Chapter one** is an introduction and research objectives. **Chapter two** Will gives a background of pavement prediction model techniques and literature review. **Chapter three** Describe the research scope, research methodology, and experimental design of the study case study. **Chapter four** Application of Micro PAVER pavement management system in to the proposed case study. **Chapter five** deals with condition analysis and prediction condition of the network pavement, models development and the results and discussion will be presenting. **Chapter six** the last one in this theses and presents the conclusion and recommendations.

Chapter Two

Literature Review

This chapter introduces a general view about pavement management system, pavement evaluation, pavement deterioration, the need for pavement deterioration, predicted parameters, model requirements, method and types of prediction models. Various and different approaches on pavement condition indices, and pavement deterioration predictions have also been discussed with examples.

2.1 Pavement Management System (PMS)

A pavement management system (PMS) consists of a coordinated set of activities, all directed toward achieving the best value possible for the available funds. This is an all inclusive set of activities, which may be characterized in term of major components or subsystems. A pavement management system must serve different management needs or levels and it must interface with the broader highway, airport, and /or transportation management system involved. Figure 2.1 shows a PMS consists of mutually interacting components as planning, programming, design, construction, maintenance, and rehabilitation.

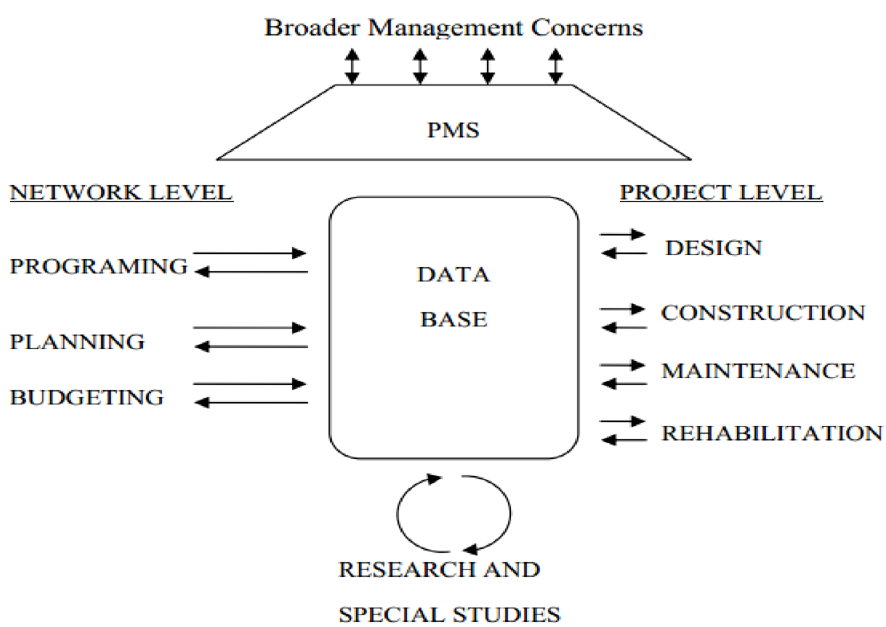


Figure 2.1: Major Component of a Pavement Management System [1].

However, the PMS components have important but changing impacts in terms of a level of influence [2]. The concept shows that the effect on the total life cycle cost of a project decreases as the project evolves as shown in Figure 2.2. The lower portion of the Figure represents the length of time each major component acts over the life of a pavement. The upper portion shows increasing expenditures and decreasing influence over the pavement life. Expenditures during the planning phase are small compared with the total cost. Similarly, the capital costs for construction are a fraction of the operating and maintenance costs associated with a pavement life cycle. However, the decisions made during the early phases of a project have far greater relative influence on later required expenditures than some of the later activities.

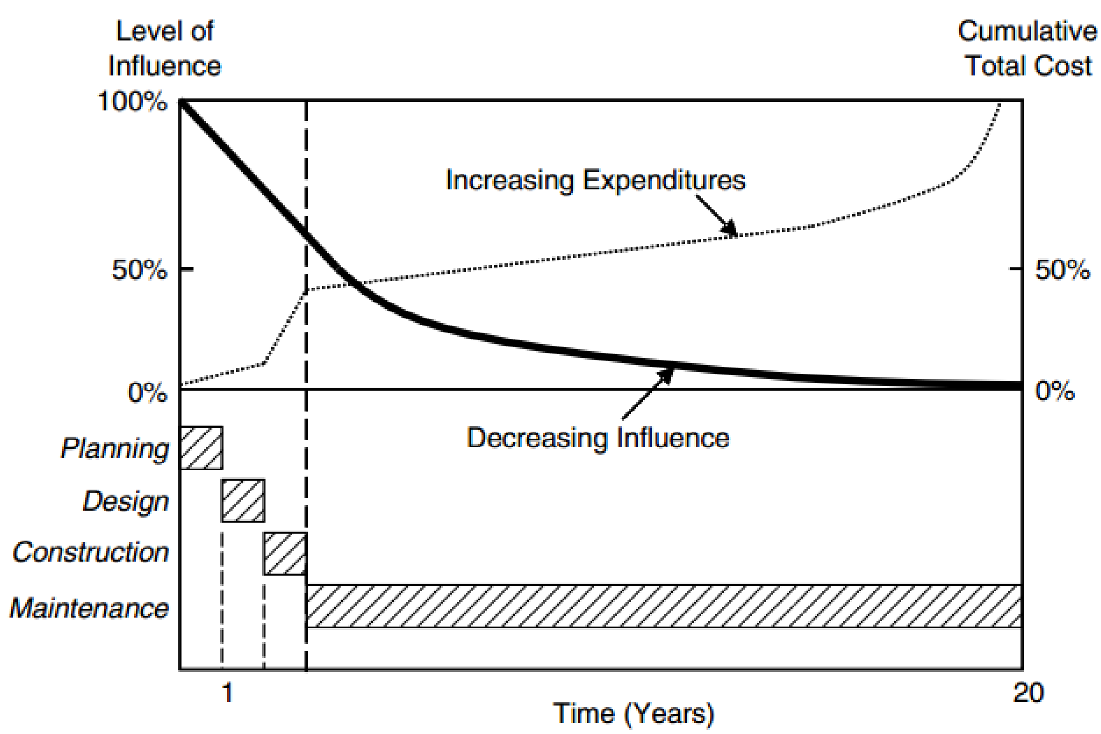


Figure 2.2 Influence Levels of PMS Subsystems on the Total Costs [1].

Hass, one of the pioneers in PMS, said “Good pavement management is not business as usual, it requires an organized and systematic approach to the way we think and in the way we do day to day business. Pavement management, in its broadest sense, includes all activities involved in the planning and programming, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program.” [1].

There is no solid agreement among most agencies and people who are working in the pavement field. However, there are definitions intended to provide a common and consistent basis for the use of certain fundamental terminology in the pavement field.

Herein, some definitions have been stated by very well-known agencies and people. According to the American Association of State Highway and Transportation Officials(AASHTO), “A pavement management system is designed to provide objective information and useful data for analysis so that highway managers can make more consistent, cost-effective and defensible decisions related to the preservation of a pavement network” [3]. The Federal Highway Administration (FHWA) developed a clear definition of PMS “A set of tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in serviceable conditions” [4]. Haas, Hudson, and Zaniewski define a PMS as “a set of tools or methods that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time” [1]. To conclude, a PMS represents a strategy to manage a road network’s needs to serve the users safely, comfortably and efficiently at least total cost and greatest benefit possible.

2.2 Pavement Evaluation

Evaluation is a key part of PMS because it provides the means for seeing how well the PMS components have been satisfied. The major types of pavement evaluation outputs versus time as shown in Figure 2.3 are measure of structural adequacy, measure of ride ability or serviceability, measure of surface distress, and measure of surface friction. In Figure 2.3, the surface distress output has reached a limit of acceptability before any of the other outputs. At this point, some rehabilitation measure has been implemented as shown by vertical discontinuity. The rehabilitation measure has been shown to affect the other outputs, such as improved surface friction, improved serviceability, and increased structural adequacy. The service life of the rehabilitation measures is ended by the serviceability reaching a minimum acceptable value. At this point, another rehabilitation measure has been applied and again the other outputs have been affected. Also, Figure 2.3 demonstrates that all the outputs of a pavement can reach a limit of acceptability one or more times during the life cycle or analysis period. Therefore, it can be concluded that the function of pavement evaluation in a PMS is measuring and assessing the mentioned four measurements in order to provide data for checking the design predictions and updating them if necessary, reschedule rehabilitation measures as indicated by these updated predictions, improve design models, improve maintenance practices, and update network programs [5].

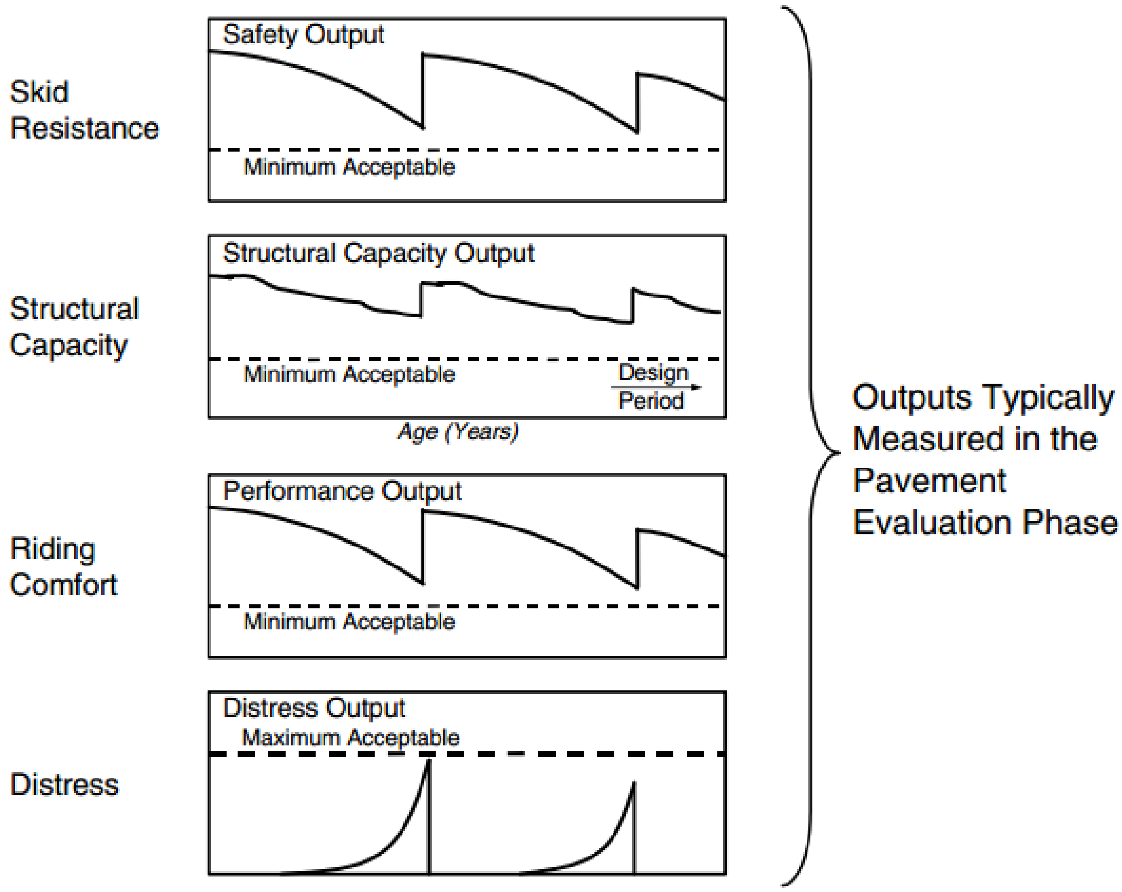


Figure 2.3 Major Types of Pavement Evaluation Outputs [1]

The uses of evaluation information are illustrated in Figure 2.4. The input variables include material and can be monitored by physical testing and sampling to provide direct information about layer thicknesses and material properties. Behavior can be defined as the immediate response of the pavement to load. Thus, deflection tests fall into this category. Distress can be defined as limiting response or damage in the pavement. Thus, the accumulated damage is monitored and evaluated. Performance can be defined as the serviceability history of the pavement, its evaluation accomplished by periodic measurements of the roughness which is directly related to user serviceability. Among the types of pavement evaluation, most agencies consider the following four as most important: serviceability, structural adequacy, surface distress, and safety. Safety is primarily in terms of surface distress and it is a user related measure. The other three considered in terms of functional behavior using serviceability performance concept.

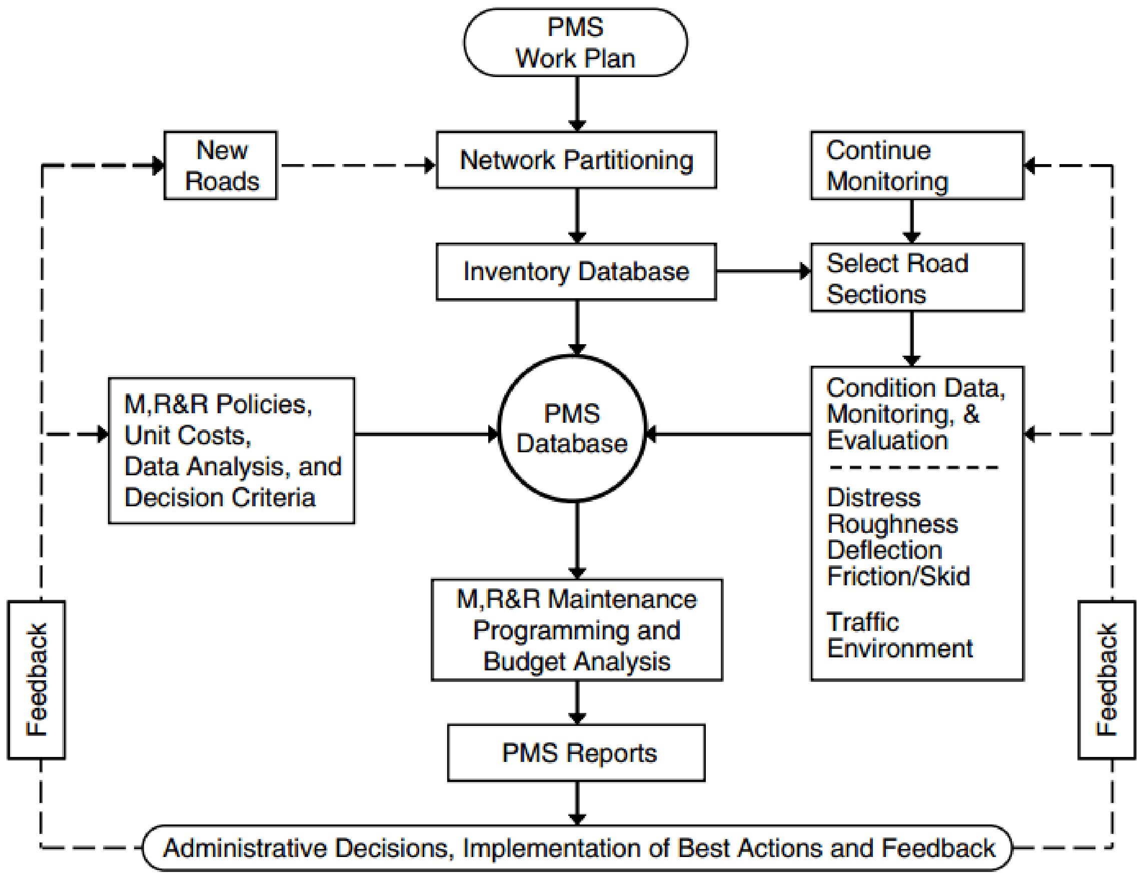


Figure 2.4: A Framework for Network Level in PMS Application [1]

2.3 Pavement Deterioration

Prediction deterioration is a mathematical description of the expected values that a pavement attribute will take during a specified analysis period [6]. An attribute is a property of a pavement section or class of pavements that provides a significant measure of the behavior, performance, adequacy, cost, or value of the pavement. In other words, it is a mathematical description that can be used to predict future pavement deterioration based on the present pavement condition, deterioration factors, and the effect of maintenance [7]. Deterioration or prediction models express the future state of a pavement as a function of explanatory variables or factors that include pavement structure, age, traffic loads, and environmental variables.

Prediction models can predict a single pavement condition indicator, such as pavement condition index (PCI) based on pavement distress, or an overall pavement condition index (combination of all distresses and ride quality), such as pavement serviceability index (PSI). However, this study recommended that at long term planning that each road agency or municipality to collect sufficient data to model the mechanism of every distress in addition to pavement condition models. Modeling each distress individually will help in estimating the pavement condition and the level of maintenance in the futurebecause these models predict the distress density much better than other overall pavement condition indices. Also prediction models permit increased understanding of pavement behavior so that steps can be taken to reduce the development of distress or extend the service life of pavement.

Once the condition of pavement sections has been defined, information about past and estimated future condition is often needed. Curve Models are often fitted through past measures of condition to show past performance. Prediction models are generally used to forecast changes in condition over some future time period. Predicted condition is used in several pavement management activities. Prediction models are some of the most important components of a pavement management system (PMS). Successful PMS are largely depending on these models. Better prediction models make a better pavement management system, which lead to considerable cost savings [6].

The road agencies and municipalities aim to know the needs analysis. In the need analysis, the measures of condition of the pavement sections are combined with other information to determine the time and type of maintenance and rehabilitation treatments needed. The needs analysis is based on a selected time period or until the condition drops to a critical level. Prediction models are used to forecast condition during that analysis period as if no treatment is applied. When the analysis process identifies that a section needs a treatment, other prediction models are used to show the expected impact of that treatment on the condition of the section at the time of treatment. Both of these models together allow needs analysis programs to show the predicted condition through the analysis period with and without the needed treatments. This study deals with developing prediction models when no treatment is applied. The impact of treatment is not included in this study due to lack of data.

Prediction models are essential for many processes of decision – making as they are useful; in establishing answers to the questions of what, where, and when, with respect to maintenance needs. Simply put, the prediction models enable us to determine the type of maintenance treatment to be adopted, the portions of the network requiring treatment, and the timing of the maintenance actions [8].

Some authors differentiate between performance and prediction models based on specific definitions developed for selected measures of condition [1]. Other authors discuss (prediction models) and (performance curves) as synonymous and do not differentiate between performance models and prediction models. In this study it was preferable to use the term prediction models to describe predicted condition because the aim of the study was to use historical data to predict the future. The predicted condition can be any one of several measures of condition. It can be distress prediction and/or condition prediction as investigated in chapter six and seven. This study used a condition and distress historical data versus time to develop the predictive models.

2.4 The Need to Predict Deterioration

Models of road deterioration help to improve management, planning techniques, and give economic justification of expenditure and standards in the highways sector. Without adequate data, the road needs can't be quantified or evaluated accurately, and planning decisions tend to become short-term. It is important, therefore, to identify which parameters are essential and relevant for predictive models. Four major applications of predictive models will greatly help in identifying the modeling process and the data needs [9]. They are: planning policy and standards; pavement management; pricing and taxation; and verification of design methodologies.

Planning deals with forecasting the needs of the road network to assess the current and future condition and the demands on the network. Such questions as "at what stage should the pavement be resurfaced or strengthened", "what should be the design life", and "which project has priority".

Pavement management systems are being applied at regional or national levels to improve the planning and effectiveness of maintenance works and expenditures. Two basic elements are:

- An information system, comprising a database of network inventory, current and historical data, data for traffic volume and loading, maintenance works, and regular monitoring of the network to update;

and A decision support system, which analyses the data, and identifies current and future needs.

- The majority of systems use predictive models to forecast future road condition, the timing, and the consequence of deferring maintenance. Some agencies use extrapolation models based on the historical trend of condition established in past regular condition surveys. Some use basic correlative models from whatever local performance data are available. In either case, the reliability of such models is low until a considerable history of data has been established.

Predictive models which have been derived from a broad empirical base, and which use the current condition and physical parameters to estimate deterioration, are extremely valuable because they are versatile and relatively little effort is required to adapt them to local conditions.

Pricing and taxation amongst various classes of road user involves two primary issues. First, the effects of vehicles and environment on road damage and repair costs are must be investigated. Second, the basis of costs must be determined and allocated. Verification of design methodologies has different forms and types. Engineering methods for designing road pavement and analyzing the effects of vehicle loading and climate on pavement condition have developed considerably due to the results of major road tests.

2.5 Predicted Parameters

Pavement condition prediction models can be developed to forecast condition in terms of one of the several different measures of condition.

Sometimes models are classified based on what types of parameters they predict. Four common groupings include [10]:

- Primary response
- Structural performance
- Functional performance
- Damage

In addition, these types of models can predict the impact of treatments on the condition of sections.

2.5.1 Primary Response

Primary response models predict the primary mechanistic response of sections to some imposed load (structural or environmental influences). Deflection, stress, and strain are common responses predicted by primary response models. Mechanistic models are generally used to predict primary responses, and primary responses are normally used only at project or research level. This study has no data set of deflection, stress, and strain. Therefore, the primary response is not the subject of this study.

2.5.2 Structural Performance

Structural information based on construction records, non-destructive testing, or laboratory testing are generally required to use this type of models. Empirical and mechanistic-empirical models are normally used to predict these types of parameters. Structural information or other related information is normally required to use this type of model. Construction records, non-destructive testing, or laboratory testing are not available for this study, therefore, the structure performance is not the subject of this study.

2.5.3 Functional Performance

Functional condition models predict measures of the condition that define how well the pavement section is meeting its basic function. Safety related prediction models normally forecast some characteristics such as the surface friction characteristics of pavement based on skid numbers developed from skid testing. These types of models are often empirical, but they may use material properties as a part of the parameters on which the models are based. Skid resistance data are not available in this study.

2.5.4 Damage

Damage models are derived from either the structural or functional models. Damage is a normalized measure of distress, roughness, surface friction, or other measure of condition. In damage analysis, a damage number of 0 indicates no damage while a damage number of 1 indicates the maximum possible damage. Using damage allows predict the maximum and minimum levels into a single function or formula. In this study, the damage is available in terms of historical condition data such as distress density and pavement condition data.

2.6 Model Requirements

Darter outlined basic requirements for a reliable prediction models as [11]:

- ❖ An adequate database based on in-service sections,
- ❖ Consideration of all factors that affect prediction or performance,
- ❖ Selection of an appropriate functional form of the model, and
- ❖ A method to assess the precision and accuracy of the model.

All the above requirements are fully investigated in the following pages.

2.6.1 Adequate Database and Factors that Affect Prediction

An adequate database would include a collection of data that would provide information adequate to support the models being developed. In general, this should include the condition measure to be predicted dependent variable and information on the factors that affect prediction that are included in the models. It must include the age and/or loading information that the models will predict the condition as function of independent variable. In many cases the available data from which models can be developed and the resources of an agency to collect future data will control the data used in a model to predict condition. The accuracy of the data on factors that affect performance used in developing models will have a direct impact of the reliability with which the models can predict future pavement condition. In general, more accurate data costs more money to collect and keep current.

2.6.1.1 Construction Dates

Age, loads, or a function of age and loads, are used in many models as the independent variable. These prediction models must have a starting point. That point is generally the date of construction. Construction can sometimes be considered the date of application of the latest major maintenance.

2.6.1.2 Maintenance and Rehabilitation

Another problem with in-service facilities is the maintenance that is applied but not recorded in the database. The purpose of most condition prediction models is to predict the change in condition without treatment and compare that to the change in condition with a treatment. Rehabilitation and reconstruction will have such a major impact on the condition and rate of deterioration, that when they are applied, the date of construction may need to be changed to the date of the rehabilitation or reconstruction. The condition of sections can also be significantly affected by application of preventive and routine maintenance. However, few agencies record the application of routine maintenance with enough detail to allow use of it in condition prediction models. If maintenance, rehabilitation and reconstruction data are not recorded, then models of condition developed as a function of time will not be accurate [12].

2.6.1.3 Condition Data

Since most of the models currently used depend on regression analysis, information for the dependent variable or the measure of condition to be predicted is the most obvious information that is needed. The condition data should be available over a range of age be predicted. However, agencies do not generally build roads and allow them to deteriorate to the worst possible condition.

2.6.1.4 Traffic Loading Effect

Traffic loading is considered as the primary factor that affects both pavement design and performance. Traffic loading characteristics include traffic volume, axle load, axle configuration, repletion of axle load, tyre pressure, and vehicle speed. The traffic loading in pavement design is well formulated and investigated whereas the method of using axle loads in PMS as a pavement condition prediction variable is still not well understood [13]. Since loadings are one of the most important factors that affects damages of most pavement section, it is often used as an independent variable in developed condition prediction equations. It is sometimes combined with age as an independent variable. Since in most circumstances, agencies want to know when in years, the pavement will need work, in some models loads are used as a factor that affects the rate of condition change as a function of time which is considered the independent variable. Few studies have discussed the effect of loading on pavement performance and how it should be used in PMS in an effective manner. For example, a new understanding of the traffic effect was investigated in the light of shake down load limit. If the pavement is subjected to a repeated load greater than the shake down limit, then the pavement will fail as a result of a result of the excessive plastic deformation, this indicates that if the design load is made more than the shakedown load limit, the pavement may gradually fail by the accumulation of plastic strain, resulting in a form of rutting and surface cracking. Excessive stresses and strain in asphalt surfaced pavement due traffic loading will eventually result in deformation and cracking [14].

According to Huang (1993), the critical tensile and compressive strains under multiple axles are only slight different from those under single axle, for example, the damage caused by the standard 18-kip (80 KN) is almost equal to the damage caused by the 36kip (160 KN)tandem axles or that of 54-kip (240 KN) tridem axles. According to AASHTO (1993), pavement distress propagation is associated with continuous traffic growth. The formulation of distress types leads to a failure in one the pavement components. AASHTO pavement design procedure requires traffic evaluation for both design and rehabilitation. Therefore, the accuracy of traffic volumes and weight is very important. Six pavement structures were analyzed where three of them are representative of Portuguese pavements, and three are representative of Brazilian pavements. It was performed a linear-elastic mechanistic analysis to determine two structural responses: horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of sub grade, associated to the most important pavement distress types in Portugal and Brazil, respectively fatigue cracking and rutting [16].

A study by Brozze and others [2], the new Mechanistic-Empirical Pavement Design Guide (MEPDG) requires comprehensive traffic inputs to predict pavement performance. Axle load spectra play a critical role in the impact of traffic on pavement performance. Weigh-in-motion (WIM) systems are becoming widely used as an efficient means of collecting traffic load data for mechanistic pavement design. The results of this study not only support but also advance the existing research in this critical area. The findings of this study can be used to estimate pavement life prediction bias when inaccurate WIM data are used. They can also serve as guidelines for state highway agencies for the selection of WIM equipment and the establishment of criteria for equipment calibration.

2.6.1.5 Soil

The natural soil is another important factor which must be considered [15]. Since most loads are eventually transmitted to the natural soil, weaker soils will require thicker and stronger supporting structures. However, this issue is very important in the design process, it is very important in the maintenance when the pavement section show a damage in form of depressions. Since the natural soil, affects the performance. The data on the supporting material should be available for use in developing the models. Generally some type of information about strength is most useful, but information on type of soil would also be helpful. Since many agencies do not have soil information, they develop models ignoring soil properties. This results in supporting materials being an unmeasured that will lead to an increase in prediction error. Some agencies have developed groupings of facilities based on distinctly different soil types and developed separate prediction equations for each. One agency developed separate models for the pavements in the coastal areas and the hill areas because of different soil conditions. Location then becomes a surrogate for soil type.

2.6.1.6 Materials

The thickness, type, and strength of each material would be the best information that uses in developing condition prediction models. That data would need to be in the database. However, few agencies have that information for all of their sections. Many agencies group sections together into type groups and develop individual models.

2.6.1.7 Environment

If the model is for a local area and all pavements will be affected the same by environmental conditions, then environment can be neglected. The condition change of the section based on age will basically include the influence of the environment. The older sections will show more influence of the environment because they have been exposed to it for a longer period of time. Many times, the age will act as a surrogate for the influences of environment. Another agency uses a modifier in condition prediction as a function of age that adjusts the prediction model for different environmental zones.

2.6.2 Appropriate Form for Prediction Models

Model building is a creative activity of the human intellect [1]. As much knowledge as available on how condition changes should be used in developing the condition prediction models. Lytton defined the following a priori conditions that must also be met by prediction models which will limit the form to those appropriate for the pavement condition measures being modeled [10]:

Initial Value: The initial value of all damage is zero. Similarly the condition of a pavement at the beginning of its service life is excellent.

Initial Slope: Most damage has a slop that is initially zero. However, some damage types such as roughness or rutting have an initial upsurge.

Overall Trend: Most damage is irreversible; the slope must always show a worsening of condition unless a treatment is applied.

Variations in Slope: Damages can be affected by variables such as changes in climatic condition, which can lead to variations in slope.

Final Slope: damage functions such as cracks, area of distress, and serviceability have an upper limit. In all these damage functions, the final slope must be zero, and this type of equation approaches a horizontal asymptotes. By contrast, other types of damages such as roughness or rutting do not have such constrains. Rutting generally starts out developing rapidly and then reduces in rate, until other distress types influence the rate of deterioration, and rutting rate again increases.

Final Value: The maximum value of damage has an upper limit only for those types of distresses for which the final slope is zero.

2.6.3 Method to Assess the Precision and Accuracy of the model

A valid statistical approach must be used in developing the condition prediction models to provide a basis for determining the precision and accuracy of the model. Since regression analysis is used in most of the model development, statistical methods that show the precision of the regression equations are often used. Probably the most commonly used tests are the standard error of estimate, the coefficient of determination, the residual analysis, correlation coefficient, F-test, and other tests are also used [17]. The specific test must be selected based on the type of regression used.

2.7 Methods of Prediction Models

A prediction model can be developed by one of the following methods [4]:

- Empirical Method
- Mechanistic Method
- Mechanistic-Empirical Method
- Probabilistic Method
- Bayesian Method.

2.7.1 Empirical Method

The empirical method is generally characterized by the collection of a large amount of data before much speculation as to their significance, or without much idea of what to expect. Empirical method is constructed on the basis of statistical models. This method is the most useful for this study because the study has a large amount of data to do statistical analysis, statistical modeling, and statistical accuracy tests.

2.7.2 Mechanistic Method

Mechanistic method in pavement analysis includes layered elastic and finite element methods. However, these types of methods require detailed structural information which limits the accurate calculation of stresses, strains, and deflections to sections for which the detailed data is available. Mechanistic method depends on the basis of theory of mechanics. So this method is highly dependent on: elastic layer theory, visco-elastic theory, fracture mechanics, and finite element analysis. This method is not appropriate for condition data because the condition data gather only surface data.

2.7.3 Mechanistic – Empirical Method

The analytical – empirical or mechanistic-empirical method has been widely applied in flexible pavement design. This approach consists of two parts: calculating the response of the pavement materials to the applied loading and predicting the pavement performance from these responses. Mixing Mechanistic-Empirical method is a good method in pavement management. However, due to lack of pavement material data, this study cannot be carried out this method.

2.7.4 Probabilistic Method

In this method, pavement condition measures can be treated as a random variable with probabilities associated with its values. The probabilities associated with all the values of random variable can be described by probability distribution. A transition probability matrix is used to define the probability that a pavement in an initial condition state will be in some future condition state. A transition matrix should be developed for each combination of factors that affect pavement performance. This transition probability matrix is basically obtained from expert views [1].

Probabilistic method is good method when there are not data can be used. This method is not suit here.

2.7.5 Bayesian Method

Bayesian methods depends on combining observed data and expert experience using Bayesian regression techniques which are primarily based on a famous paper published by the Rev. Thomas Bayes (1702-1761). In Bayesian regression analysis, the regression parameters are considered random variables with associated probability distribution. Bayes' theorem can be expressed mathematically as [17]:

$$P(p|:x) = \frac{P(x|p).x\ P(p)}{\sum[P(x|p)x\ P(p)]}$$ Ege (2-1)

Where,

P(x) = distribution of variants over all possible fraction variants

P (p) = prior distribution

P (x|p) = sampling distribution

P (p|x) = posterior distribution

Since this study has enough real data from the field, no need to obtain more data from expert views, and therefore Bayesian method can be avoided.

2.8 Types of Prediction Models

Generally, three major classification models have been developed in pavement management systems so far: Deterministic models, Probabilistic models, and Bayesian models.

However, a classification of prediction models has been suggested by Mahoney based on earlier work [10]. It considers the network and project levels of pavement management and two basic types or classes of models. They are deterministic models and probabilistic models.

Other classifications in use are disaggregating and aggregate models [8].

Disaggregate models predicate the evolution of an individual measure of distress. Aggregate models predict composite measures; for example, damage index, condition rating, or serviceability.

Other classification by Hass (1994) pavement models has different forms and types. They can be categorized into the following four basic types

1. Purely mechanistic models based on some primary response (behavior) parameters such as stress, strain, or deflection. The pavement responses are normally due to traffic and /or environmental condition.

2. Regression (empirical) models, where the dependent variable of observed or measured structural functional deterioration is related to one or more independent variables like sub grade strength, axle load reputations, pavement layer thickness and properties, environmental factors, and their interactions.

3. Mechanistic-Empirical models, where a response parameter is related measured structural or functional deterioration, such as distress or roughness through regression equations,

4. Subjective (probabilistic model), where experience is captured in a formalized or structured way, using transition process , for example, to develop deterioration prediction model.

As explained earlier, the available data for this study has a great impact on which method of modeling and which types of model the study will be carried out. The following Table summarizes the advantage and disadvantage of different types of model [3].

Table 2.1 Models Comparison

Models	Advantage	Disadvantage
Regression	*Microcomputer software packages are now widely available for analysis which makes modeling easy and less time consuming. *These models can be easily installed in a PMS. *Models take less time and storage to run	*Needs large database for a better model. * Works only within the range of input data. *Faulty data sometimes get mixed up and induces poor prediction. Needs data censorship. *Selection of proper form is difficult and time taking.
Survivor Curve	*Comparatively easy to develop. * It is simpler as it gives only the probability of failure corresponding to pavement age.	*Considerable error may be expected if small group of units are used
Markov	*Provides a convenient way to incorporate data feedback. * reflects performance trends regardless of non-linear trends	*No readymade software is available. * Past performance has no influence * It does not provide guidance on physical factors which contribute to change. *Needs large computer storage and time.

Semi-Markov	*Can be developed solely on subjective inputs. * Needs much less field data. *Provides a convenient way to incorporate data feedback. *Past performance can be used	*No readymade software is available. *Needs large computer storage and time
Mechanistic	*Prediction is based on cause-and-effect relationship, hence gives the best result	*Needs maximum computer power, storage and time. * Uses large number of variables (e.g. material properties, environment conditions, geometric elements, loading characteristics etc.). *Predicts only basic material responses
Mechanistic-empirical	*Primarily based on cause-and-effect relationship, hence its prediction is better. *Easy to work with the final empirical model. * Needs less computer power and time.	*Depends on field data for the development of empirical model. *Does not lend itself to subjective inputs. *Works within a fixed domain of independent variable. *Generally works with large number of input variables (material properties, environment conditions, geometric elements, etc.) which are oftne not available in a PMS.
Bayesian	*Can be developed from past experience and limited field data. *Simpler than Markov and Semi-Markov models. *Can be suitably enhanced using feedback data.	*May not consider mechanistic behavior. *Improper judgment can lead to erroneous model

2.9 Prediction Models using Statistical Analysis

The development of prediction models using statistical analysis is a more complex activity than creating average rates of deterioration. Often agencies accomplish the creation of these models within the pavement management software they utilize. For example, those agencies that use The Micro PAVER software developed by the U.S. Army Corps of Engineers develop performance prediction models using a general procedure called the Family Method. The method consists of the following steps [19]:

1. Define the pavement family – A group of pavement sections with similar deterioration curves is defined as the family. The Micro PAVER software allows the user to define the family based on stored inventory data (e.g., pavement type, functional classification, traffic information, etc.). Once a family is created, the condition data, in terms of PCI, and pavement age information for all pavement segments in the family are compiled into a file that is used to create the performance model.

2. Filter the data – The Micro PAVER software flags data for sections that show condition increases as the pavement section ages. Also, the software flags data that is outside of defined boundaries that are used to indicate when pavement sections have conditions that do not meet expected conditions over the life of the pavement.

3. Conduct data outlier analysis – The software also allows for the statistical removal of unusual data that may be improperly impacting the performance modeling of a pavement family. Data is removed using statistical analysis to detect data that exceed user-defined confidence intervals.

4. Develop the family model – With data filtered and outliers removed, the Micro PAVER software allows for the creation of a prediction model. The model is constrained to have a decreasing slope since the condition cannot increase with age. The developed model, which defines the average behavior of the pavement sections, extends across the available condition data and future conditions are predicted by extrapolating the curve.

5. Predict the pavement section condition – Within Micro PAVER, the predicted condition of pavement segments are defined by the pavement section's position relative to the family prediction curve. A modified prediction curve for each pavement segment is created by "shifting" the family curve to the latest condition/age point for the segment and using the shifted performance model to predict future pavement section conditions. Example family and segment performance prediction curves are shown in figure 2-5.

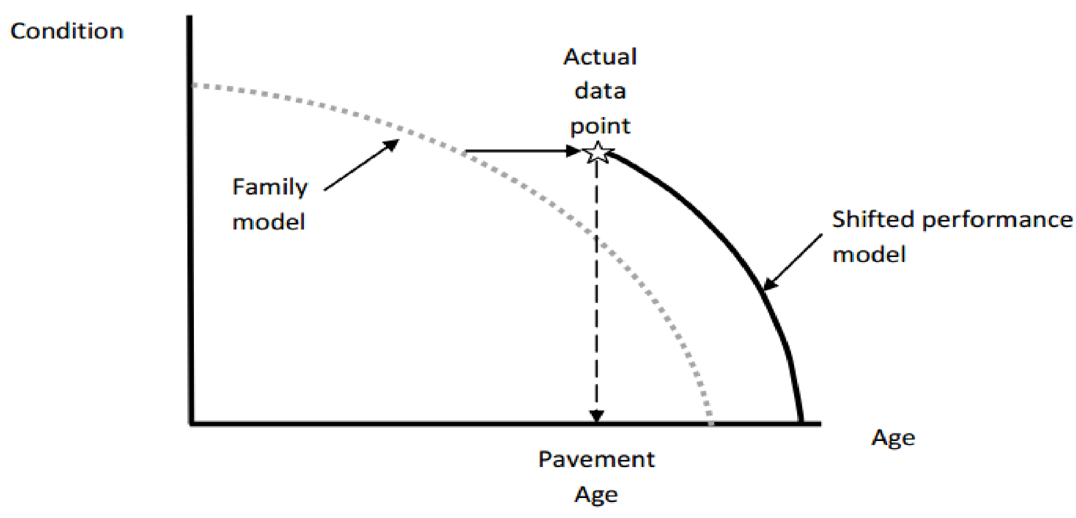


Figure 2.5: Pavement segment prediction in relation to a family model [19].

Various agencies have created statistically developed performance models using other pavement management software and spreadsheet tools. Figure

2-6 illustrates an asphalt surface (AC) performance curve used by Champaign County. The curve is representative of the pavement's anticipated performance over time. The development of pavement prediction models based on condition data were used by Champaign County to gain approval for budget allocation for county roads.

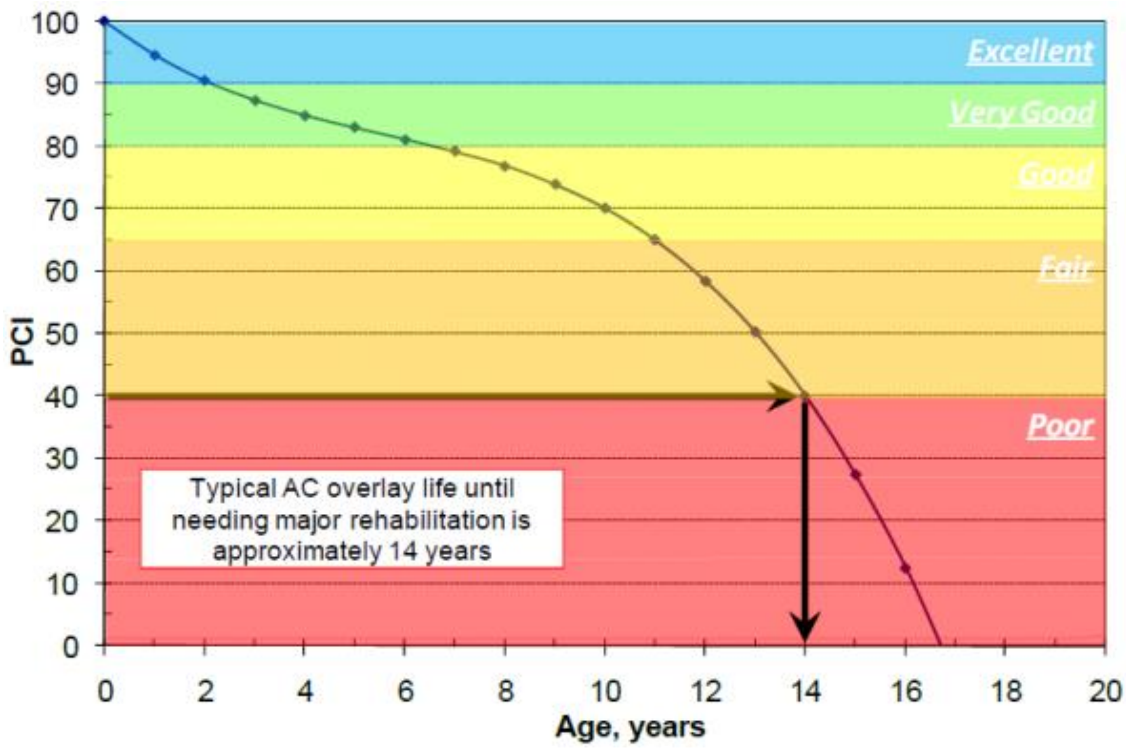


Figure 2-6: Champaign County performance prediction model for AC pavements [20].

Chapter Three

Methodology

Methodology

3.1 Introduction

To achieve the objectives of the research which were written in chapter one, a research methodology should be stated clearly and specifically. The proposed methodology written in this chapter defines the research scope, research methodology, survey data and distress identification and rating procedure. A brief discussion on Micro PAVER pavement management System Overview and the data set development, and Model parameters has been highlighted.

3.2 Scope, Methodology and Limitation

This research aims to develop major targets for the Sudan National Highway Northern Kordofan State parts (NKSN); In order to achieve these major targets; the following points were made to clarify the proposed methodology for this research:

The study focuses on (NKSN) only. Northern Kordofan State Local Road Network (NKSLN) is not included.

Road at each network were inspected and the resulting information were interred in to Micro PAVER data base.

The data collected and pavement survey information presented in this study are used to estimate the condition of specific section of pavement at an individual Highway or any group of pavement in the data base. In conjunction with relevant cost information, the Micro PAVER software can aid in preparing various budgets and prioritization scenarios, investigated and the benefit compared.

The road network subdivided into Branch, which are uniform in respect of traffic, environment, geometry, and pavement type, and construction history. The links subdivided into sections which are uniform in respect of pavement condition. The sections subdivided into sample units. Analyzing the links, sections and sample units then type and severity of pavement distress assessed by visual inspection.

After building the required databases, they will be subjected individually to two major steps.

- The first major step is that each database will be analyzed in terms of normality, and then PCI are calculation.

The distress data ware used to calculate the PCI for each sample unit. The PCI of the pavement section was determined based on the PCI of the inspected sample units within the section.

The PCI is a numerical indicator that rates the surface condition of the pavement is adopted to measure the present condition of the pavement based on the distress observed on the surface of the surveyed sample units. The illustration of condition of pavement rating by photos and descriptions are attached in appendix of this research.

- The second major step is to apply the models and predict the future condition of the pavements sections.

The developed models will be assessed against standard error. Adequacy measures of the developed models will be analyzed in terms of a residual analysis. 95% confidence limits for the data will be produced for the model. 95% confidence limits for the models will be also produced.

3.3 Survey Date

The pavement condition survey has carried out by the national highway authorities (NHA) of Sudan as a part of road sector management – training program funded by Swedish International Development Agency (SIDA), Organized by Road Administration and under supervision of Sweroad consultant [21].

The inspection is covered all national highway paved network in Sudan .In this case study we are select 4 roads a part of Sudan national highway. It is Northern Kordofan state. Inspection has been entered into Micro Paver Pavement Management System, the selected network account for a total length of 626 km. This data is very important to study the progression of the deterioration, and assist current condition of pavement, develop prediction model to predict future condition of pavement network.

3.3.1 Branch

A branch is any identifiable part of the pavement network which is a single entity and has a distinct function. The branch number is a unique code that is used to help store and retrieve data from the data base. The NKSN is divided into four branches. Each branch was given a name and number as shown in table (3.1).

3.3.2 Section Number

A section is a division of a branch; it has certain consistent characteristics throughout its area or length. The reference number is given by NHA to each section, starting from the beginning of the road under consideration.

Section number depends on the branch number, district code, and region code as shown in table (3.1).

3.3.3 Sample Unit

A sample unit (number) is any identifiable area of the pavement section; it is the smallest component of the pavement network. Each pavement section is divided into sample units for pavement inspection table (3.1) show the number of sample units for each section.

Table 3.1: The Pavement network, branch, section, No. of sample units and length of (NKSN)

Branch Name	Branch ID	Section ID	Section name	No. of samples	Length in Km
Elobied-Elkhwi	18W2	18W2	Elobied- Elkhwi	20	103
Elobied-Bara	19S2	19S2	Elobied-Bara	11	56
Elobied-Eldillinj	19S3	19S3/1	Elobied-Kazgile	09	47
		19S3/2	Kazgile- Eldillinj	22	113
Elobied-Kosti	18w1	18w1/1	Elobied-Wdashan	38	191
		18w1/2	Wdashan- Kosti	25	116

Figure (3.1) & (3.2) show the sections lengths and number of sample units in the section within the network respectively.

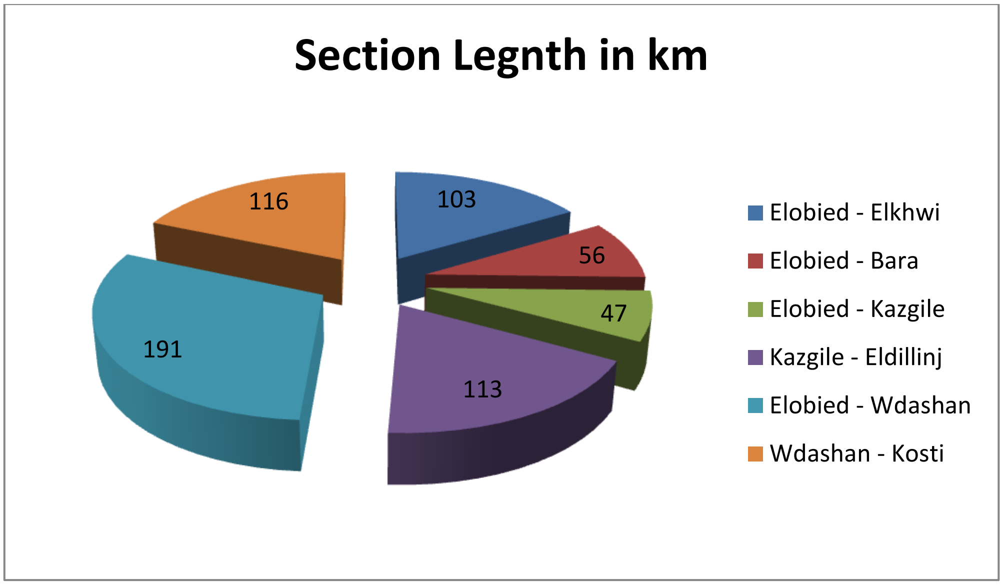


Figure (3.1): Pavement Network section length

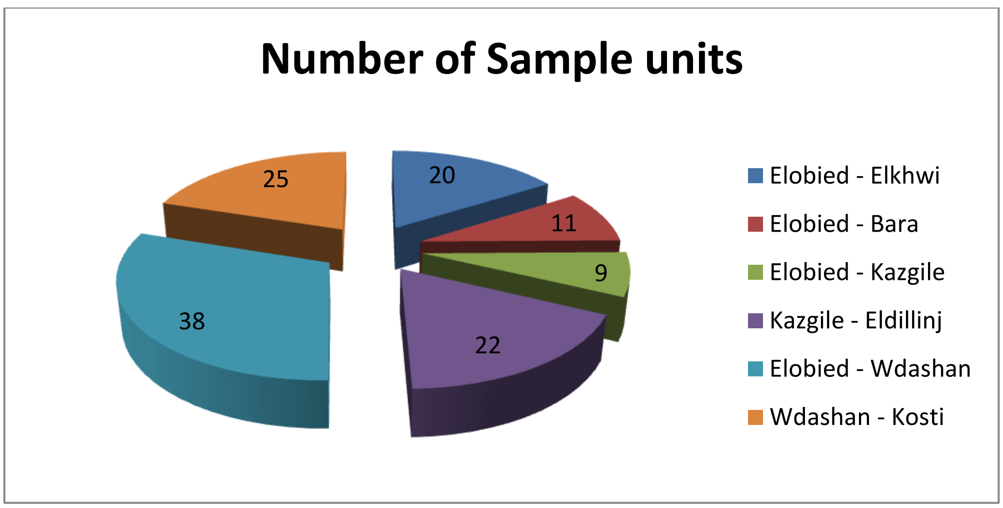


Figure (3.2): Number of sample units in the section

3.4 Distresses Identification and Rating Procedure

3.4.1 Sampling and Sample Units

The following procedure was followed in order to identify branches of the pavement with different uses such as roadways on the network layout plan [20].

Divide each branch into sections based on the pavements design, construction history, traffic, condition and according to network coding and numbering system.

Divide the pavement sections into sample units. Individual sample units to be inspected should be marked or identified in a manner to allow inspectors and quality control personnel to easily locate them on the pavement surface. Paint marks along the edge and sketches with locations connected to physical pavement features are acceptable. It is necessary to be able to accurately relocate the sample units to allow verification of current distress data, to examine changes in condition with time of a particular sample unit, and to enable future inspections of the same sample unit if desired.

Select the sample units to be inspected. The number of sample units to be inspected may vary from the following: all of the sample units in the section, a number of sample units that provides a 95 % confidence level, or a lesser number. All sample units in the section may be inspected to determine the average PCI of the section. This is usually precluded for routine management purposes by available manpower, funds, and time. Total sampling, however, is desirable for project analysis to help estimate maintenance and repair quantities [20].

The minimum number of sample units (n) that must be surveyed within a given section to obtain a statistically adequate estimate (95 % confidence) of the PCI of the section is calculated using the following formula and rounding n to the next highest whole number (see equation Eq. 1 below).

$$n = Ns^2/(\left(\frac{e^2}{4}\right)(N-1)+s^2) \qquad (3.1)$$

Where,

e = acceptable error in estimating the section PCI; commonly, e = ±5 PCI points;

s = standard deviation of the PCI from one sample unit to another within the section.

When performing the initial inspection the standard deviation is assumed to be ten for AC pavements. This assumption should be checked as described below after PCI values are determined.

For subsequent inspections, the standard deviation from the preceding inspection should be used to determine n; and,

N = total number of sample units in the section.

If obtaining the 95 % confidence level is critical, the adequacy of the number of sample units surveyed must be confirmed.

The number of sample units was estimated based on an assumed standard deviation. Calculate the actual standard Deviation as follows (see equation Eq. 2 below):

$$s = \left(\sum_{i=1}^{n}(PCI_I - PCI_S)^2/(n-1)\right)^{1/2} \quad (3.2)$$

Where:

PCI_i = PCI of surveyed sample units i,

PCI_s = PCI of section (mean PCI of surveyed sample units), and

n = total number of sample units surveyed.

Calculate the revised minimum number of sample units (Eq1) to be surveyed using the calculated standard deviation (Eq2). If the revised number of sample units to be surveyed is greater than the number of sample units already surveyed, select and survey additional random sample units. These sample units should be spaced evenly across the section. Repeat the process of checking the revised number of sample units and surveying additional random sample units until the total number of sample units surveyed equals or exceeds the minimum required sample units (n) in Eq1, using the actual total sample standard deviation[20].

3.4.2 Inspection Procedure

The definitions and guidelines for quantifying distresses for PCI determination are given here after, Using of this method, inspectors should identify distress types accurately 95 % of the time. Linear measurements should be considered accurate when they are within 10 % if re-measured, and area measurements should be considered accurate when they are within 20 % if re-measured. Individually inspect each sample unit chosen. Sketch the sample unit, including orientation [20].

Record the branch and section number and the number and type of the sample unit (random or additional). Record the sample unit size measured with the hand odometer.

Once the number of sample units to be inspected has been determined, compute the spacing interval of the units using systematic random sampling. Samples are spaced equally throughout the section with the first sample selected at random. The spacing interval (I) of the units to be sampled is calculated by the following formula rounded to the next lowest whole number:

$$I=N/n \qquad (3.3)$$

Where:

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

n = number of sample units to be inspected.

The first sample unit to be inspected is selected at random from sample units 1 through i. The sample units within a section that are successive increments of the interval i after the first randomly selected unit also are inspected. A lesser sampling rate than the above mentioned 95 % Confidence level can be used based on the condition survey Objective. As an example, one agency uses the following table for selecting the number of sample units to be inspected for strategy or programming analysis purposes rather than project analysis Given Survey as shown in the table(3.2).

Additional sample units only are to be inspected when no representative distresses are observed as defined before. Conduct the distress inspection by walking over the sidewalk/shoulder of the sample unit being surveyed, measuring the quantity of each severity level of every distress type present, and recording the data. Each distress must correspond in type and severity to that described in this chapter, the method of measurement is included with each distress description. Repeat this procedure for each sample unit to be inspected.

Table (3.2): Number of sample units for inspection [18].

Total No. of Sample Units in Section	No. of sample for inspection
1 - 5	1
6 -10	2
11-15	3
16-40	4
Over 40	10%

3.4.3 Calculation the Pavement condition (PCI) Manually

Step 1: Add up the total quantity of each distress type at each severity level, and record them in the “Total Severities” section. The units for the quantities shall be in square meters, linear meters, or number of occurrences, depending on the distress type.

Step 2: Divide the total quantity of each distress type at each severity level as determined above by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity.

Step 3: Determine the deduct value (DV) for each distress type and severity level combination from the distress deduct value curves in Appendix.

Step 4: Determine the maximum corrected deduct value (CDV) according to the following procedure.

- If none or only one individual deduct value is greater than two, the total value is used in place of the maximum CDV in determining the PCI; otherwise, maximum CDV must be determined using the procedure described in the following.
- List the individual deducts values in descending order.

- Determine the allowable number of deducts, m, using the following formula see (Eq4):

  $m=1+ (9/98) (100-HDV) \le 10$ (3.4)

Where:

m = allowable number of deducts including fractions (must be less than or equal to ten), and

HDV = highest individual deduct value.

The number of the individual deduct values is reduced to the m largest deduct values, including the fractional part.

Step 5: Determine total deduct value by summing individual deduct values according to the following procedure.

- Determine q as the number of deducts with a value greater than 2.0.
- Determine the CDV from total deduct value and q by looking up the appropriate correction curve for AC pavements in Fig. 20 in the appendix.
- Reduce the smallest individual deduct value greater than 2.0 to 2.0 and repeat the last three steps until q = 1.
- -Maximum CDV is the largest of the CDVs.

Step 6: Calculate PCI by subtracting the maximum CDV from 100:

$PCI = 100- \max CDV.$ (3.5)

3.4.4 Determination of Section PCI

If all surveyed sample units are selected randomly or if every sample unit is surveyed then the PCI of the section is the average of the PCIs of the sample units. If additional sample units, as defined in before, are surveyed then a weighted average is used as follows:

$$PCI_s = (N-A)(PCI_A)/N + A(PCI_A)/N \quad (3.5)$$

Where:

PCI_S = weighted PCI of the section,

N = total number of sample units in the section,

A = number of additional sample units,

PCI_R = mean PCI of randomly selected sample units, and

PCI_A = mean PCI of additional selected sample units.

Determine the overall condition rating of the section by using the section PCI and the condition rating scale in Fig. (3.4) [20].

In this study all distress data obtain from field survey carry out by NHA Sudan interred in to Micro PAVER software which is a Pavement Management System developed by the US Army Corps of Engineers to calculate pavement condition index (PCI) for all network, develop the family model, and predict future condition of pavement.

3.5 Micro PAVER Software

Micro PAVER is a Pavement Management System developed by the US Army Corps of Engineers. It was first released in 1981 and supported by many agencies i n the USA. Development of a Pavement Maintenance Management System Army, US Air force, Federal Aviation Administration (FAA) and Federal Highway Administration

(FHA). Micro PAVER aids pavement managers in deciding when and where to appropriate funds for pavement maintenance and rehabilitation. Micro PAVER provides pavement management capabilities to [22]:

- Develop and organize the pavement inventory.
- Assess the current condition of pavements.
- Develop models to predict future conditions.
- Report on past and future pavement performance.
- Develop scenarios for pavement maintenance based on budget or condition requirements.

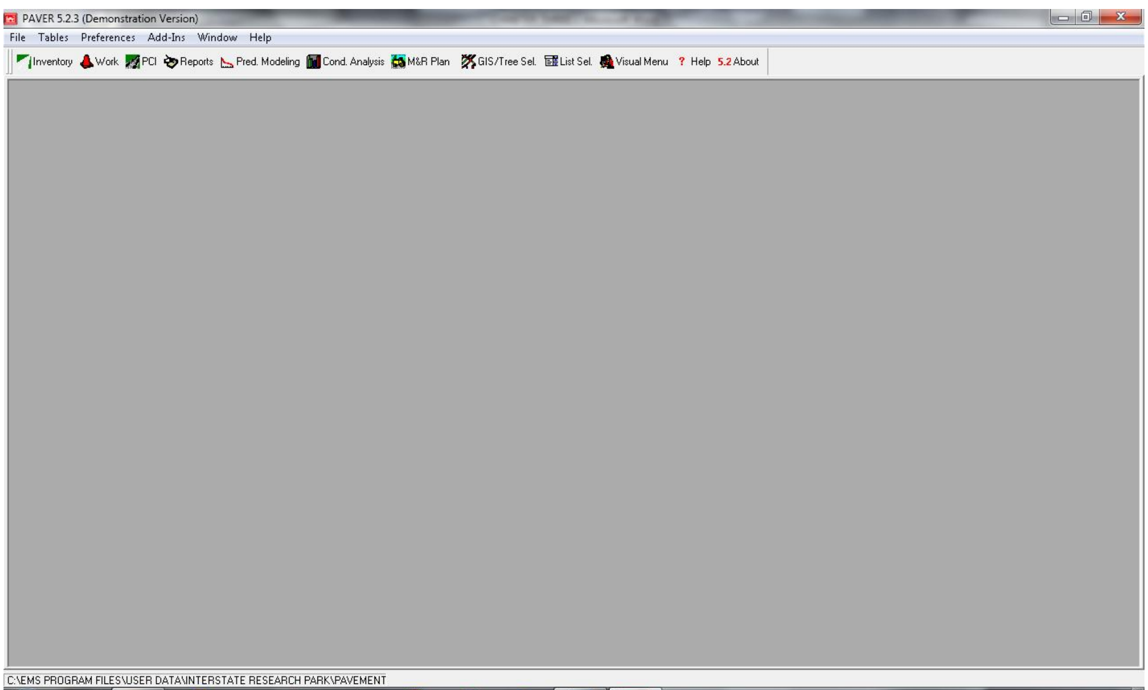


Fig (3.3): The Main Page Screen of Micro PAVER.

Micro PAVER inventory management i s based on a hierarchical structure composed of networks, branches and sections, with the section being the smallest managed unit. Figure (3.3) shows the main page screen of the

Micro PAVER. To assess pavement condition, Micro PAVER uses the Pavement Condition Index (PCI) as the primary standard. Micro PAVER al so provides users an interface for recording the results of an inspection. In addition, condition analysis, condition prediction and work plans can be made by i t.

3.6 Micro PAVER Pavement Management System Overview

The Micro PAVER pavement management system helps agencies determine when, where, and what level of pavement maintenance and rehabilitation (M&R) is required and approximately how much it will cost. The system provides a suite of pavement management software tools that assist agencies in: (1) developing and organizing their pavement inventory; (2) assessing the current condition of their pavements; (3) developing models to predict future pavement conditions; (4) reporting on past and future pavement performance; (5) developing scenarios for M&R based on either budget or condition requirements; and (6) planning M&R projects. The primary Micro PAVER modules include [22]:

- Inventory
- M&R History
- Inspection
- Prediction Modeling
- Condition Analysis
- M&R Planning
- Project Planning
- Reporting

A brief description of these modules is presented in the following sections.

3.6.1 Inventory and M&R History Modules

The Micro PAVER Inventory and Work History modules are based on a hierarchical structure composed of networks, branches, and sections, with the section being the smallest "managed" pavement area (e.g., street block). This structure allows users to easily organize their inventory and historical M&R data while providing numerous fields for storing pavement data.

3.6.2 Inspection Module

Micro PAVER uses the Pavement Condition Index (PCI) per ASTM D 6433 as its primary measure of pavement condition. The Inspection module enables agencies to store raw pavement condition survey data and then calculate PCI values.

3.6.3 Prediction Modeling Module

The Prediction Modeling module in Micro PAVER helps identify and group pavements of similar construction that are subjected to similar traffic, weather, and any other factors affecting pavement performance. Historical pavement condition data are used to build models that can be used to predict future pavement performance. If historical pavement data are not available, Micro PAVER provides default pavement prediction curves and allows the user to develop custom prediction curves.

3.6.4 Condition Analysis Module

The Condition Analysis module allows agencies to view the condition of the entire pavement network or any specified subset of the network over time. The module reports past conditions based on interpolated values between historical conditions data, and it reports projected conditions based on prediction models.

3.6.5 M&R Planning Module

The Micro PAVER M&R Planning module is a sophisticated, flexible tool for multi-year, network-level and project-level M&R planning, scheduling, and budgeting. The M&R Planning module is able to determine the consequence of a predetermined budget on pavement condition and the resulting backlog of major work and is also able to determine budget requirements to meet specific management objectives. These capabilities enable agencies to:

(1) Develop optimal M&R programs given available resources, and

(2) Justify optimal M&R budget needs.

3.6.6 Reporting Module

Each module of Micro PAVER is capable of generating reports that assist the user in analyzing and interpreting data. Micro PAVER also comes equipped with several “canned” reports, which include:

- ❖ Summary Charts – Simple graphs and data tables of inventory and inspection data
- ❖ Inspection Reports – Summary of collected pavement condition data
- ❖ Work History – Summary of historical maintenance, repair, and rehabilitation data
- ❖ Branch Listing – Summary of overall pavement inventory data
- ❖ Branch Condition – Summary of overall pavement condition data
- ❖ Section Condition – Summary of individual section data

- GIS reports – Internal/external reporting of inventory and condition data.

Micro PAVER is capable of generating “user-defined” reports, which can be tailored to meet the agency’s specific reporting needs. Micro PAVER user-defined reports enable the user to extract any data stored in the system and export it to either a spreadsheet or a text file. The enhancements made to Micro PAVER will improve the ability of road agencies to manage their pavements. User interface modifications as well as improvement to analysis capabilities of the software will improve the efficiency of both daily users and decision makers, respectively. The incorporation of internal GIS-based inventory selection and reporting tools give Micro PAVER an enhanced visual component, while the ability to create PCI-based and other distresses greatly improve the flexibility of the software. Enhanced reporting capabilities make extracting data from the system easier and interactive work planning routines make budget analysis less time consuming [22].

3.7 Dataset Development

To obtain generic models for NKSNRN that can be utilized with a significant level of confidence, this study has covered all possible and accessible pavement sections that satisfy the research scope discussed in section 3.2.

For this study, the dataset was developed though different steps as follows:

• Some apparent outliers exist within the data but all data was analyzed so that extreme values could be identified as part of modeling process.

• Section boundary modifications were as checked. Any section that had been merged with another due to any reason was removed to ensure accuracy for the selected sections used in building the research dataset.

• Any section satisfies the above conditions was used to build the research work or the dataset for the research and can be considered as the original work in this study.

• Each section contains different number of sample unit depends on the geometry of the section.

• Each sample unit contains one or more than pavement distress type's record (type, severity, density) and only one DI value (these values from the NHA database).

• For the DI dataset, the original work used the DI of pavement section at given survey date by averaging the sample DI values.

• This value has been used as one reading in the dataset.

• The dataset of the DI models was built based on the above steps.

A brief description for database development in this research will be presented. The number of pavement sections in the network is more than 626km [21]. In that stage the data was filtered, stored and removed irrelevant data. The data was classified according to the following parameters. The classification was formatted to cover all possible cases. The possible cases depend on parameters that are under investigation in this study. In general, the parameters are; road class, traffic count, drainage condition, pavement condition values, distress types, and distress density.

3.8 Model Parameters Definition

The model parameters depend on; the features of the study, the nature of the collected data, the requirements of the study, and the parameters that affect the behavior of the pavement. It was hypothesized that these parameters should include: distress type, distress severity, distress density, pavement condition, maintenance type, pavement age, highway class, traffic volume, drainage, and climate condition. However, not all parameters will be included in the process of modeling. The following is a brief discussion of these parameters

3.8.1 Distress Type

Development and implementation of a pavement distress survey procedure requires a clear definition of the distress type. During field survey carried by NHA Sudan to national roads in Sudan, the survey considers 19 distress types which are commonly observed on the Northern Kordofan roads and they are, Fatigue Cracks, Block Cracks, Longitudinal &transverse Cracks, Patching, Potholes, Depression, Rutting, Shoving, Bleeding, Polished Aggregate, Weathering & Raveling, Patching Cracks, Patching Depressions, Patching Potholes, and Patching Weathering & Raveling. This study will consider only the most common distress types on Northern Kordofan roads [21].

3.8.2 Distress Severity

Distress types can take on a variety of severity conditions. These are divided into three levels: low, medium and high. Although these levels are subjective descriptions, they describe distinct categories of the progression of the distress type that relate well to rehabilitation needs. In general, the three levels of distress severity are; low, medium, and high. This study will consider these severity levels.

3.8.3 Distress Density

The quantity of each type and severity level measured and expressed inconvenient units. Density for distress types measured by the square meter is calculated as follows [33];

$$\text{Density} = \frac{\text{distress amount in square meters}}{\text{sample unit area in square meters}} \times 100 \qquad (3.6)$$

Density for distress types measured by the linear meter is calculated as follows;

$$\text{Density} = \frac{\text{distress amount in linear meters}}{\text{sample unit area in square meters}} \times 100 \qquad (3.7)$$

Density for distress types measured by number (potholes) is calculated as follows;

$$\text{Density} = \frac{\text{number of potholes}}{\text{sample unit area in square meters}} \times 100 \qquad (3.8)$$

3.8.4 Pavement Condition

3.8.4.1 Objective

The objective of the pavement condition inspection was to assess the existing condition of the roadway pavements managed by the NHA. This was accomplished by performing a manual, network-level pavement condition inspection based on the Pavement Condition Index (PCI) method.

3.8.4.2 Pavement Condition Index (PCI) Procedure

The pavement condition survey was performed using the modified ASTM D6433-based PCI procedure described in the textbook, Pavement Management for Airports, Roads, and Parking Lots, 2nd Ed. by M. Y. Shahin. The PCI procedure is a more objective and repeatable method for determining existing pavement condition. A PCI value provides an indication of the structural integrity and operational condition for a pavement section. The PCI procedure consists of a routine visual inspection, during which pavement distress types, severity levels, and quantities are identified and recorded. These data are then input into the PCI algorithm to calculate a PCI value. PCI values range from 0 to 100, as shown in Figure 3.4.

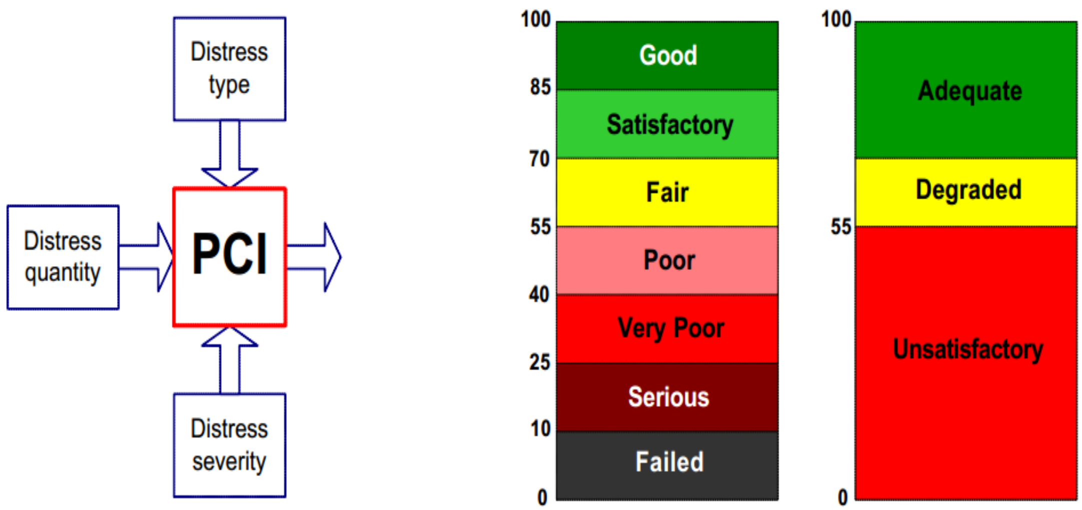


Figure 3.4: PCI Inputs and the Network Condition Assessment Scale [22]

If properly designed and constructed, a new pavement begins its service life with a PCI of 100. Due to the effects of loading and aging, a pavement deteriorates over time. For each combination of distress type, severity level, and quantity observed, points are deducted from 100, and its PCI decreases. When multiple distresses are present, the deduct values are modified such that the impact of multiple distresses is somewhat lessened. Due to the complexity of the PCI algorithm, PCI values are typically computed using a pavement management software package, such as Micro PAVER. During a PCI inspection, nineteen (19) distress types are identified and evaluated for asphalt pavements, as shown in Table. The NHA roadway network consists of asphalt-surfaced pavement as well as a few gravel roadways.

Chapter four

Case Study Application of Software

Case Study Software Application

4.1 Introduction

This chapter describes the case study development and application using Micro PAVER pavement management system for the Northern Kordofan state roads. It includes the description of network at study area, data source and management, and development of case study data base. The pavement condition index for the case study calculation by Micro PAVER and resulting assessment are presented in this chapter.

4-2 Case Study Area (Networks)

A field survey of the functional condition of the project road network has been carried out in November 2005. The survey include all the 19 paver distress required by the Micro PAVER software, the pavement condition survey data used was collected by National Highway Authority (NHA) as a part of road sector management training program funded by Swedish International Development Agency (SIDA), organized by Swedish Road Administration and under supervision of SweRoad Consultant [21]. The inspection covers all National Highway paved network in Sudan. In this case studies four roads were selected from the networks as a part of Sudan National Highway they are located in Northern Kordofan State. Inspection data have been fed into Micro PAVER Pavement Management System. The total network account length of 626 km, some part of these roads has been rehabilitated, and most the asphalt surface is more than 10 years old Fig 4.1, shows case study location network.

The road networks have subdivided in to 4 approaches each of which is uniform with respect to traffic, environments, geometry, and pavement type, and construction history. The approach has been subdivided into 6 sections which are uniform in respect of pavement condition. Each section is divided into sample units, with 5000m of length and of 7m of width, true area of each 3500m^2, for purpose of project analysis the approaches or links, sections, and sample units have been the same for every strategic analysis, Table 4.1, show the network, branches, and section.

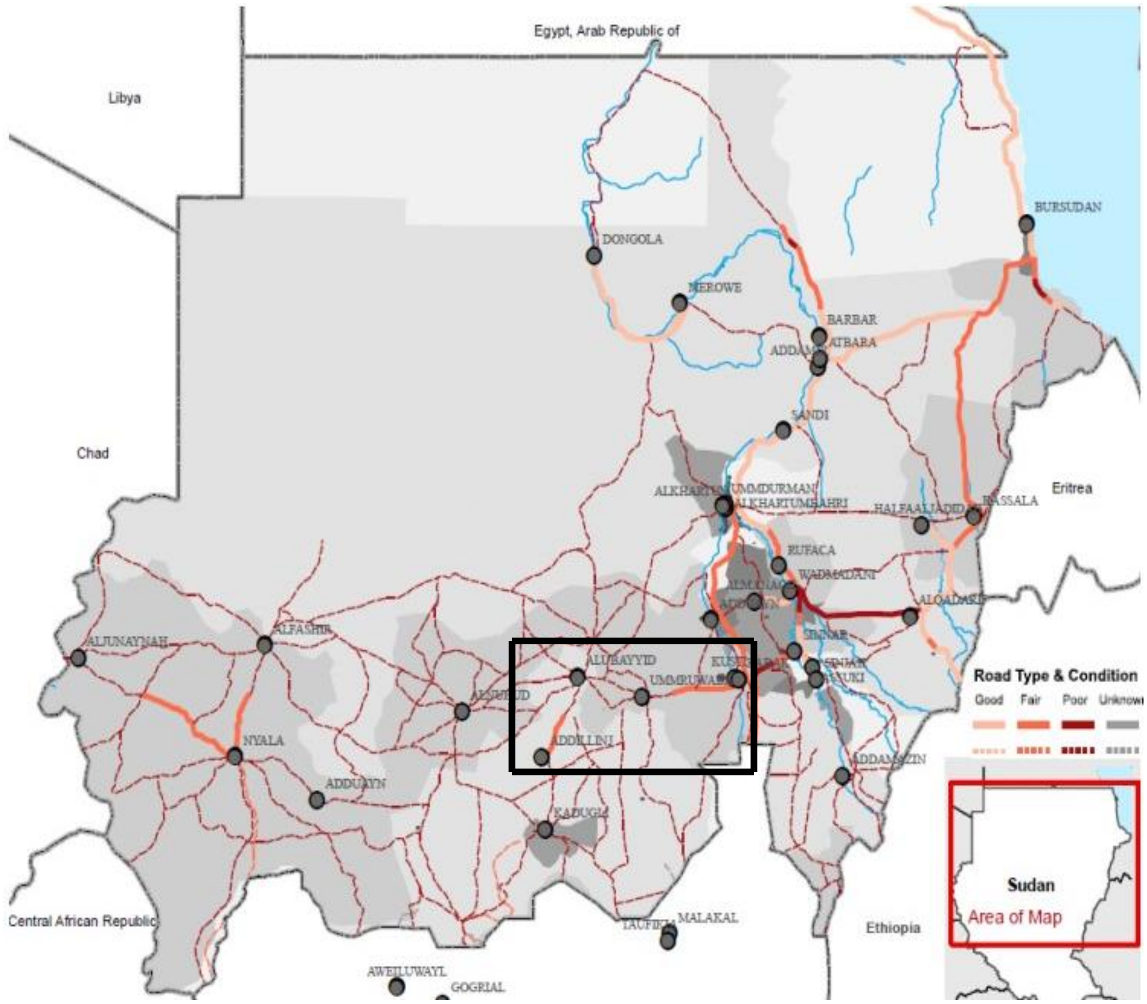


Figure 4.1: Case study Network location, Source (AICD 2010) [25].

Table 4.1: Case study network, Branch, and, Sections from Micro PAVER

Branch Listing Reports						
Pavement Data Base						
Network 1D	Branch ID	No. of sections	Section ID	Section name	use	True area in sq.m
1	18W2	1	18W2	Elobied - Elkhwi	Roadway	721000
2	19S2	1	19S2	Elobied - Bara	Roadway	392000
3	19S3	2	19S3/1	Elobied - Kazgile	Roadway	1120000
			19S3/2	Kazgile -Eldillinj	Roadway	791000
4	18w1	2	18w1/1	Elobied-wdashan	Roadway	1337000
			18w1/2	Wdashan - Kosti	Roadway	812000
Total number of Branches				4		
Total number of Sections				6		

4.3 Data Source and Management

Data source and information are collect from National Highway Authority, of Sudan as a part road sector management –training program funded by SIDA “Swedish International Development Agency”, organized by Swedish road administration and under supervision of SweRoad consultant. Fig (4.4) shows sample form data and distresses survey sheet.

MINISTRY OF TRANSPORT

ROADS & BRIDGES

NATIONAL HIGHWAY AUTHORITY

Link ID: 18W1 Section ID: 18W1/2

Link Name: KOSTI-ELOBIED Section Name: WAD ASHANA - ELOBIED

Sample Units: km 34 -km 39 Area of Sample Unit (M): = 35000

SHEET 5

DISTR	Sevr.	QUANTITIES														Total	DENS	D.V
9	L	2297														2297	6.56	6
9	M	63														63	0.18	0
7	L	2041														2041	5.83	3
7	H	231														231	0.66	9
6	L	10.5	3.8													14.3	0.04	0
6	H	56														56	0.16	12
8	M	7														7	0.02	0
12	L	1.43	0.54													1.97	0.01	0
3	L	1582														1582	4.52	3
3	M	182	294	126	252	133										987	2.82	7
3	H	3	0.63	1.05	0.84											5.52	0.02	0
10	H	63.01	1.87	0.66	2.16	2.25	2.7	3.6	72	220	539					907.3	2.59	72
10	M	0.54	0.84	72	120	72	55	70	24	209	20	16	24.8			684.1	1.95	46
1	L	2.25	1.32	0.48	4	1.2	0.24	0.6	45	0.6						55.69	0.16	3
																0	0.00	

COMMENTS

SIGN. ....

NAME ....

NOTE: THE DEDUCT VALUE SHOULD BE OBTAINED USING RESPECTIVE DISTRESS CURVE SHOWN IN PAVEMENT CONDITION SURVEY MANUAL

Figure 4-2: sample from data Source and Distresses survey sheet

4.4 Development of Case Study Micro PAVER Database

The first step in the Micro PAVER system was to divide the Network roadway pavements into pavement sections. Each pavement section typically represents a single “block” of pavement (i.e., intersection to intersection). Pavement sections may be thought of as “homogenous” areas of pavement to which Major M&R (e.g., resurfacing and reconstruction) would be applied. The software windows in Fig(4.2) & Fig(4.3) are the inventory data window. In this window, the main tabs are for the edit of inventory data, there are tab for Network, Branch and Section. In order to chanage the displayed inventory item, locate the item in the select inventory item window. The invintory data window data update itself accordingly.

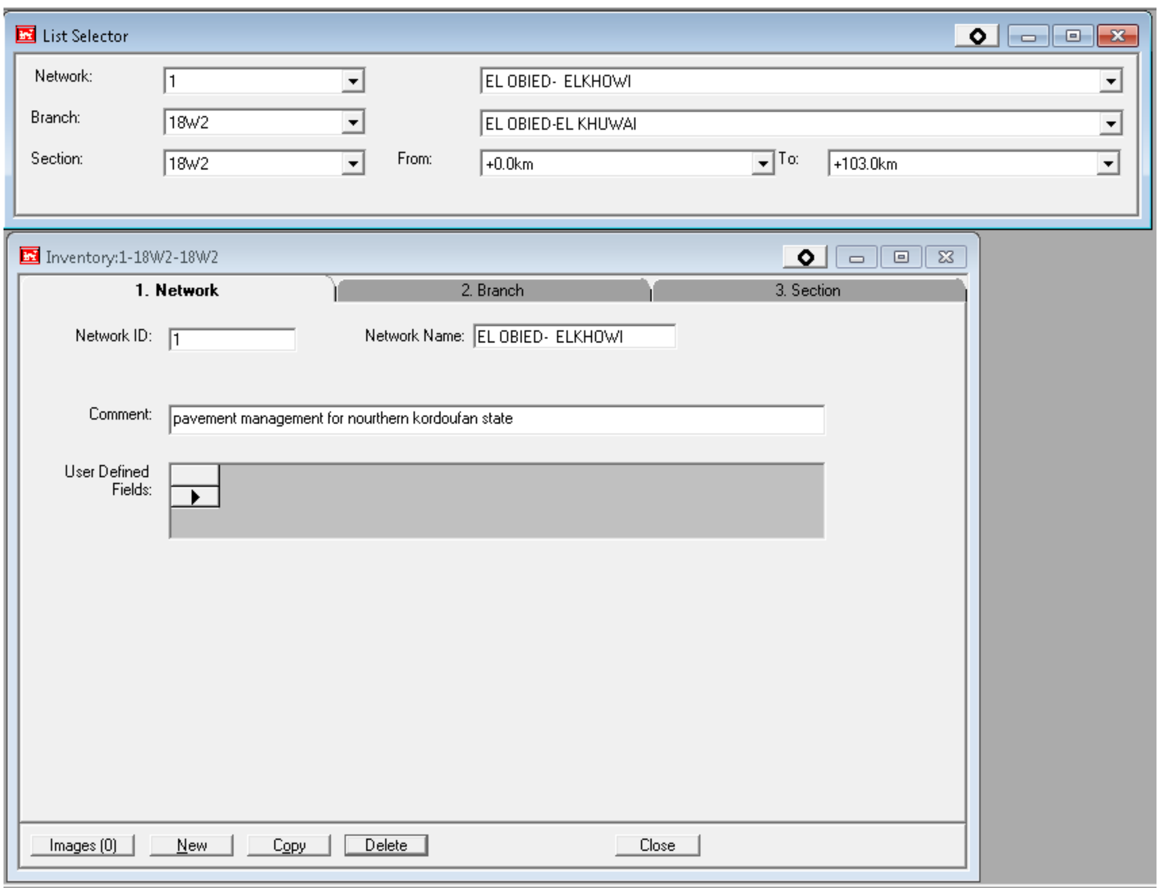


Figure 4-3: Inventory Data Windows in Micro PAVER

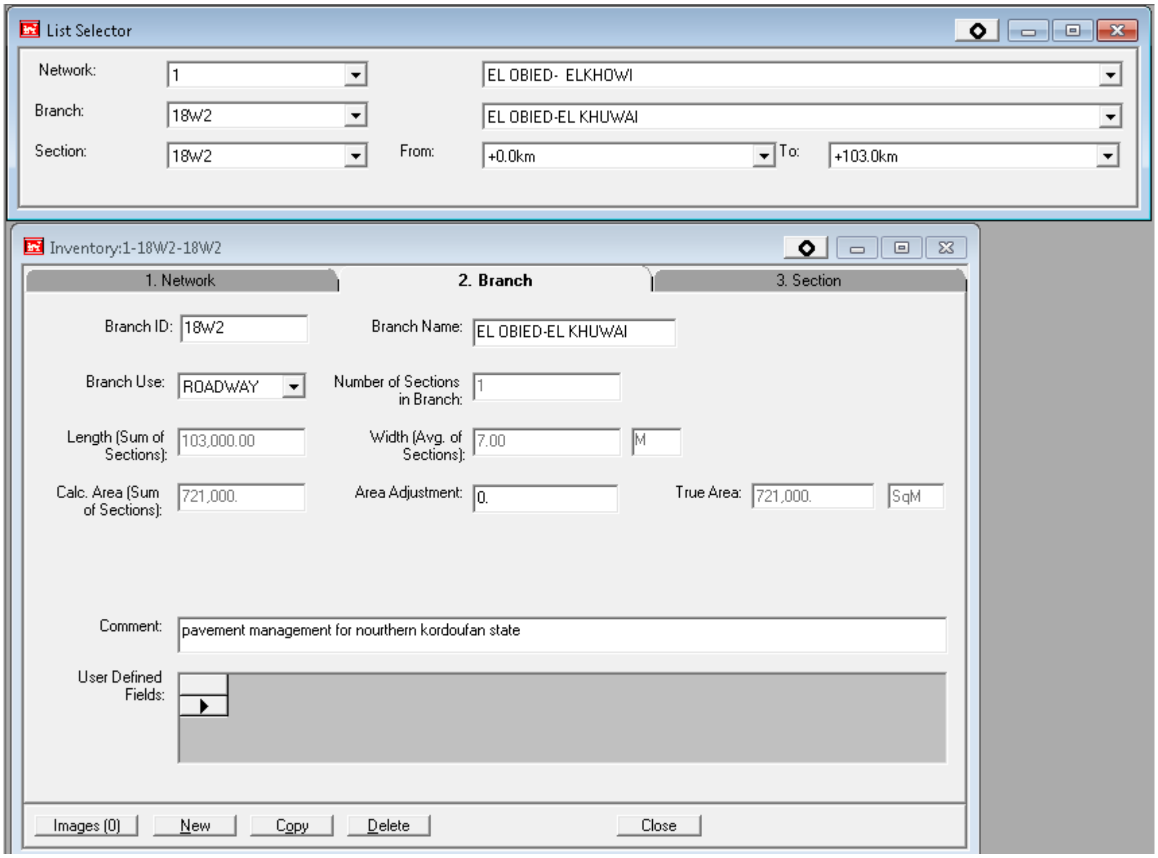


Figure 4-4: Inventory Data Branch Windows in Micro PAVER

4.4.1 Section identification

A section has been viewed as smallest management unit in application and selection of major maintenance and repair (M&R) treatments. A section has same surface type. Each branch consists section, dividing branches into sections are according to pavement surface, construction history, traffic, pavement rank (or functional classification), drainage facilities and shoulders, condition, and size. Fig (4.5) shows section application in Micro PAVER.

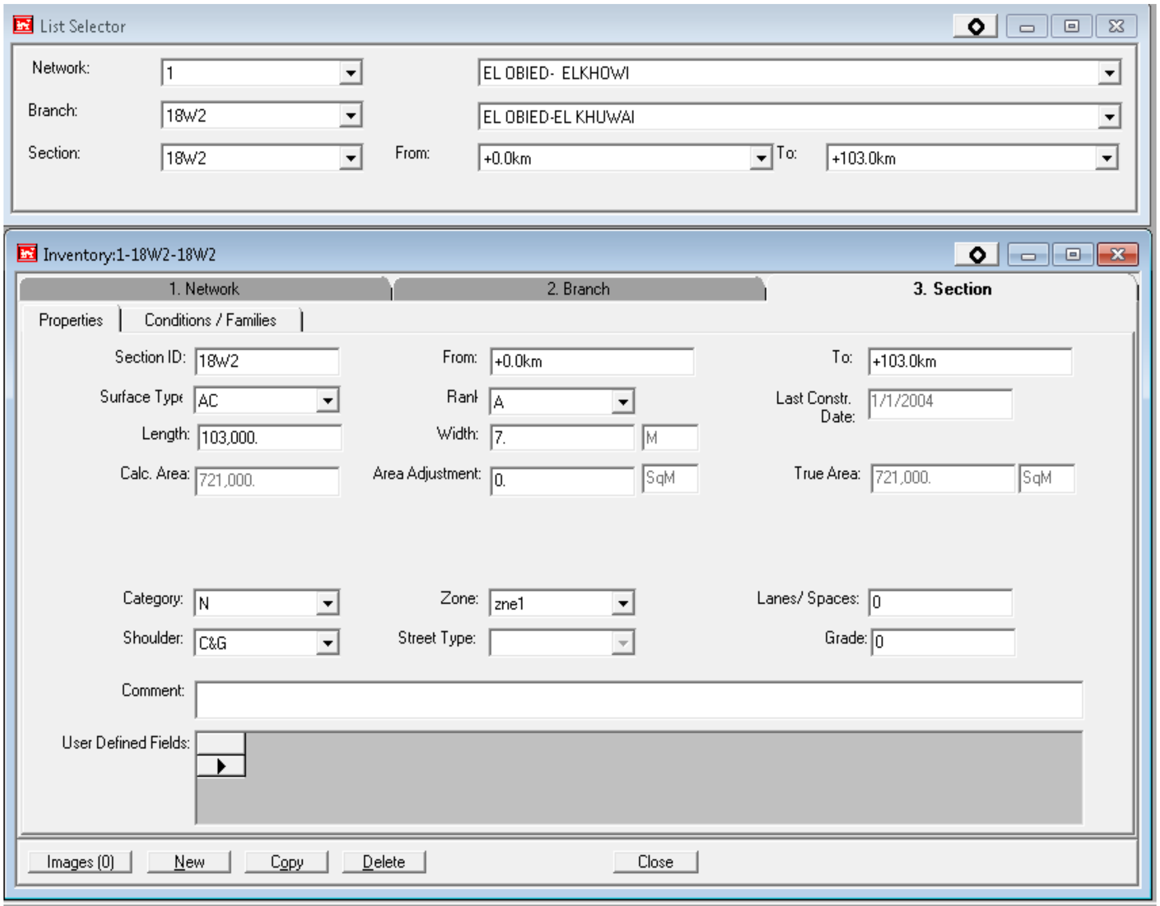


Figure 4-5: Sample Application of Section in Micro PAVER.

4.4.2 Section Size

Section size can have a considerable impact on the economics of implementation. Defining very short sections, to ensure uniformity, requires a higher implementation effort and cost. The sections may also be too small to schedule individual M&R work productively. If they are too large, the characteristics may not be consistent across the entire area. This situation could result in non-uniform sections which in turn results in inefficient design and budget decisions. It is also recommended that sections be numbered in a consistent way. For example, west to east, north to south, and clockwise for circular roads. In our case study the sections selected is uniform section consist of constant width of 7m and different length according city location.

4.4.3 Surface type

For each section a surface type was entered. The information for most report can be retrieved by surface type. The surface type was taken from the National Highway Authority of Sudan networks data. Table (4-2) shows the surface type options use in Micro PAVER system. AC and ST are used in our case study application.

Table 4-2: Surface Type use in Micro PAVER

Name	Descriptions	Surface Category
AAC	Asphalt overlay over asphalt concrete	Asphalt
ABR	Asphalt over brick	Asphalt
AC	Asphalt Concrete	Asphalt
ACT	Asphalt over cement treated base	Asphalt
APC	Asphalt overlay over Portland cement concrete	Asphalt
APZ	Asphalt over pozzolanic base	Asphalt
BR	Brick	Asphalt
COB	Cobblestone	Asphalt
GR	Gravel	Un surfaced
PCC	Portland cement concrete	Cement
PVB	Paving blocks	Asphalt
ST	Service treatment	Asphalt
X	Other	Un surfaced

Figure (4.6) and (4.7), Shows the surface type use in our case study by approximately 74% of the section pavements are asphalt surfaced (AC). Double service treatment sections account for 26% of the pavement network selected.

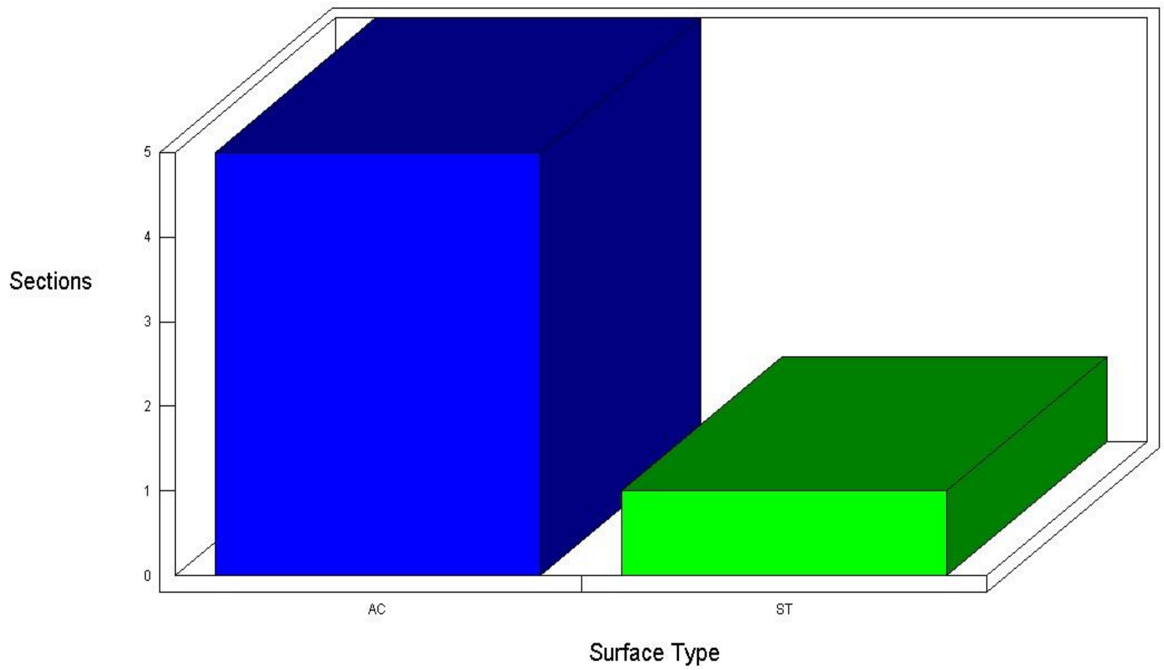


Figure 4-6: Type of pavement surface used in case study

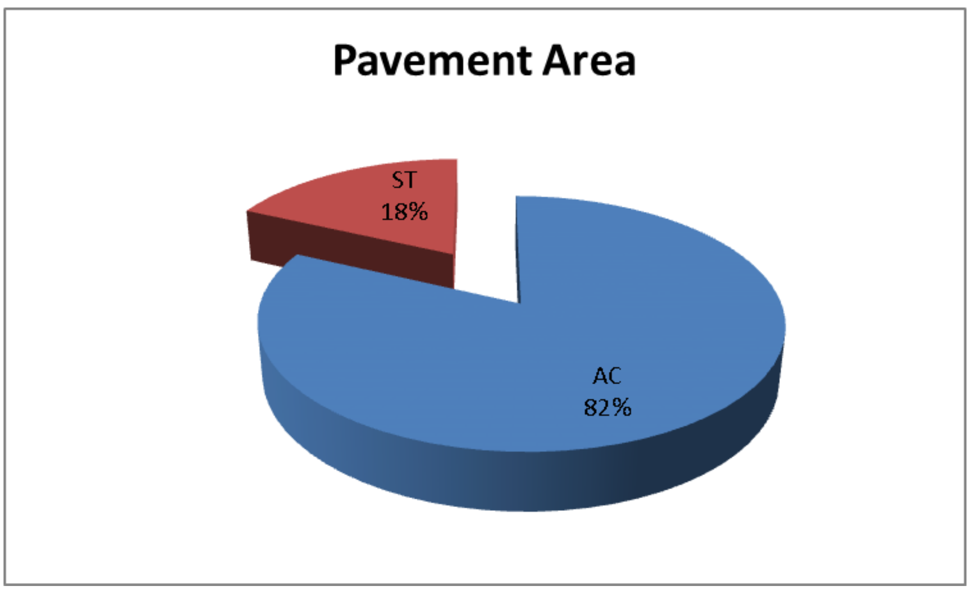


Figure 4-7: Percentage area of Pavement Surface used in case study

4.4.4 Pavement Rank

Pavement typically used to include either the traffic level, or priority of the section. All road entered into the database were designed A-principle, B-Arterial, according to number of lane has been given and truck traffic. An intersection treated as a separate section only if it likely to receive major rehabilitation independence of the surrounding pavement. Table describes section priority and its function used in Micro PAVER.

Table 4-3: Section Rank Use in Micro PAVER

Section Rank	Description	priority
A	Principal	High
B	Arterial	High
C	Collector	Low
I	Industrial	Low
E	Residential	Low
N	Not Applicable	Low
P	Primary	Low
S	Secondary	Low
T	Tertiary	Low
O	Other	Low

In our case study there are four sections in rank (A) and two sections in rank (B) as shown in Table (4-4) and Figure (4-8) describe the level of traffic are used.

Table 4-4: Section Rank Used in Case Study Network

Section Rank	**Sections**	**Pavement Area**	**Section Area Units**
A	4	3,262,000.00	SqM
B	2	1,120,000.00	SqM

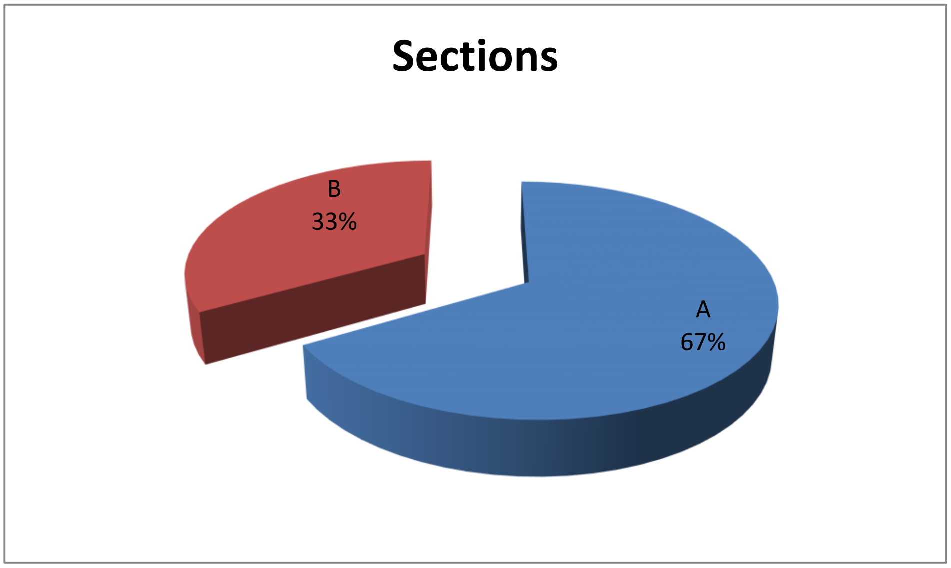


Figure 4-8 Distribution of Section According to Their Rank

4.4.5 Pavements Age

Pavement age is calculated from the date of resurfacing or reconstruction that is stored in the Micro PAVER database. If a pavement has not been resurfaced or reconstructed, its age is calculated from its original construction date. Figure (4.9) shows the distribution of pavement network ID by age.

Figure 4-9: Distribution of Network by Age

It is important to note that the ages shown in Figure (4.9) are based on available historical construction records. Some records are not available or are incomplete. Based on available records, the entire pavement network has been constructed within the past 10 to 20 years.

4.4.6 Last Construction Date

In the Micro PAVER System, application the last construction date indicates when the pavement was built or last overlaid. The data for entering this field come from the construction history data collected by (NHA) record and are found on the PMS for Sudan. In this case study there are four approaches were selected for application. They are, Elobied-Elkhwi, Elobied-Bara, Elobied - Eldillinj, Elobied- Kosti. The structural condition of the case studies application was initially assessed based on information obtains from (NHA). Table (4.5) shows pavement types and construction history gathered from NHA. Figure (4.10) shows sample from of construction record fed into Micro PAVER.

Table 4-5: Construction History of Case study Sections used in Micro PAVER

Section Name	Start km	End km	Const. year	Surface type	Base type
EL OBIED-EL KHUWAI	+0.0	+103.0	01/01/2004	AC	Granular
EO BIED – BARA	+0.0	+56.0	01/01/2003	AC	Granular
KAZGILE - EL DILLINJ	+47.0	+160.0	01/10/2004	ST	Granular
EL OBIED – KAZGILE	+0.0	+47.0	01/11/2000	AC	Granular
WDASHANA – KOSTI	+191.0	+307.0	01/01/1991	AC	Granular
EL OBIED- WDASHANA	+0.0	+191.0	01/01/1994	AC	Granular

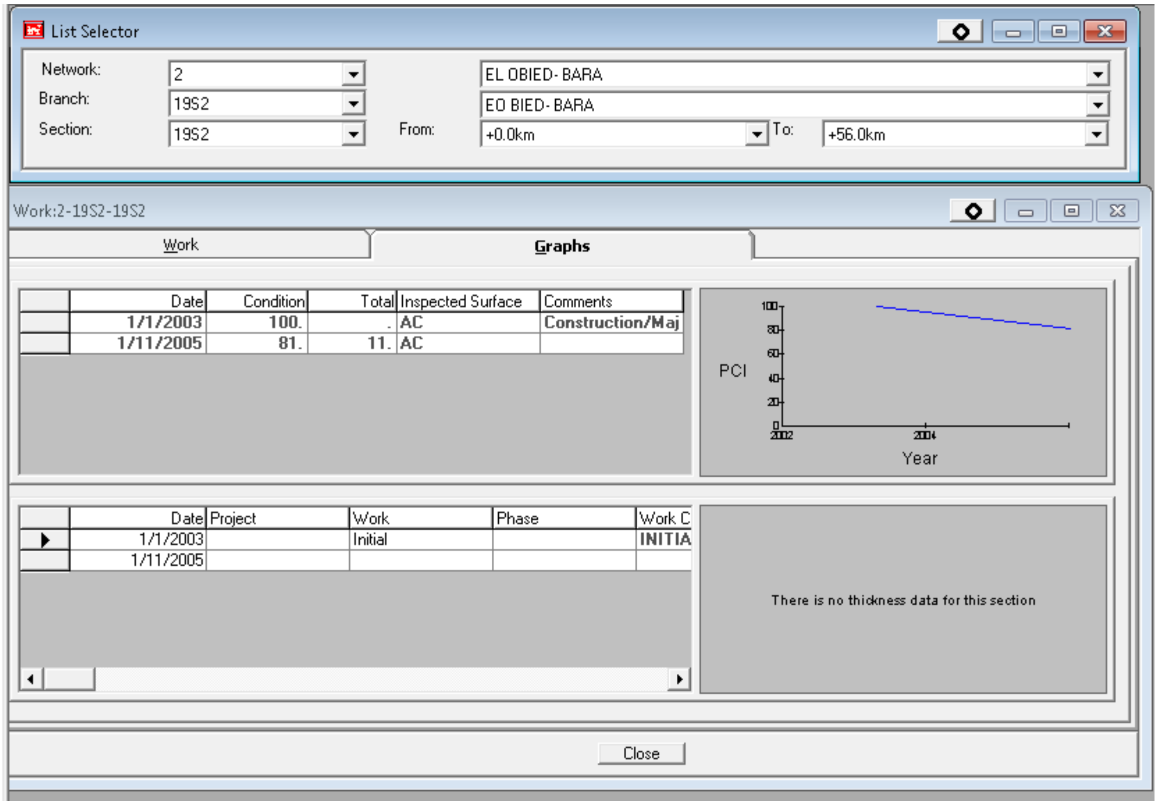


Figure 4-10: Sample of Construction Record

4.4.7 Sample Units

The network level procedure requires that the selected sample unit to be surveyed that are representing of the section to be inspected. The recommended method is to use random sampling procedure with higher sampling rate. The number of sample unit inspected in case studies shows in Table (4.6). Figure (4.11) shows Micro PAAVER sample distress entry.

Table 4-6: Surface Type Use in Micro PAVER

Network ID	Branch Name	Sections	From km	To km	Length km	Width m	Samples
1	EL OBIED-EL KHUWAI	1	+0.0	+103.0	103	7	20
2	EO BIED - BARA	1	+0.0	+56.0	56	7	11
3	EL OBIED - EL DILLINJ	2	+47.0	+160.0	113	7	22
3	EL OBIED - EL DILLINJ	2	+0.0	+47.0	47	7	9
4	EL OBIED - KOSTI	2	+191.0	+307.0	116	7	25
4	EL OBIED - KOSTI	2	+0.0	+191.0	191	7	38

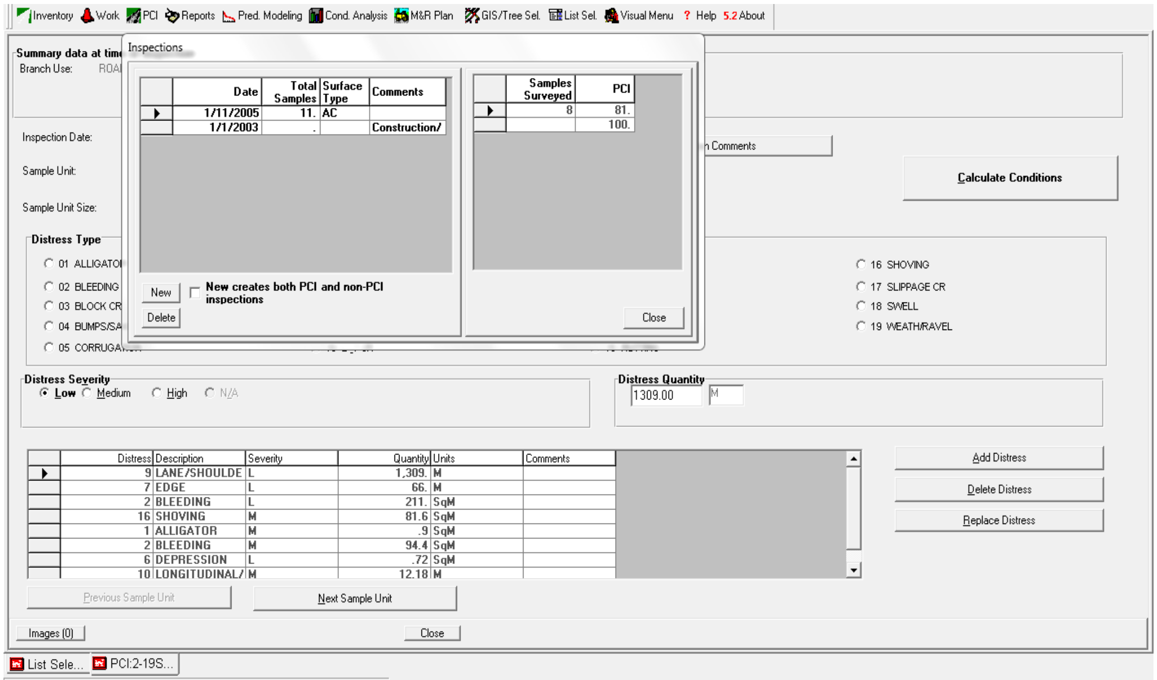


Figure 4-11: Micro PAVER Sample Distress Entry.

4.5 PCI Calculation Using Micro PAVER

Computing the PCI manually is not a tedious operation for a single sample unit, but the volume of data generated from a survey is generally quite large, and calculations involving these data are time consuming. Once distress information has been entered into Micro PAVER, the software automatically calculates the PCI of each sample unit surveyed and Determines an overall PCI for a section, as well as extrapolated distress quantities .The software can also determine the percentage of deduct values based on distress mechanism (i.e., load, climate, and other) for a section. The percentage of deduct values attributed to each distress mechanism is for determining the primary causes of Pavement deterioration. Figure 4-12 shows an example of an automated PCI calculation from the micro PAVER system. All sections PCI result can be found on the PCI report and presenting into appendix of this thesis.

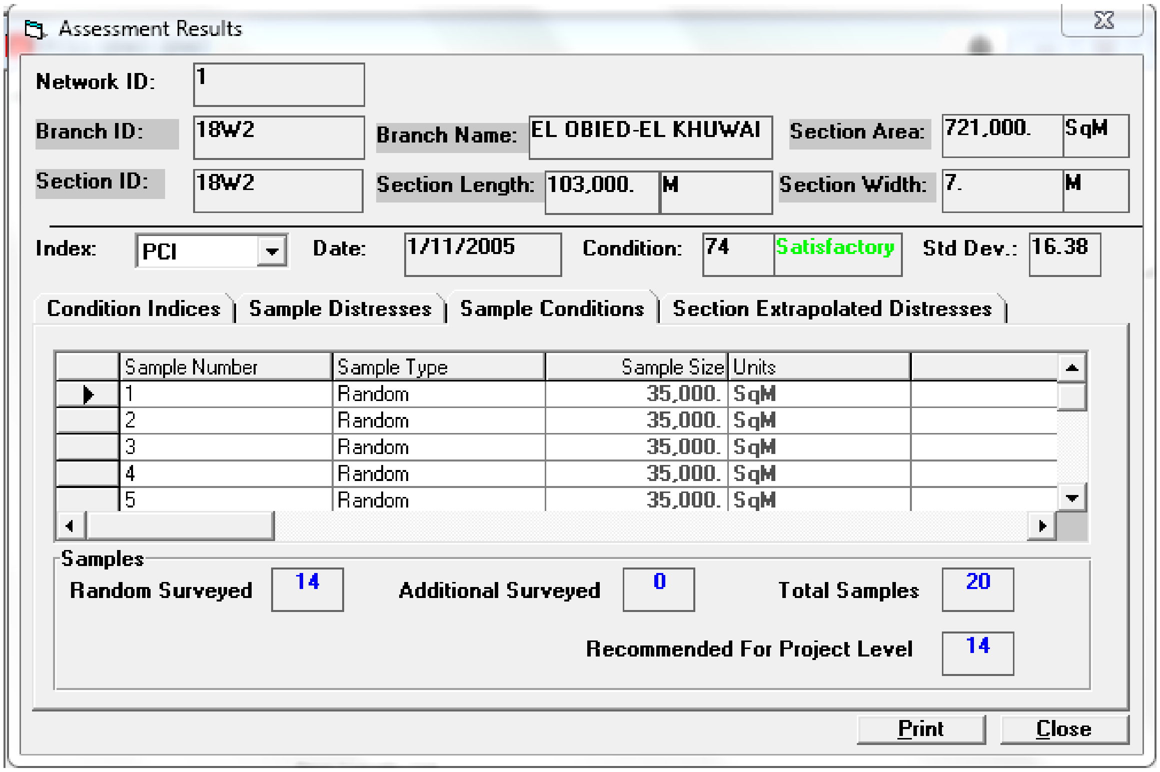


Figure 4.12: Example of Automated PCI Calculation from the MicroPAVER System

4.6 Assessment of Results

Once the resulting distress data were fed into Micro PAVER, the PCI values were calculated for each pavement section. Table 4-7 shows the PCI condition assessment criteria used to analyze the pavement network.

Table 4-7: Pavement Condition Assessment Criteria

Name	Low Value	High Value	GIS/Text Color	Graph Color
Failed	0	10	Grey	Dark Gray
Serious	11	25	Dark Red	Brown
Very Poor	26	40	Red	Red
Poor	41	55	Light Red	Light Red
Fair	56	70	Yellow	Yellow
Satisfactory	71	85	Green	Green
Good	86	100	Dark Green	Green

At the time of NHA 2005 inspections, the roadway pavements were found 18% of pavement area in l section "Good" condition with average PCI of 90, 33% of pavement area in 3 section in a "satisfactory" condition with Avg. PCI of 78, 31% of pavement area in 1section in a "fair "condition with Avg. PCI of 64, and 19% of pavement area in I section in" a poor "condition with an Avg. PCI of 54. The overall average PCI of networks is 76(satisfactory). The condition distribution of the pavements at the time of inspection vs. pavement area is shown in Figure 4.13.

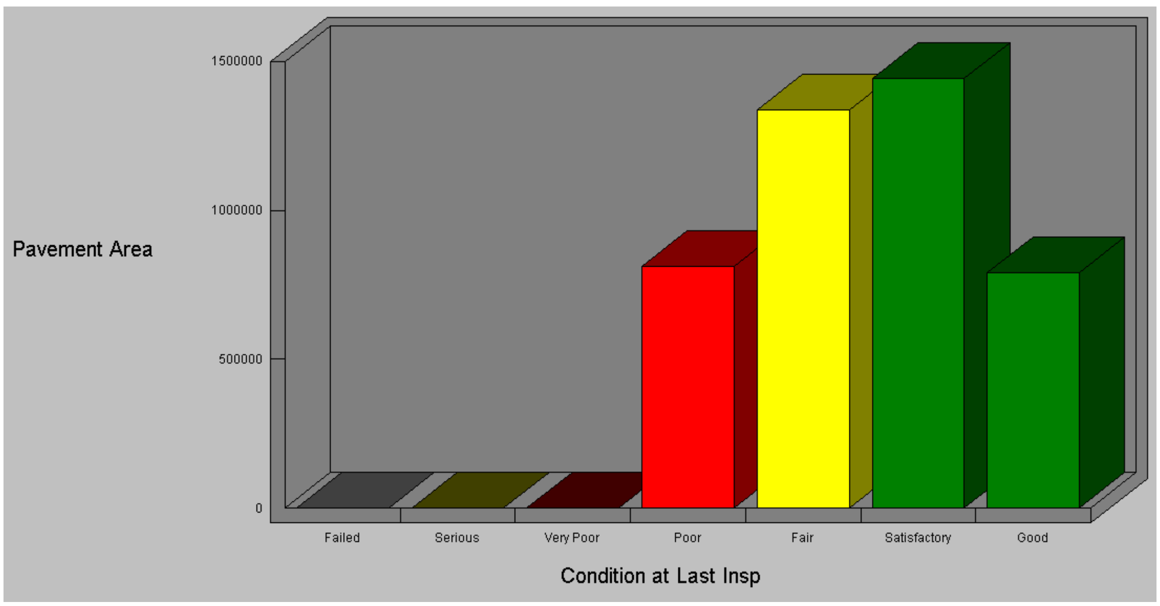


Figure 4-13: Overall Roadway Pavement Condition Distribution

Table 4-8 illustrates pavement condition by pavement surface type and sections distributions.

Table 4-8: Roadway Pavement Condition Distribution by Surface Type

Pavement Surface Type	Inspection Pavement Area (Sq.m)	Pavement Area (%)	Sections	2005 Average PCI
Asphalt Concrete (AC)	3591000	82	5	70
Double service treatment (ST)	791000	18	1	90

The causes of pavement deterioration may be divided into the following three general categories: (1) Load Related, (2) Climate/Durability Related, and (3) Other. The results assessed by Micro PAVER are shown in Figure (4.16) that most of the distress observed on the pavement were due to other reasons are 69 %, furthermore load related causes were 22 % and environmental effects 19% according to micro PAVER classification method. Table (4-9) and Figure (4-14) shows distress classification in case study.

Table 4-9: Percentage of Distress Causes Distribution

Network ID	Section Name	Section ID	Length km	Load Related %	Climate Related %	Other %
1	EL OBIED-EL KHUWAI	18W2	103	13	2	85
2	EO BIED - BARA	19S2	56	13	1	86
3	KAZGILE - EL DILLINJ	19S3/1	113	9	22	69
3	EL OBIED - KAZGILE	19S3/2	47	46	19	35
4	WDASHANA - KOSTI	18w1/1	116	19	7	74
4	EL OBIED- WDASHANA	18w1/2	191	31	5	64
Average percentage %				22	9	69

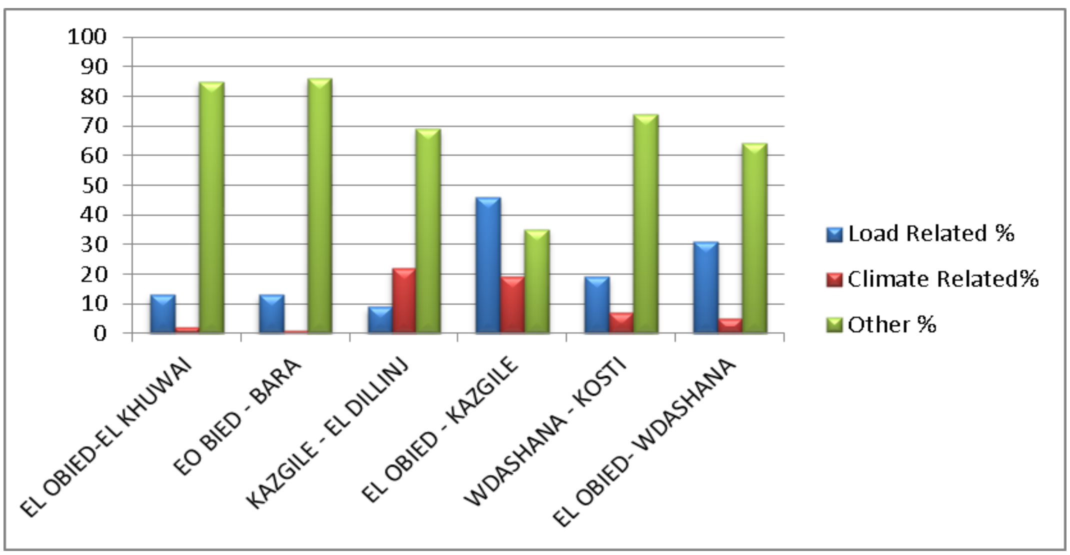


Figure 4-14: Pavement Distresses Causes Distribution in Sections

The distresses caused due to climate reason such as (joint reflection cracking and longitudinal, transverse cracking) representing about 22 %, KAZGILE-ELDILLINJ is the most common pavement deteriorated by this category, and distresses caused due to other reason such as (bleeding, batching, lane shoulder drop off and swell) representing about 69% of the distresses causes, ELOBIED-BARA is the most common section that deteriorated by such. And the remaining portion 9% of distresses caused is due to load related reasons such as (rutting and alligator cracking) ELOBIED-KAZGILE is the most common section that subjected to such.

Table (4-10) and Figure (4-15) show summary of the categorization of pavement distressed causes.

Table 4-10: Categorization of Observed Roadway Pavement Distresses causes

Distress Category	Example Distresses	Amount in Study
Load Related	AC distresses such as rutting and alligator cracking.	131
Climatic/Durability Related	AC distresses such as weathering, longitudinal and transverse cracking	56
Other	AC distresses such as bleeding, patching, and slippage cracking.	413

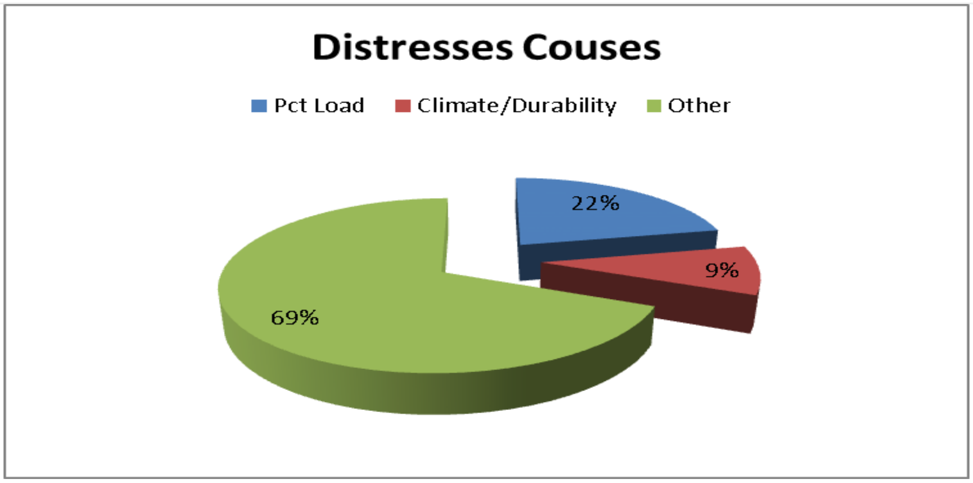


Figure 4-15: Percentage of Pavement Distresses Causes

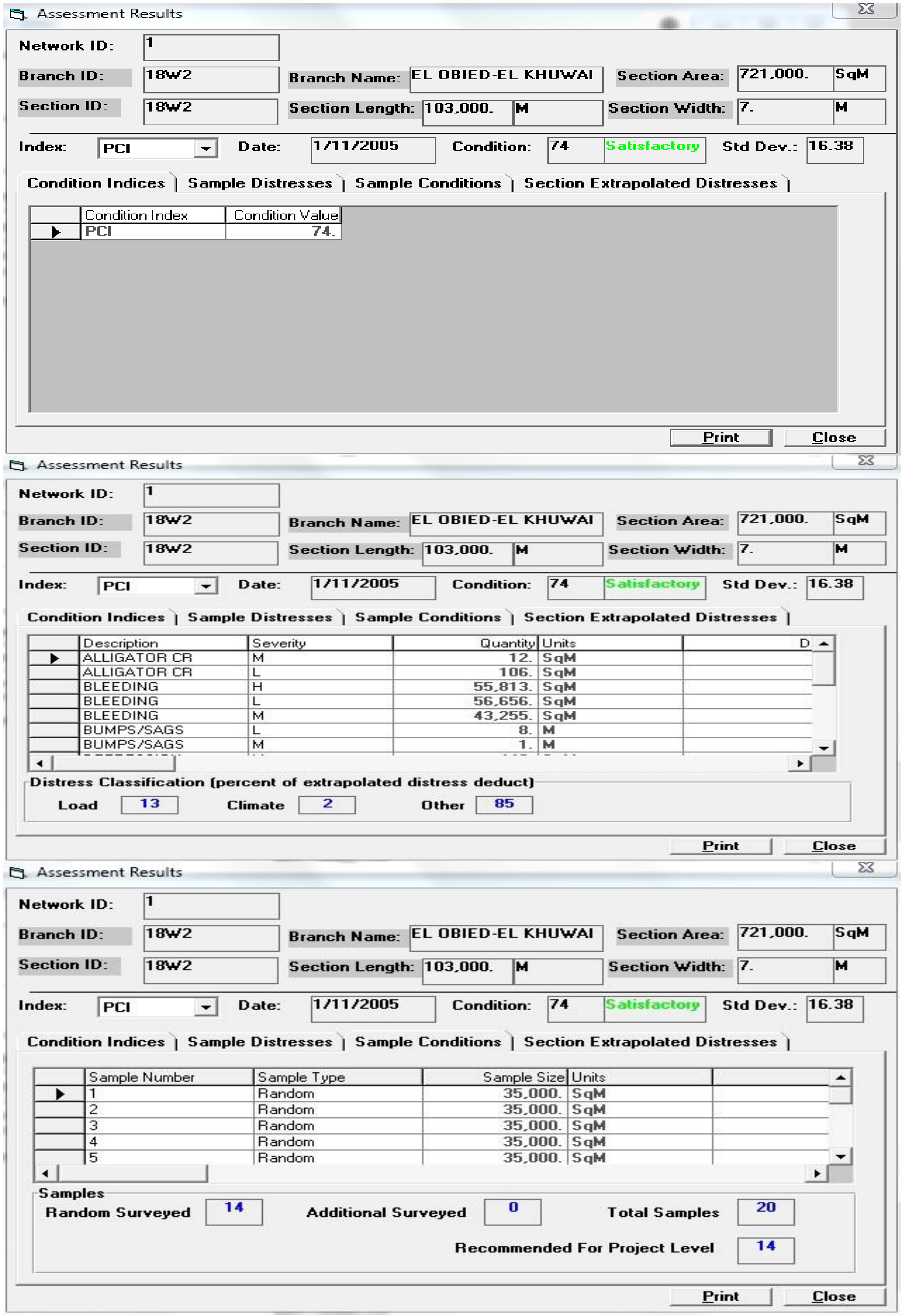


Figure 4-16: Application Assessment Result of ELOBIED-ELKHUWAI Network

Chapter five

Results and Discussions

5.1 Introduction

This chapter demonstrates and discusses the pavement condition results achieved by the Micro PAVER software, the discussion presented summary chart report and the PCI report, comparison of PCI result for road section, network condition analysis and prediction and sections condition analysis and prediction, the predicted condition of pavement for November 2014 and the Micro PAVER prediction models, and finally the summary models for the case study application are discussed in this chapter.

5.2 Summary Chart and PCI Report

Micro PAVER report condition includes summary chart report and the PCI report. The summary chart report contains selected pavement statistics presented in chart format. It showing pavement area, number of sections, average section PCI and area weighted PCI grouped by pavement age, pct. Area, Avg. condition and Age at Inspection. The comprehensives section information's are included in the PCI report in additions to age at last inspection and Pavement condition index.

Figures (5.1) to (5.3) presented the case studies application reports, condition at last inspection vs. Pavement condition section (Pct.), section average condition and number of sections in the network vs. network ID.

Also the reports are grouped of pavement and sort the data based on any variable in the report output. Table (5-1) & (5-2) shows condition networks and section condition reports.

Micro PAVER system frequency reports calculate expected condition of each section in the networks and list each section in the data base report. It shows one section total out of total 6 has pavement condition is good, three sections the pavement condition is satisfactory and one section in fair condition that needs some maintenance and rehabilitation and finally poor condition occurs in 1 section that pavement need reconstruction.

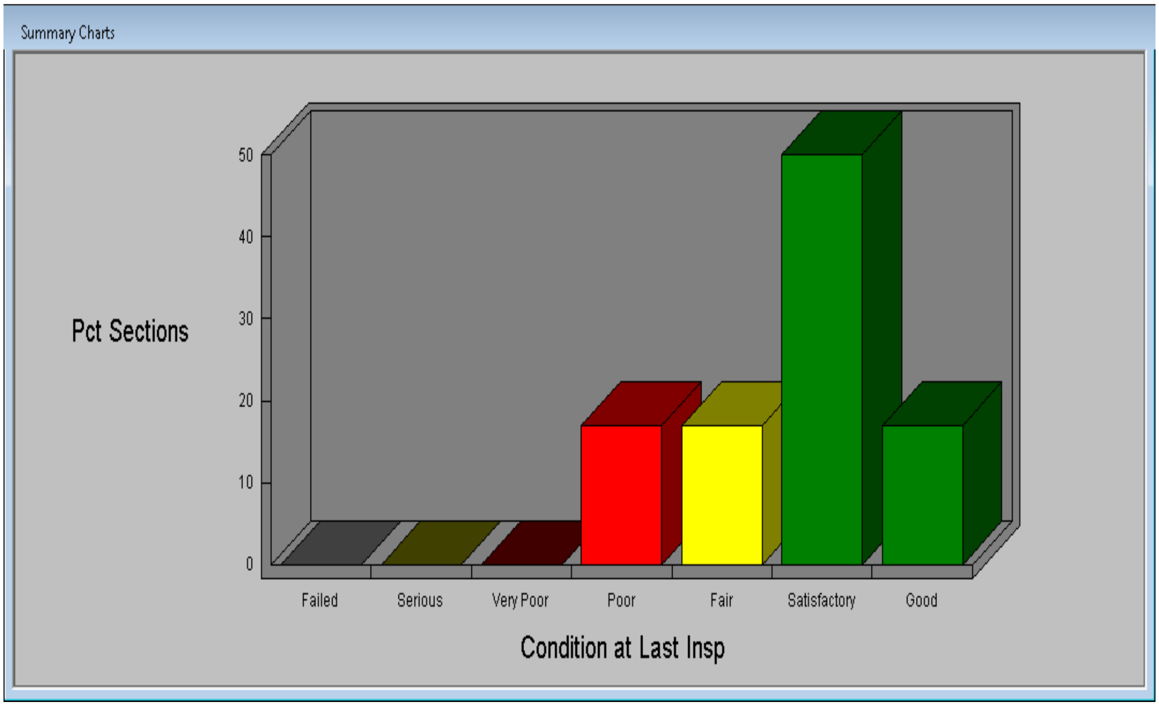


Figure 5-1: section condition at last inspection date

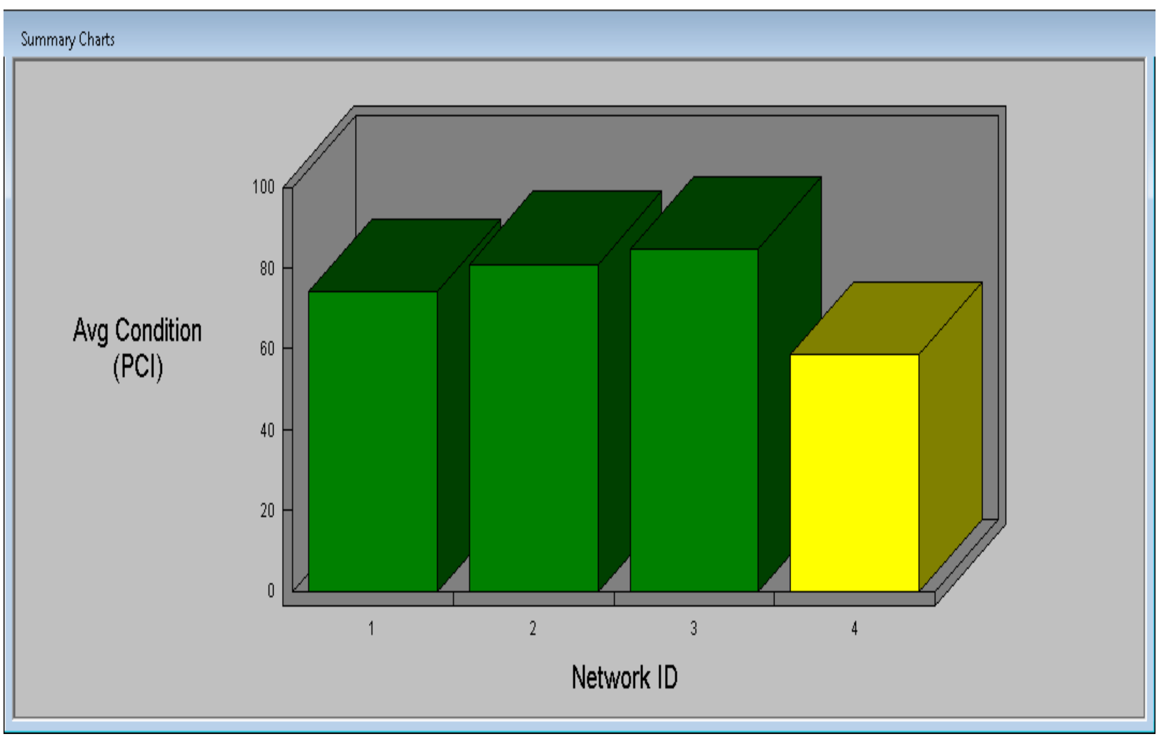


Figure 5-2: Average condition of network

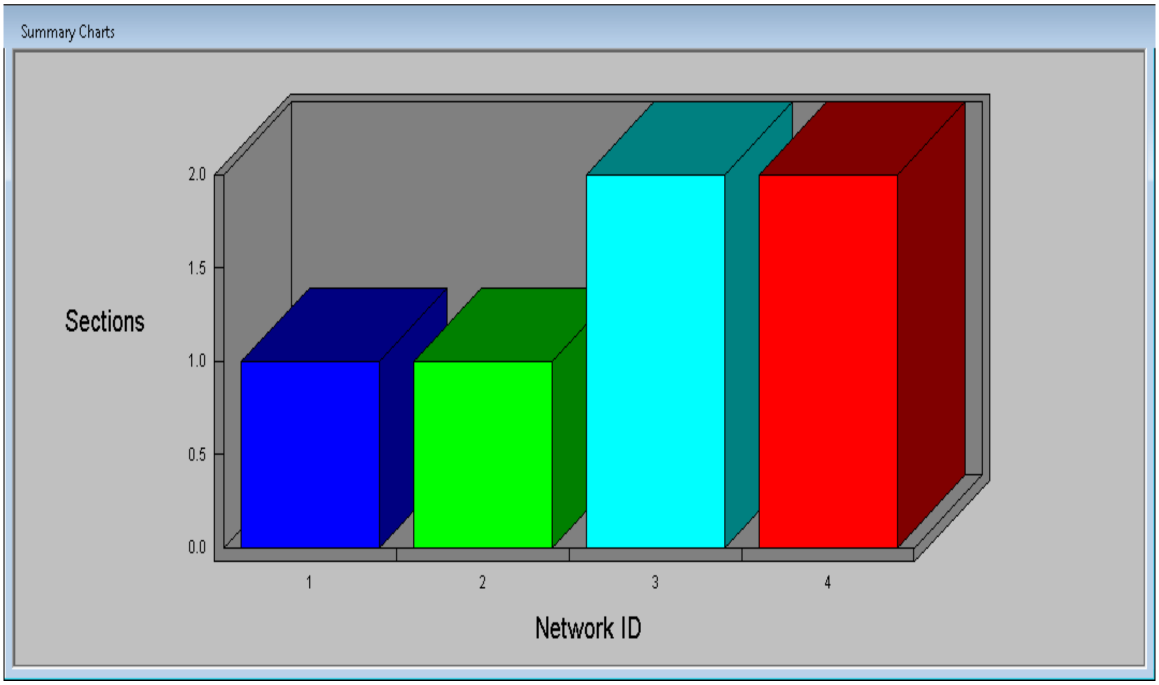


Figure 5-3: Average condition of network

Table 5-1: Section Reports for the case study application

Condition Category	Sections	Pavement Area	Unit	Pct. Area	Pct. Sections	Age at Report	Avg. Condition
Failed	0				0		
Serious	0				0		
Very Poor	0				0		
Poor	1	812,000.00	SqM	19	17	23	53
Fair	1	1,337,000.00	SqM	31	17	23	64
Satisfactory	3	1,442,000.00	SqM	33	50	10.33	78
Good	1	791,000.00	SqM	18	17	10	90

Table 5-2: Network Condition Reports for the case study area

Section Condition Report									
Date: 1/6/2014									
Pavement Management System									
Section Name	Section ID	Last Cons. date	Surface	Use	Rank	True Area	Last Insp. Date	Age at Insp.	PCI
EL OBIED-EL KHUWAI	18W2	01/01/2004	AC	ROADWAY	A	721,000.00	01/11/2005	1	74
EO BIED - BARA	19S2	01/01/2003	AC	ROADWAY	A	392,000.00	01/11/2005	2	81
KAZGILE - EL DILLINJ	19S3/2	01/10/2004	ST	ROADWAY	B	791,000.00	01/11/2005	1	90
EL OBIED - KAZGILE	19S3/1	01/11/2004	ST	ROADWAY	B	329,000.00	01/11/2005	1	79
WDASHANA - KOSTI	18w1/2	01/01/1991	AC	ROADWAY	A	812,000.00	01/11/2005	14	53
EL OBIED- WDASHANA	18W1/1	01/01/1991	AC	ROADWAY	A	1,337,000.00	01/11/2005	14	64

5.3 Compression of PCI Result for Road Section

Compression of Pavement Condition Index of surface distress surveyed by the National Highway Authority, with that determinate by Micro PAVER software is listed in Table (5-3) and Figure (5-4). It shows no big difference between the two results calculated.

Table 5-3: Compression of PCI Result between Micro PAVER and NHA Calculation

Section Name	Section ID	Length km	NHA Result Mean PCI	Rating	Micro-PAVER Result	Rating
EL OBIED-EL KHUWAI	18W2	103	72	V.GOOD	74	Satisfactory
EO BIED - BARA	19S2	56	93	EXCELENT	81	Satisfactory
KAZGILE - EL DILLINJ	19S3/1	113	90	EXCELENT	90	GOOD
EL OBIED - KAZGILE	19S3/2	47	83	V.GOOD	79	Satisfactory
WDASHANA - KOSTI	18w1/1	116	46	FAIR	53	Poor
EL OBIED-WDASHANA	18w1/2	191	66	GOOD	64	Fair

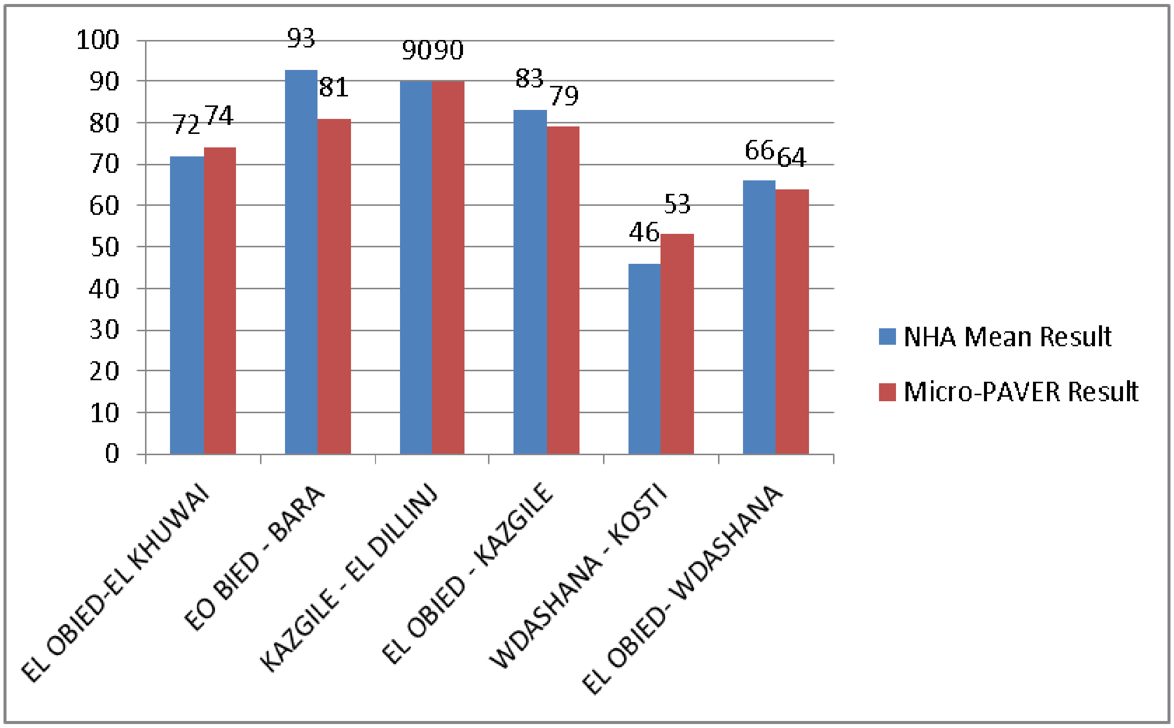


Figure 5-4: Compression of PCI Result in Our Case Study Application

5.4 Network Condition Analysis and Prediction

The main purpose of pavement condition analysis is to determine changes in pavement condition .Primarily, how is the pavement condition now compared to the condition x years in the past and what would it be y years in the future if no preventive or major M&R is performed? Past pavement condition (prior to last inspection date) is deter-mined by interpolation using last construction date (last major M&R date) [18].

The Micro PAVER frequency report and calculate expected condition of each pavement sections. In the case study the data input in the data inspection survey. The condition analysis view network branch and section condition performance. Figure (5-5) and Table (5-4) shows the condition network analysis for 15 years.

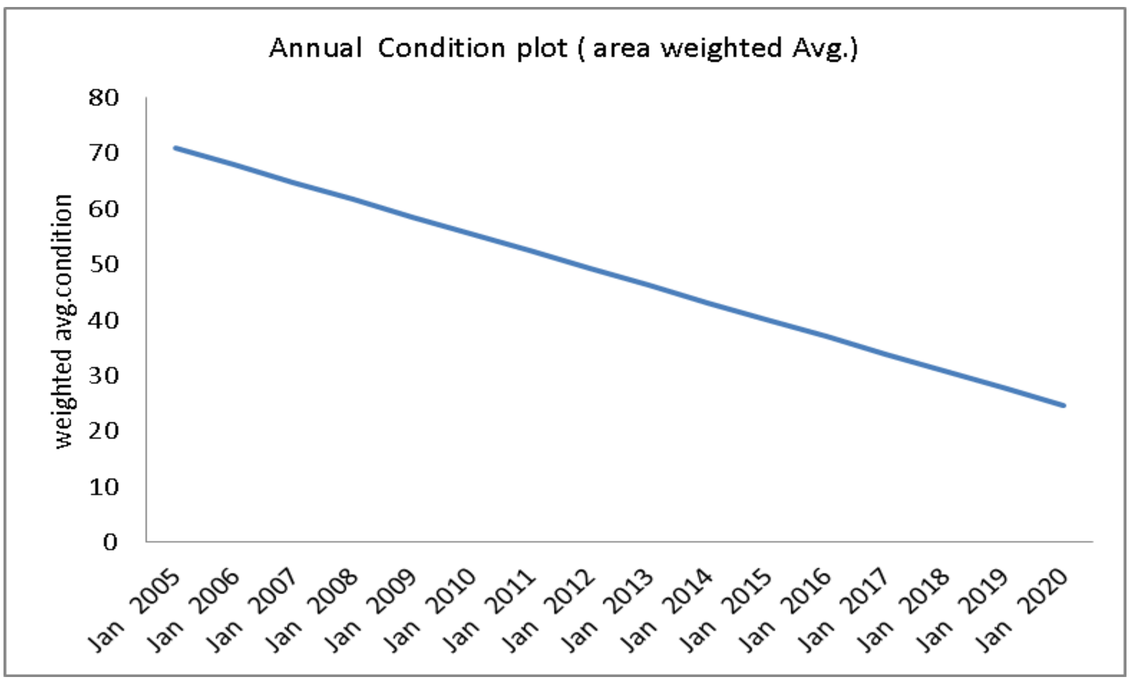


Figure 4-18: Over All Network Condition Analysis for 15 Years

Table 5-4: Annual Condition Analysis for 15 Year for the case study application

Network ID	Branch ID	Jan 2005	Jan 2006	Jan 2007	Jan 2008	Jan 2009	Jan 2010	Jan 2011	Jan 2012	Jan 2013	Jan 2014	Jan 2015	Jan 2016	Jan 2017	Jan 2018	Jan 2019	Jan 2020
<all networks>	< all >	70.95	67.87	64.78	61.7	58.61	55.53	52.45	49.36	46.27	43.19	40.11	37.03	33.94	30.85	27.77	24.69
1	< all >	74	70.92	67.84	64.75	61.66	58.58	55.5	52.42	49.33	46.24	43.16	40.08	36.99	33.91	30.82	27.74
2	< all >	81	77.92	74.84	71.75	68.66	65.58	62.5	59.42	56.33	53.24	50.16	47.08	43.99	40.91	37.82	34.74
3	< all >	86.77	83.69	80.6	77.52	74.43	71.35	68.27	65.19	62.09	59.01	55.93	52.85	49.76	46.68	43.59	40.51
4	< all >	59.84	56.76	53.68	50.6	47.51	44.42	41.34	38.26	35.17	32.09	29.01	25.92	22.83	19.75	16.67	13.59
1	18W2	74	70.92	67.84	64.75	61.66	58.58	55.5	52.42	49.33	46.24	43.16	40.08	36.99	33.91	30.82	27.74
2	19S2	81	77.92	74.84	71.75	68.66	65.58	62.5	59.42	56.33	53.24	50.16	47.08	43.99	40.91	37.82	34.74
3	19S3	86.77	83.69	80.6	77.52	74.43	71.35	68.27	65.19	62.09	59.01	55.93	52.85	49.76	46.68	43.59	40.51
4	18W1	59.84	56.76	53.68	50.6	47.51	44.42	41.34	38.26	35.17	32.09	29.01	25.92	22.83	19.75	16.67	13.59

Table (5-5) shows condition frequency by the percent of area for 15 years analysis and Figure (5-6) shows distribution of condition by the percent of area, for all network used in case study.

Table (5-5): The Condition Frequency (percentage area)

Date	% Failed	% Serious	% Very Poor	% Poor	% Fair	%Satisfactory	%Good
01/11/2005	0	0	0	19	31	33	18
01/11/2006	0	0	0	19	31	33	18
01/11/2007	0	0	0	19	47	35	0
01/11/2008	0	0	0	49	24	27	0
01/11/2009	0	0	0	49	33	18	0
01/11/2010	0	0	19	31	33	18	0
01/11/2011	0	0	19	47	16	18	0
01/11/2012	0	0	19	47	35	0	0
01/11/2013	0	0	49	24	27	0	0
01/11/2014	0	19	31	33	18	0	0
01/11/2015	0	19	31	33	18	0	0
01/11/2016	0	19	47	16	18	0	0
01/11/2017	0	19	47	35	0	0	0
01/11/2018	0	49	24	27	0	0	0
01/11/2019	19	31	33	18	0	0	0
01/11/2020	19	31	33	18	0	0	0

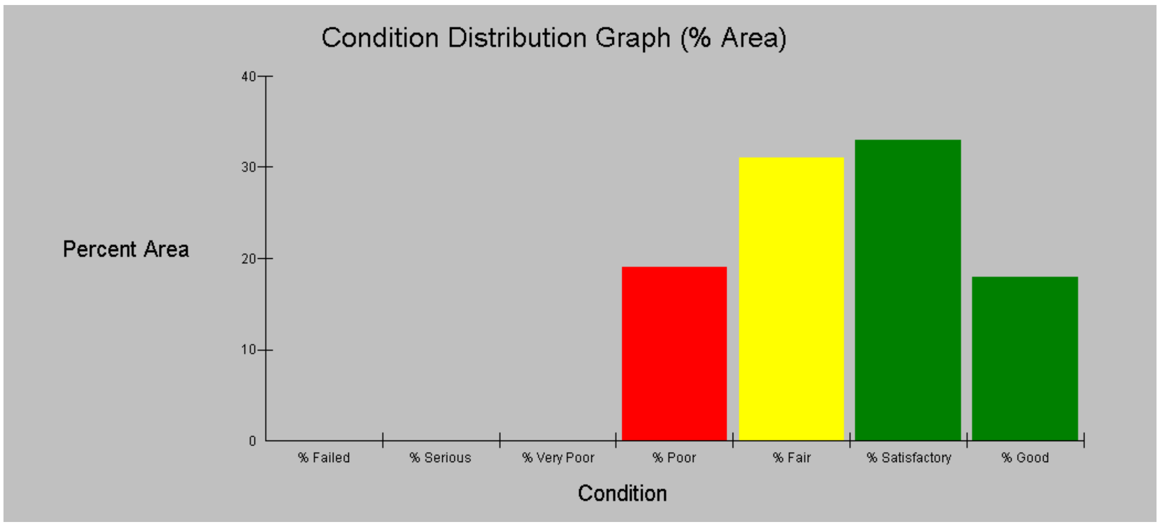


Figure 5-6: Distribution of Condition vs. Percent Area

5-5 Sections Condition Analysis and Prediction

The simplest condition prediction is based on a straight-line extrapolation of the last two condition points. This method is applicable only for individual pavement sections and does not lead to the development of a model that can be used with other pavement sections. The method assumes that traffic loadings and previous maintenance levels will continue as in the past.

The flowing Figures from Figure (5-7) to Figure (5-12) represent the prediction curves of the pavement condition analysis for 15 years, for all sections that used in case study application. The x-axis stand for the year of analysis, and y-axis stand for the average condition of section. Theses prediction condition carve are decreasing together with year, as shown in the flowing Figures.

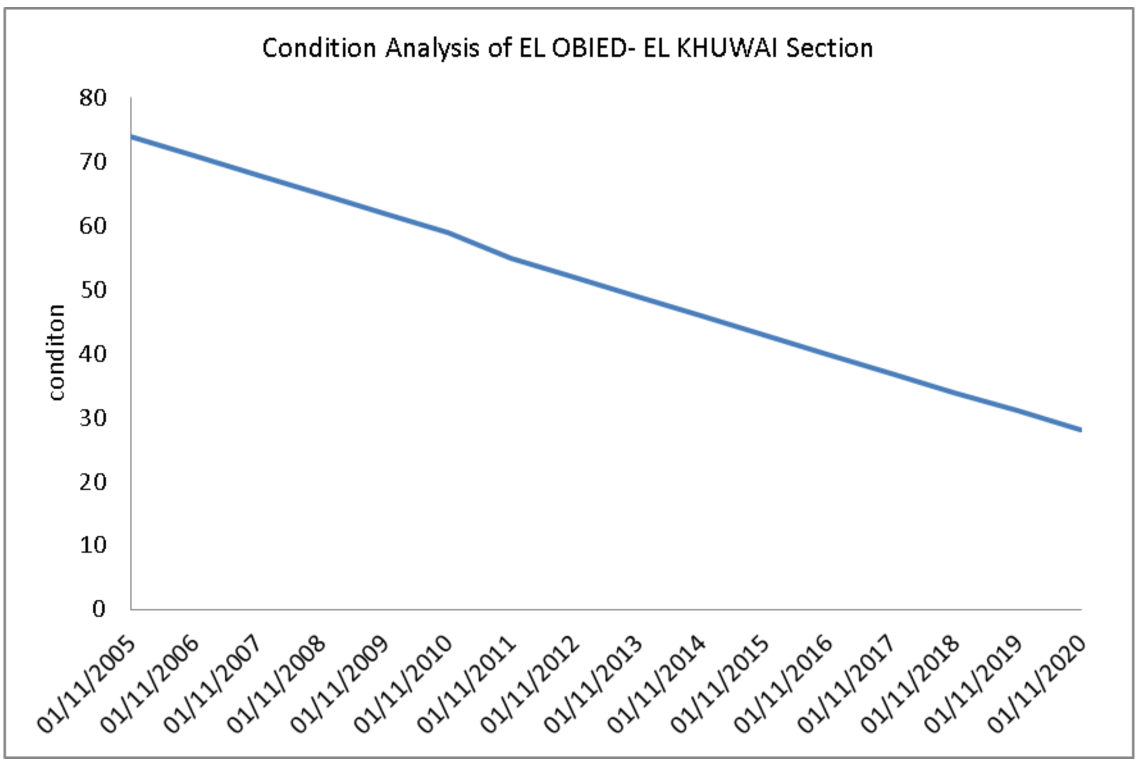


Figure 5-7: PredictionCondition Curve of EL OBIED- ELKHUWAI Section

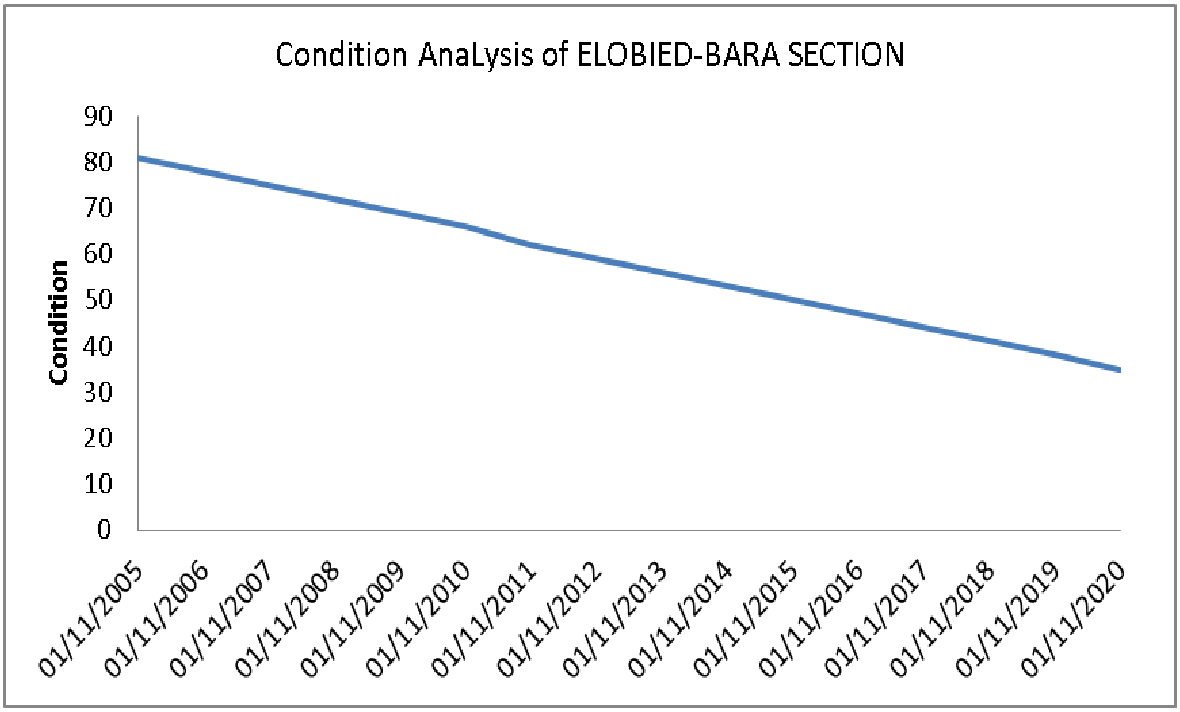


Figure 5-8: Prediction Condition Curve of EL OBIED- BARA Section

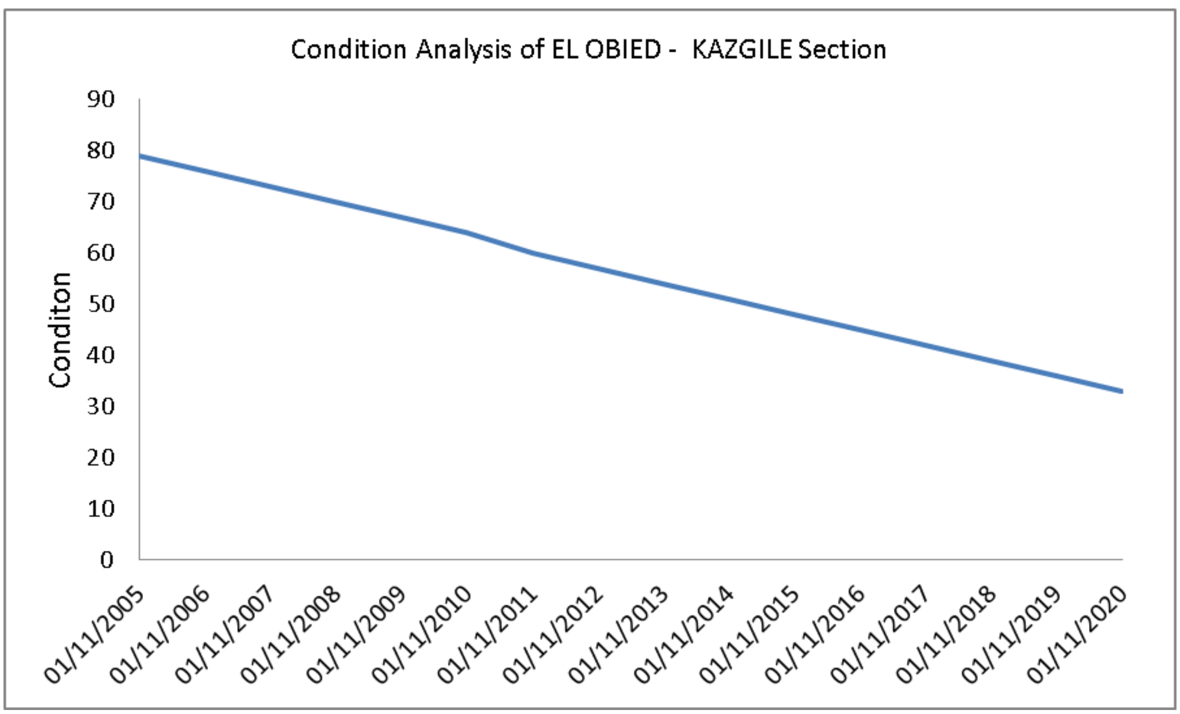


Figure 5-10: Prediction Condition Curve of EL OBIED- KAZGILE Section

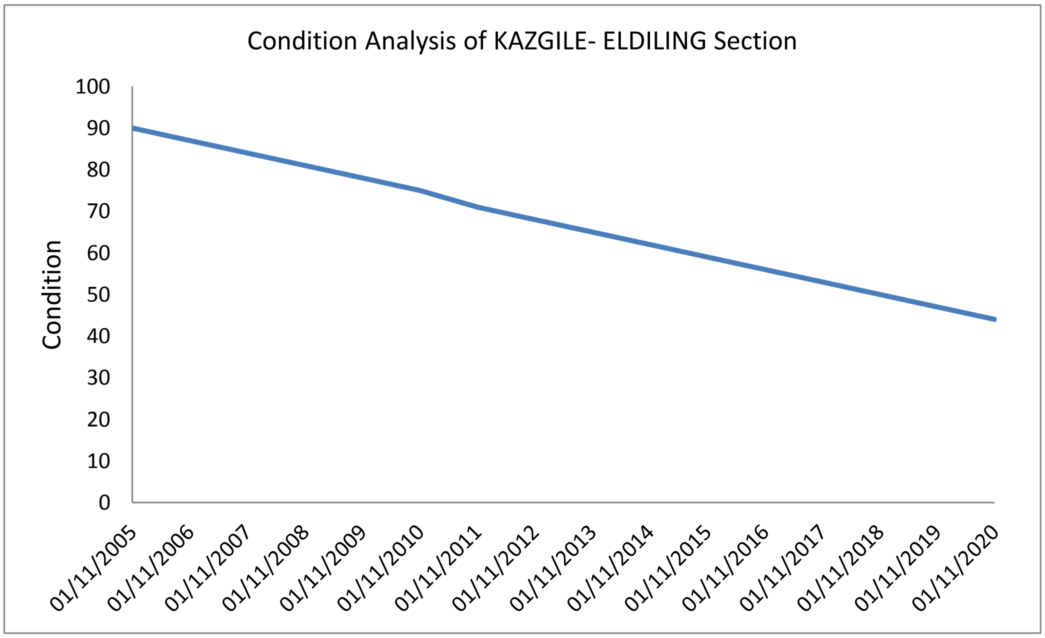


Figure 5-9: Prediction Condition Curve of KAZGILE- ELDILLING Section

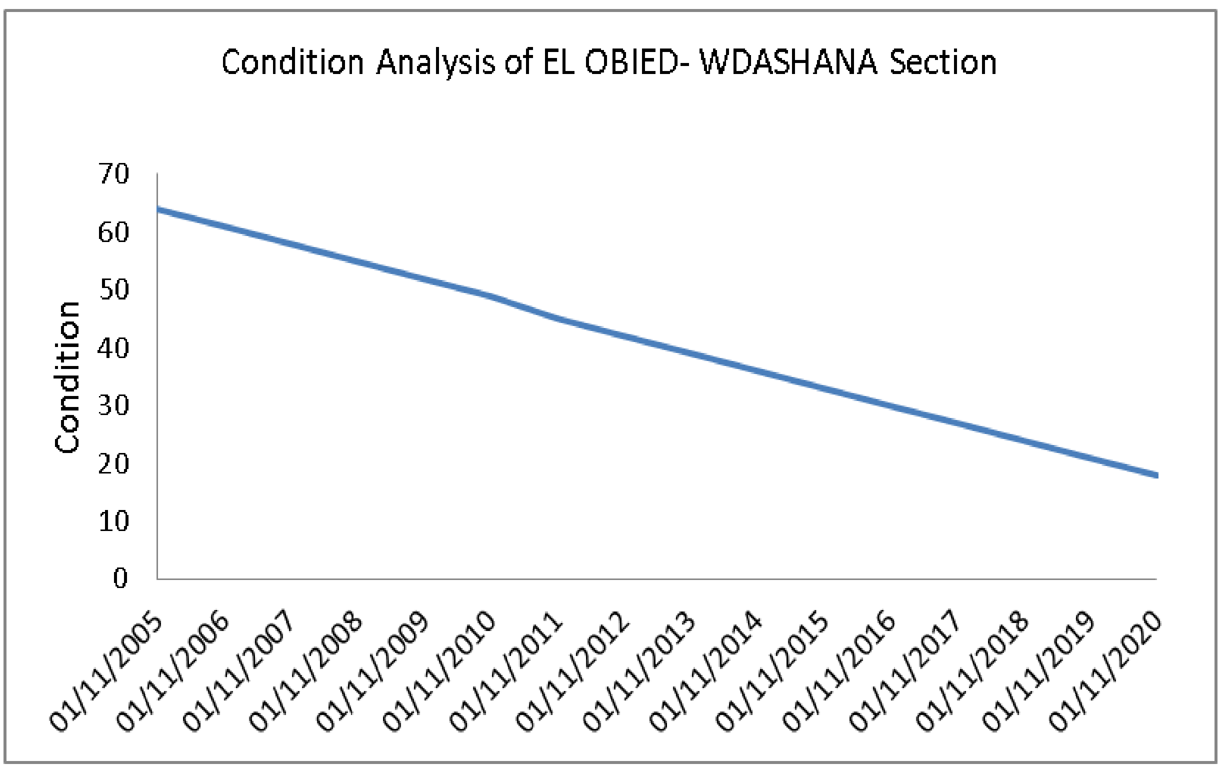


Figure 5-12: Prediction Condition Curve of EL OBIED- WDASHANA Section

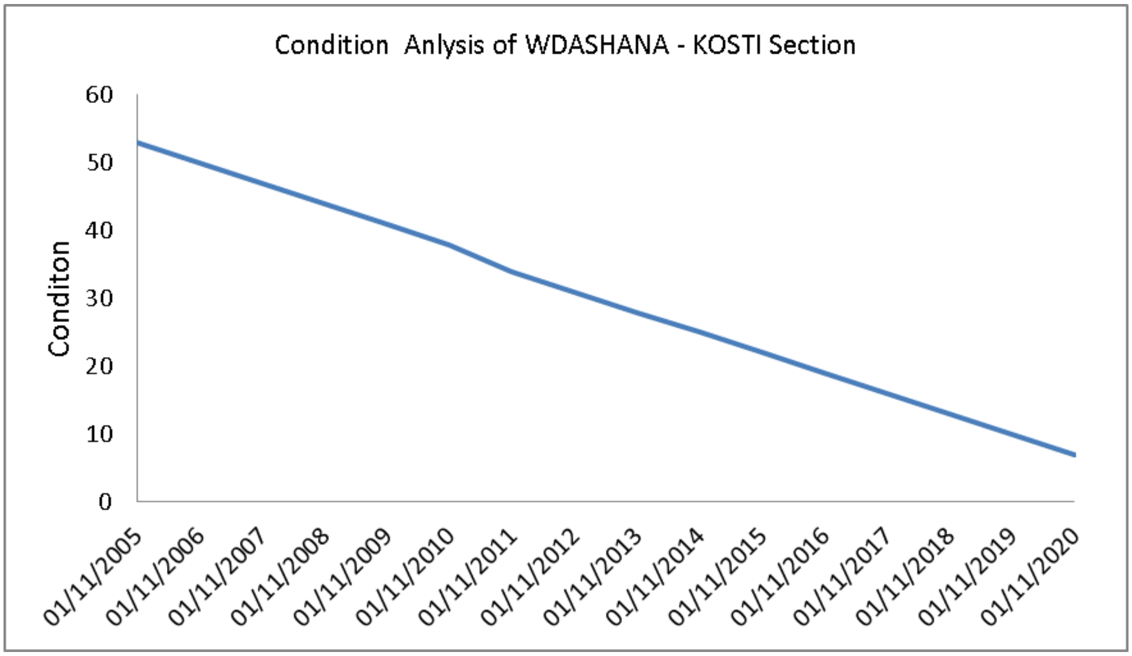


Figure 5-11: Prediction Condition Curve of EL WDASHANA - KOSTI Section

The flowing Tables from Table (5-6) to Table (5-11) presenting the result of pavement condition analysis for 15 years, for all sections that used in the case study application. These years start from the time of inspection (1/112005), which is determine the current condition of the pavement and calculate the average PCI of the section, through the analysis years the condition of pavement section for every year can be predicting, as shown in the flowing Tables.

Table 5-6: Condition Analysis of EL OBIED-EL KHUWAI Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
1	18W2	18W2	01/11/2005	Inspection	74	1	Satisfactory	721,000.00
1	18W2	18W2	01/11/2005	Inspection	74	1	Satisfactory	721,000.00
1	18W2	18W2	01/11/2006	Prediction	71	2	Satisfactory	721,000.00
1	18W2	18W2	01/11/2007	Prediction	68	3	Fair	721,000.00
1	18W2	18W2	01/11/2008	Prediction	65	4	Fair	721,000.00
1	18W2	18W2	01/11/2009	Prediction	62	5	Fair	721,000.00
1	18W2	18W2	01/11/2010	Prediction	59	6	Fair	721,000.00
1	18W2	18W2	01/11/2011	Prediction	55	7	Poor	721,000.00
1	18W2	18W2	01/11/2012	Prediction	52	8	Poor	721,000.00
1	18W2	18W2	01/11/2013	Prediction	49	9	Poor	721,000.00
1	18W2	18W2	01/11/2014	Prediction	46	10	Poor	721,000.00
1	18W2	18W2	01/11/2015	Prediction	43	11	Poor	721,000.00
1	18W2	18W2	01/11/2016	Prediction	40	12	Very Poor	721,000.00
1	18W2	18W2	01/11/2017	Prediction	37	13	Very Poor	721,000.00
1	18W2	18W2	01/11/2018	Prediction	34	14	Very Poor	721,000.00
1	18W2	18W2	01/11/2019	Prediction	31	15	Very Poor	721,000.00
1	18W2	18W2	01/11/2020	Prediction	28	16	Very Poor	721,000.00

Table 5-7: Condition Analysis of EO BIED - BARA Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
2	19S2	19S2	01/11/2005	Inspection	81	2	Satisfactory	392,000.00
2	19S2	19S2	01/11/2005	Inspection	81	2	Satisfactory	392,000.00
2	19S2	19S2	01/11/2006	Prediction	78	3	Satisfactory	392,000.00
2	19S2	19S2	01/11/2007	Prediction	75	4	Satisfactory	392,000.00
2	19S2	19S2	01/11/2008	Prediction	72	5	Satisfactory	392,000.00
2	19S2	19S2	01/11/2009	Prediction	69	6	Fair	392,000.00
2	19S2	19S2	01/11/2010	Prediction	66	7	Fair	392,000.00
2	19S2	19S2	01/11/2011	Prediction	62	8	Fair	392,000.00
2	19S2	19S2	01/11/2012	Prediction	59	9	Fair	392,000.00
2	19S2	19S2	01/11/2013	Prediction	56	10	Fair	392,000.00
2	19S2	19S2	01/11/2014	Prediction	53	11	Poor	392,000.00
2	19S2	19S2	01/11/2015	Prediction	50	12	Poor	392,000.00
2	19S2	19S2	01/11/2016	Prediction	47	13	Poor	392,000.00
2	19S2	19S2	01/11/2017	Prediction	44	14	Poor	392,000.00
2	19S2	19S2	01/11/2018	Prediction	41	15	Poor	392,000.00
2	19S2	19S2	01/11/2019	Prediction	38	16	Very Poor	392,000.00
2	19S2	19S2	01/11/2020	Prediction	35	17	Very Poor	392,000.00

Table 5-8: Condition Analysis of KAZGILE- ELDILLING Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
3	19S3	19S3/2	01/01/2005	Interpolation	90	1	Good	791,000.00
3	19S3	19S3/2	01/11/2005	Inspection	90	1	Good	791,000.00
3	19S3	19S3/2	01/01/2006	Prediction	87	2	Good	791,000.00
3	19S3	19S3/2	01/01/2007	Prediction	84	3	Satisfactory	791,000.00
3	19S3	19S3/2	01/01/2008	Prediction	81	4	Satisfactory	791,000.00
3	19S3	19S3/2	01/01/2009	Prediction	78	5	Satisfactory	791,000.00
3	19S3	19S3/2	01/01/2010	Prediction	75	6	Satisfactory	791,000.00
3	19S3	19S3/2	01/01/2011	Prediction	72	7	Satisfactory	791,000.00
3	19S3	19S3/2	01/01/2012	Prediction	68	8	Fair	791,000.00
3	19S3	19S3/2	01/01/2013	Prediction	65	9	Fair	791,000.00
3	19S3	19S3/2	01/01/2014	Prediction	62	10	Fair	791,000.00
3	19S3	19S3/2	01/01/2015	Prediction	59	11	Fair	791,000.00
3	19S3	19S3/2	01/01/2016	Prediction	56	12	Fair	791,000.00
3	19S3	19S3/2	01/01/2017	Prediction	53	13	Poor	791,000.00
3	19S3	19S3/2	01/01/2018	Prediction	50	14	Poor	791,000.00
3	19S3	19S3/2	01/01/2019	Prediction	47	15	Poor	791,000.00
3	19S3	19S3/2	01/01/2020	Prediction	44	16	Poor	791,000.00

Table 5-9: Condition Analysis of EL OBIED-KAZGILE Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
3	19S3	19S3/1	01/11/2005	Inspection	79	1	Satisfactory	329,000.00
3	19S3	19S3/1	01/11/2005	Inspection	79	1	Satisfactory	329,000.00
3	19S3	19S3/1	01/11/2006	Prediction	76	2	Satisfactory	329,000.00
3	19S3	19S3/1	01/11/2007	Prediction	73	3	Satisfactory	329,000.00
3	19S3	19S3/1	01/11/2008	Prediction	70	4	Fair	329,000.00
3	19S3	19S3/1	01/11/2009	Prediction	67	5	Fair	329,000.00
3	19S3	19S3/1	01/11/2010	Prediction	64	6	Fair	329,000.00
3	19S3	19S3/1	01/11/2011	Prediction	60	7	Fair	329,000.00
3	19S3	19S3/1	01/11/2012	Prediction	57	8	Fair	329,000.00
3	19S3	19S3/1	01/11/2013	Prediction	54	9	Poor	329,000.00
3	19S3	19S3/1	01/11/2014	Prediction	51	10	Poor	329,000.00
3	19S3	19S3/1	01/11/2015	Prediction	48	11	Poor	329,000.00
3	19S3	19S3/1	01/11/2016	Prediction	45	12	Poor	329,000.00
3	19S3	19S3/1	01/11/2017	Prediction	42	13	Poor	329,000.00
3	19S3	19S3/1	01/11/2018	Prediction	39	14	Very Poor	329,000.00
3	19S3	19S3/1	01/11/2019	Prediction	36	15	Very Poor	329,000.00
3	19S3	19S3/1	01/11/2020	Prediction	33	16	Very Poor	329,000.00

Table 5-10: Condition Analysis of WDASHANA - KOSTI Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
4	18W1	18w1/2	01/11/2005	Inspection	53	14	Poor	812,000.00
4	18W1	18w1/2	01/11/2005	Inspection	53	14	Poor	812,000.00
4	18W1	18w1/2	01/11/2006	Prediction	50	15	Poor	812,000.00
4	18W1	18w1/2	01/11/2007	Prediction	47	16	Poor	812,000.00
4	18W1	18w1/2	01/11/2008	Prediction	44	17	Poor	812,000.00
4	18W1	18w1/2	01/11/2009	Prediction	41	18	Poor	812,000.00
4	18W1	18w1/2	01/11/2010	Prediction	38	19	Very Poor	812,000.00
4	18W1	18w1/2	01/11/2011	Prediction	34	20	Very Poor	812,000.00
4	18W1	18w1/2	01/11/2012	Prediction	31	21	Very Poor	812,000.00
4	18W1	18w1/2	01/11/2013	Prediction	28	22	Very Poor	812,000.00
4	18W1	18w1/2	01/11/2014	Prediction	25	23	Serious	812,000.00
4	18W1	18w1/2	01/11/2015	Prediction	22	24	Serious	812,000.00
4	18W1	18w1/2	01/11/2016	Prediction	19	25	Serious	812,000.00
4	18W1	18w1/2	01/11/2017	Prediction	16	26	Serious	812,000.00
4	18W1	18w1/2	01/11/2018	Prediction	13	27	Serious	812,000.00
4	18W1	18w1/2	01/11/2019	Prediction	10	28	Failed	812,000.00
4	18W1	18w1/2	01/11/2020	Prediction	7	29	Failed	812,000.00

Table 5-11: Condition Analysis of EL OBIED- WDASHANA Section

Network ID	Branch ID	Section ID	Activity Date	Activity	Condition	Age	Condition Category	Area
4	18W1	18W1/1	01/11/2005	Inspection	64	14	Fair	1,337,000.00
4	18W1	18W1/1	01/11/2005	Inspection	64	14	Fair	1,337,000.00
4	18W1	18W1/1	01/11/2006	Prediction	61	15	Fair	1,337,000.00
4	18W1	18W1/1	01/11/2007	Prediction	58	16	Fair	1,337,000.00
4	18W1	18W1/1	01/11/2008	Prediction	55	17	Poor	1,337,000.00
4	18W1	18W1/1	01/11/2009	Prediction	52	18	Poor	1,337,000.00
4	18W1	18W1/1	01/11/2010	Prediction	49	19	Poor	1,337,000.00
4	18W1	18W1/1	01/11/2011	Prediction	45	20	Poor	1,337,000.00
4	18W1	18W1/1	01/11/2012	Prediction	42	21	Poor	1,337,000.00
4	18W1	18W1/1	01/11/2013	Prediction	39	22	Very Poor	1,337,000.00
4	18W1	18W1/1	01/11/2014	Prediction	36	23	Very Poor	1,337,000.00
4	18W1	18W1/1	01/11/2015	Prediction	33	24	Very Poor	1,337,000.00
4	18W1	18W1/1	01/11/2016	Prediction	30	25	Very Poor	1,337,000.00
4	18W1	18W1/1	01/11/2017	Prediction	27	26	Very Poor	1,337,000.00
4	18W1	18W1/1	01/11/2018	Prediction	24	27	Serious	1,337,000.00
4	18W1	18W1/1	01/11/2019	Prediction	21	28	Serious	1,337,000.00
4	18W1	18W1/1	01/11/2020	Prediction	18	29	Serious	1,337,000.00

5.6 The 2014 Predicted Condition of Pavement

Figure (5-13) show the distribution of network condition by percentage area predict to November 2014.The summary of predicted condition of the Pavement sections to November 2014 are shown in Table (5-12).

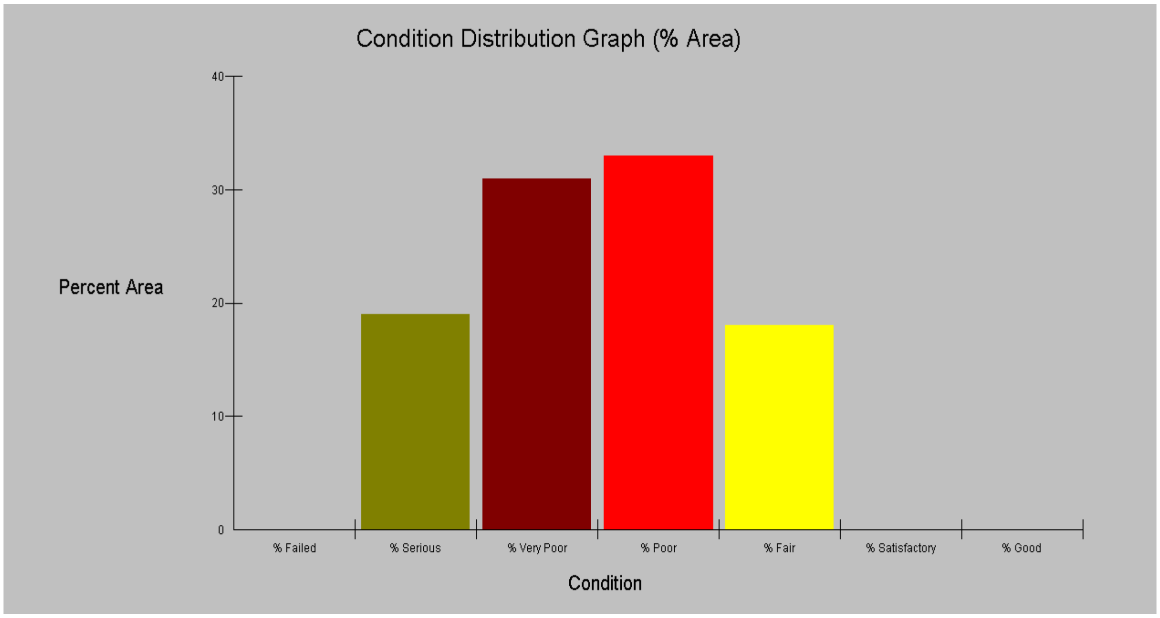


Figure 5-13: distribution of current condition by the percentage area

Table 5-12: The Section Prediction Condition in November 2014.

Section Name	Section ID	Last Cons. date	Predicted PCI	Age	Condition category
ALL NETWORK	ALL	01/01/2004	43.19	10	poor
EL OBIED-EL KHUWAI	18W2	01/01/2004	46	10	Poor
EO BIED - BARA	19S2	01/01/2003	53	11	Poor
KAZGILE - EL DILLINJ	19S3/2	01/10/2004	51	10	Poor
EL OBIED - KAZGILE	19S3/1	01/11/2004	51	10	Poor
WDASHANA - KOSTI	18w1/2	01/01/1991	25	23	Serious
EL OBIED-WDASHANA	18W1/1	01/01/1991	36	23	Very Poor

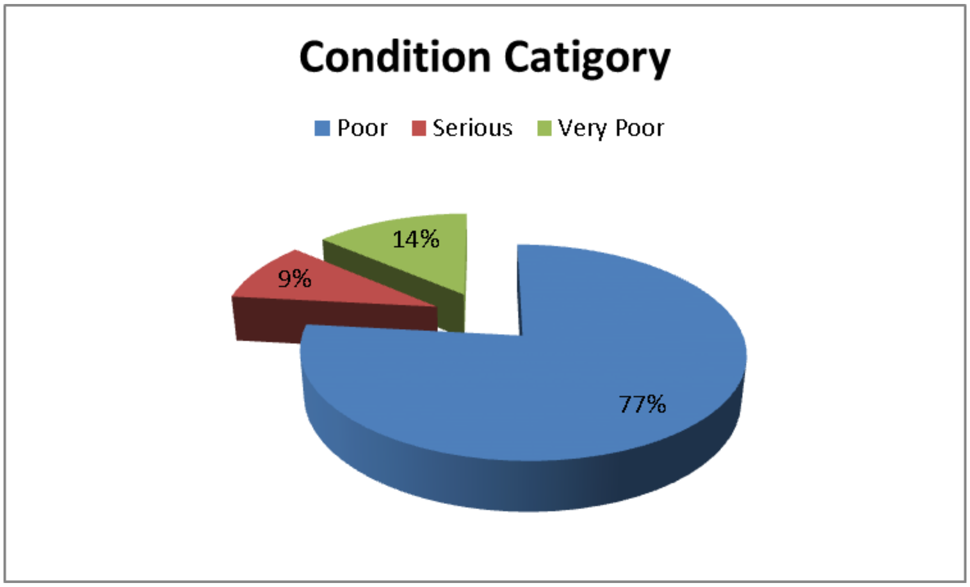


Figure 5-14: Prediction Category of Network.

As shown in Figure 5-14, the prediction condition for November 2014 show about 77% from the pavement area are lies in poor condition, 14% is in very poor condition and 9% is in serious condition.

5.7 Prediction Model

5.7.1 Building Family Models

The essence of the prediction modeling (family modeling) process is to identify and group pavements of similar construction that are subjected to similar traffic patterns, weather, and other factors that affect pavement life. The historical data on pavement condition can be used to build a model that can accurately predict the future performance of a group of pavements that possess similar attributes. This model of pavement life is assigned a name, and in the PAVER vocabulary it is referred to as a "family".

Each pavement section in PAVER is assigned a family. When predictions about the future performance of a pavement are desired, a section's family assignment is used to predict a section's future condition. If the user has not assigned a family model to a section, PAVER will use its default family to predict future pavement performance.

However, factors such as original construction, maintenance, weather, and traffic, greatly affect the life of a pavement and a generic guess, one of which is the default family, is not likely to be as accurate as a model that takes these factors into consideration. The Prediction Model is designed to allow users to blend unique knowledge about their pavements, measured local condition information, and powerful modeling tools together to produce highly accurate estimates of future pavement life. Figure (5-15) show the main view of prediction model screen used in Micro PAVER system [22].

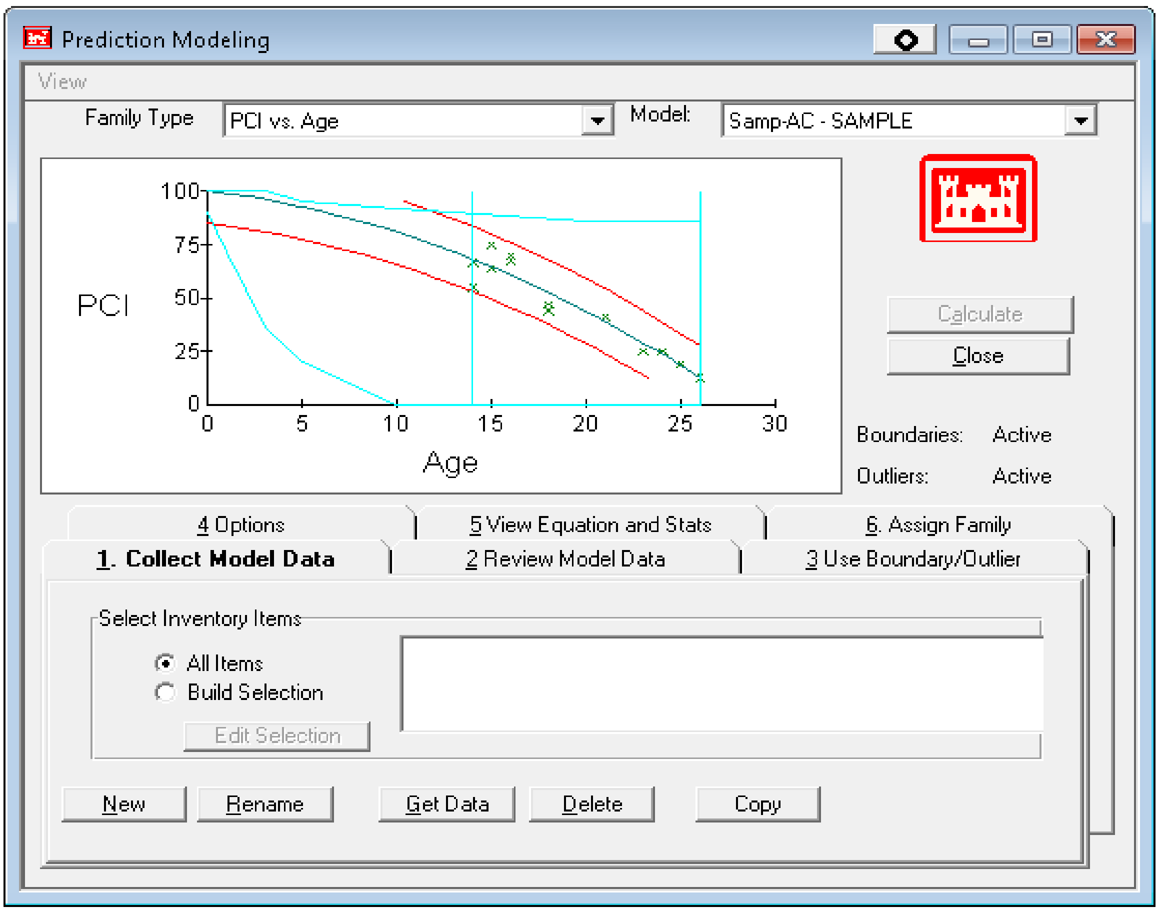


Figure 5-15: Main View of Prediction Modeling Screen

5.7.2 Assign Family

Once a new family model has been completed, the Assign Family card can be used to assign the active family model to the pavement sections that were used to create the model. When you select the Assign Family card, the program checks the contents of Review Model Data card to build a list of the sections used to estimate the current family model. When you select the Assign Family card, the program first checks whether any sections in the current database are assigned to the selected Family Model. If the Family Model is not assigned to any sections, a message comes up indicating both that there are currently no sections assigned this model and asking whether you would like to assign the sections used to build the model (i.e. sections that fit the selection criteria on the Collect Model Data card). You may choose to assign these sections to the current family or continue without assigning the family to the sections [22].

Once the Assign Family card is active, the card contains a table and two buttons. The table lists the pavement sections in your database that are assigned the current family model. The two buttons arrayed on the card below the Assign Family table, Add Members to Family and Remove Current Members, are used to edit the pavement sections assigned to the current family model. To drop a section from the current family, highlight the section in family assignment table and click Remove Current Member.

The section that is dropped is assigned the default family. The Add Members to Family button launches the same process as the Edit Selection routine on the Collect Model Data card. When you click the Add Members to Family button, the EMS Query Tool appears. You can use the EMS Query Tool to identify the sections you would like to assign the active family model to. When you have completed the query, the selected sections are added to the Assign Family table. Table (5-13) show the group of data used in a family model for the case study application.

5.7.3 View Equation and Stats

The View Equations and Stats card displays the intercept and coefficient values for the equation estimated to be the best fit for the data. The card also lists various "goodness-of-fit" statistics for the estimated model Figure (5-16) show the model equation and their fitness for the case study application.

The equation displayed for the family model is PCI = 100-3.08428X (X=age), with coefficient of correlation is 0.885.

5.7.4 Other Condition Prediction Model Features

When the Prediction Model is open, a View menu appears at the top of the window.

This option allows you to turn on and off various graphing features including Boundaries, Outliers, Good Points, and Bad Points. These features only affect the view of the data, not the underlying statistical routines. For example, if you use the view menu to turn off the boundaries, the boundaries do not appear on the plot of the graph. However, points in the model that do not meet the boundary conditions are still excluded from the modeling process.

Table 5-13: Micro PAVER Group Data Analysis for Family Model

Age at Insp.	PCI	Model	Difference	Network ID	Branch ID	Section ID	Surface	Rank	Insp. Date
2.03	81	94	13	2	19S2	19S2	AC	A	01/11/2005
0.03	79	100	21	3	19S3	19S3/1	ST	B	01/11/2005
14.03	53	57	4	4	18W1	18w1/2	AC	A	01/11/2005
14.03	64	57	-7	4	18W1	18W1/1	AC	A	01/11/2005
0.03	90	100	10	3	19S3	19S3/2	ST	B	01/11/2005
1.03	74	97	23	1	18W2	18W2	AC	A	01/11/2005

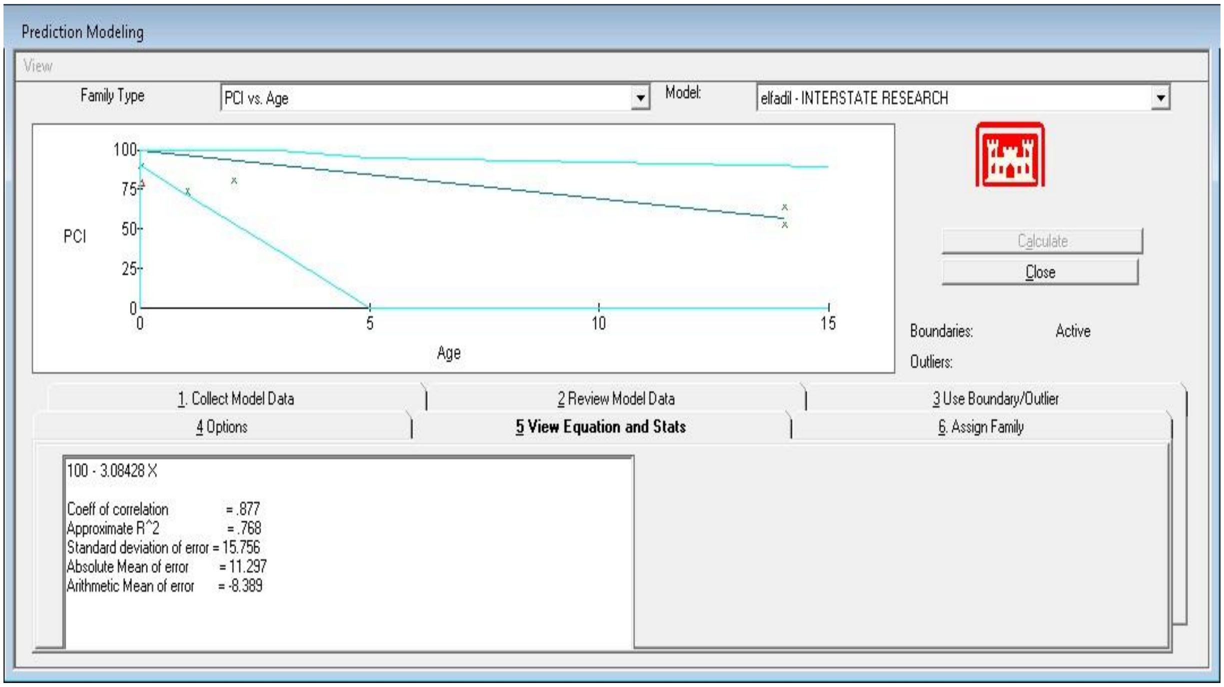


Figure 5-16: Family Model Curve of Pavement Condition in Case Study

5.8 The Summary of Micro PAVER Pavement Prediction Models

Pavement prediction models developed for NKSN were used to predict future pavement conditions for the network. The seven prediction models used to model condition of the pavements of case study application are shown in Table (5-14). In the future, it is recommended that prediction models be developed using the NHA pavement condition data.

Table 5-14: The Micro PAVER Prediction models based on 2005 Data only

Model Number	Model Name	Description	Equation	Critical PCI*
1	ALL NETWORK	Composed AC and ST surface	100-3.08428X	55
2	EL OBIED-ELKHUWAI	AC surface 10 years old	77.0667-3.0667X	55
3	EO BIED – BARA	AC surface more than 10 years old	87.1334-3.0667X	55

4	KAZGILE - ELDILLINJ	St Surface for more than 10 years old	93.0667-3.0667X	55
5	EL OBIED – KAZGILE	St Surface for more than 10 years old	82.0667 -3.0667X	55
6	WDASHANA – KOSTI	AC surface more than 22 years old	95.9338-3.0667X	55
7	EL OBIED-WDASHANA	AC surface more than 22 years old	106.9338-3.0667X	55

***** The critical PCI value represents the condition at or below which the Major M&R (e.g. Resurfacing and Reconstruction) is typically recommended.

Chapter six

Conclusion & Recommendations

Conclusion

6.1Summary

It is evident that the pavement condition and the maintenance affect the total transportation cost significantly. This is particularly more relevant in the Sudan national roads where the geographical and climatic environments, construction methods and technologies and traffic characteristics are more diverse. Therefore, the pavement performance guided by the pavement condition models are of greater use in planning of maintenance and budgets for the road pavements. Database is the key in any kind of pavement management system (PMS), including the formulation of model, predict future condition, hence accuracy and reliability in data should be the foremost requisite for the National Highway Authority in Sudan.

6.2 Results

Based on the data obtained from the NHA -Sudan and analyzed by using of Micro PAVER pavement management system the prediction condition and modeling results that are presented in the previous chapter, the following conclusions may be drawn

1- The most of the distress observed on the pavement were due to other reasons are 69 %, furthermore load related causes were 22 % and environmental effects 19% according to micro PAVER classification method for the NKSN application.

2- The result of pavement condition index in 2005 shows that one section total out of six, its pavement condition is “good” rating with average PCI =90, and three sections have pavement condition “satisfactory” rating with an average PCI of 78, and one section in fair condition with an average PCI of 64, and finally poor condition occurs in one section with an average PCI of 53. In the overall, the network had an average weighted PCI of 71, which was considered "satisfactory" rating.

3- The prediction condition for November 2014 shows that the overall predicted condition of the network had an average weighted PCI of 43, which was considered "poor" rating. In details four road section having 77% from the pavement area are lies in poor condition with an average PCI of 49. And one section having 14% the pavement area is in very poor condition with an average PCI of 36. The remaining 9% is in serious condition with an average PCI of 25 which is simulating one section from network under study. Ideally, this network should receive maintenance as soon as possible to avoid costly maintenance actions in the future.
4- The family models are successfully developed for the Network under study which is the first of this kind in Sudan National Highway - Northern Kordofan State sector for the bituminous pavements which are newly constructed. The model is able to predict the condition and performances for the pavements which have need Maintenance strategy using family model using Micro PAVER pavement management system.
5- This study uses the PCI of 55as a critical PCI value, which is represents the condition at or below which the major reconstruction and Rehabilitation is typically recommended. This threshold value is also recommended and used by NHA-Sudan.
6- The pavement condition index values calculated by Micro PAVER compared with the manually calculated by NHA road sector is almost typical, but the utilization of Micro PAVER software is saving time.

7- The prediction equation generated by the software for the family road network is PCI=100-3.08428x (x=age sine last construction or rehabilitation). The equation is having coefficient of correlation =0.885 which acceptable.

8- The below table contain seven equation developed in this research represent the Prediction models based on 2005 Data only.

Model Number	Model Name	Description	Equation	Critical PCI*
1	ALL NETWORK	Composed AC and ST surface	100-3.08428X	55
2	EL OBIED - ELKHUWAI	AC surface 10 years old	77.0667-3.0667X	55
3	EO BIED – BARA	AC surface more than 10 years old	87.1334-3.0667X	55
4	KAZGILE - ELDILLINJ	St Surface for more than 10 years old	93.0667-3.0667X	55
5	EL OBIED – KAZGILE	St Surface for more than 10 years old	82.0667 -3.0667X	55
6	WDASHANA – KOSTI	AC surface more than 22 years old	95.9338-3.0667X	55
7	EL OBIED-WDASHANA	AC surface more than 22 years old	106.9338-3.0667X	55

6.3 Recommendations

The following recommendations seem to be an appropriate for the future prediction of pavement condition and modeling development since the modeling process is always need the extensive data.

1. The pavement condition models developed in this research should be utilized to evaluate the pavement condition and to implement the maintenance strategy for the network.
2. The prediction condition curves are used to forecast the pavement condition propagation over time, so the maintenance strategies and activities as well as funds allocation can be scheduled a head of time at which the pavement should receive the suitable corrections.
3. The NHA - Sudan should increase the awareness of PMS and the asset management of road infrastructure for all part of National Roads and keep the pest qualified engineers in the depart of road maintenance and support them by good equipment and continues training.
4. They should support pavement inventory, condition assessment especially pavement distress survey every two or three years, keeping all record and build central dataset contains everything related to the road infrastructure in general and pavement section in particular, building prediction and performance models based on the datasets, a framework to identify needs and set priorities. Also, it should ensure that funding is available for maintenance in general corrective and preventive maintenance programs in particular to avoid the more costly and timely consumed activity such as reconstruction and habitation. And should adopt comprehensive program to keep the

road infrastructure into acceptable condition by applied preventive and routine maintenance program.

5. The Micro PAVER pavement management system and geographical information system should be implemented for pavement maintenance management system (PMMS) for all road infrastructures in Sudan.
6. The NHA need to continue developing of the PMMS system using the new evaluation equipment using high techniques.

6.4 Future works

1. In further the high precise models like HDM-4 need to be applied for National Highway pavement which it can be possible when more information is available in the future. The information should comprise of distress type, distress severity, distress density, pavement condition, maintenance type, pavement age, highway class, traffic volume, drainage, and climate condition. Until the purchasing of precise models Micro PAVER software should be used to calculate and predicts pavement condition.
2. Future developments should be made to ensure full integration between the Micro PAVER pavement management system and Highway Development Maintenance (HDM4).

List of references

[1]. Haas R, Hudson W, and Zaniewski, 'Modern Pavement Management', Krieger Publishing Company, Malabar, Florida, J 1994.

[2]. Barrie, S., and Paulson, B, 'Professional Construction Management: Including CM, Design-Construct and General Contracting', McGraw-Hill Book Company, 1992.

[3]. American Association of State Highway and Transportation Officials (AASHTO),'Pavement management Guide, AASHTO, Washington, D.C, 2001

[4]. Federal Highway Administration (FHWA), 'Pavement Management Systems Manual', FHWA, Washington, D.C, 1990.

[5]. Transportation Association of Canada (TAC), 'Pavement design and Management Guide', National Project Team, TAC, Ottawa, Ontario, 1997.

[6]. Hudson, W., Hass, R., and Darly R, 'Pavement Management System Development', NCHRP report 215, 1979.

[7]. Organization for Economic Co-operation and Development (OCED), 'Pavement Management System', OCED, Paris, France, 1987.

[8]. George, K., Pajagopal A., and Lim, L, 'Prediction of Pavement Remaining Life', Transportation Research Board, TRR 1524, Washington, D.C, 1996.

[9]. Paterson, W, 'Road Deterioration and Maintenance Effects, Models for Planning and Management', the World Bank, Washington, D.C, 1987.

[10]. Lytton, R, 'Concept of Pavement Performance Prediction and Modelling', Proceedings 2nd North American Conference on Managing Pavement, Toronto, Canada, 1987.

[11]. Darter, M, 'Requirement for Reliable Predictive Pavement Models', Transportation Research Board, TRR 766, Washington, D.C, 1980.

[12]. Ramaswamy, R., and Ben-Akiva, 'Estimation of Highway Pavement Deterioration from In-Service Data', Transportation Research Record, TRR 1272, Washington, DC, 1990.

[13]. Wijk, A., and Sodzik, E, 'Use of Axle Load-Information in Pavement Management System', in proceeding 4th International Conference on Managing Pavements, Durban, 1998.

[14]. Shaiu, S. and Yu, H, 'Load and Displacement Prediction for Shakedown Analysis of Layered Pavement', Transportation Research Board, TRR 1730, Washington, D.C, 2000

[15]. American Association of State Highway and Transportation Officials (AASHTO), 'AASHTO Guide for the design of Pavement Structures', AASHTO, Washington, D.C, 1993.

[16]. Fernandes, J., Pais, J., and Pereia, P, 'Effects of Traffic Loading on Portuguese and Brazilian pavement Performance' Transportation Research Board (TRB), 85th Annual Meeting, Washington, D.C, 2005.

[17]. Smith, G, 'Probability and Statistics in Civil Engineering', Nichols Publishing Company, New York, US, 1986.

[18]. Shahin, M, 'Pavement for Airports, Roads, and Parking Lots', Chapman & Hall, New York, 2002.

[19] Shahin, M, 'Pavement for Airports, Roads, and Parking Lots', Chapman & Hall, New York, 1994.

[20]. ASTM, D6433, Stander practice of roads and parking lots pavement condition index surveys, 2003.

[21]. Pavement condition survey manual, Sudan, (2005).

[22]. ERDC-CERL, Micro Paver pavement management system, (2004). www.cecr,army.mail/paver

[23]. Federal Highway Administration (FHWA), 'Our Nation's Highways: Selected Facts and Figures', 2008. http://www.fhwa.dot.gov/policyinformation/pubs/pl08021/pdf/onh.pdf

[24]. Masaoud, KA (2013-2014). Lecture notes and handouts, National Highway Authority Sudan, unpublished

[25]. Rupa Ranganathan and Cecilia Briceño-Garmendia, African Infrastructure Country Diagnostic (AICD), 2011.

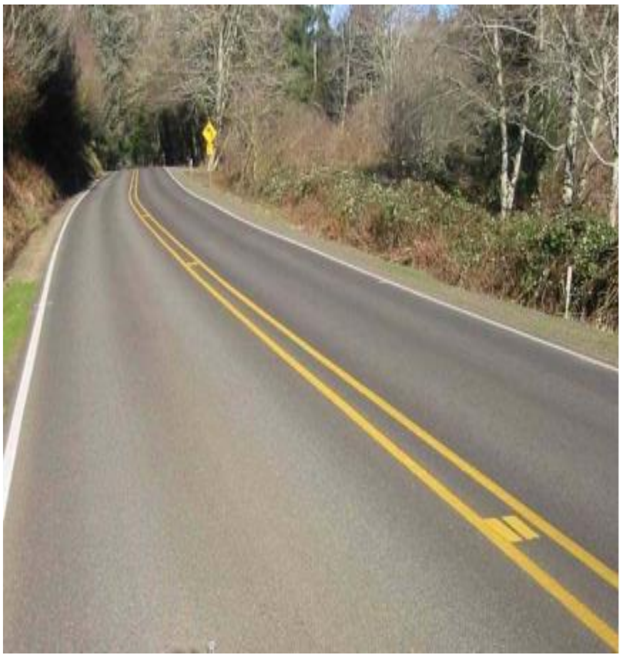
Appendices

Appendix (1)

Photo Illustrations of Pavement Condition Categories for Asphalt Concrete

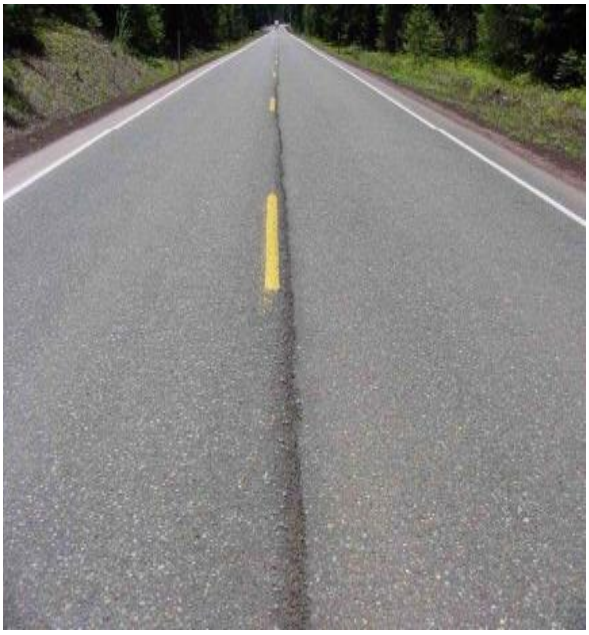
Condition - Good

Pavement structure is stable. No cracking, patching, or deformation evident Riding qualities are excellent. Nothing would improve this pavement at this time. Roadways in this category are usually fairly new.



Condition- Satisfactory

Pavement is stable. Minor cracking may be present, but cracks are generally hairline and hard to detect. Minor amounts of patching and deformation may be present .It may have a dry or light-colored appearance. It is very good riding qualities. Rutting is less than ½”.



Condition – Fair

Pavement structure is generally stable with minor areas of structural weakness evident. Cracking is easier to detect. It may be patched, but not excessively. Deformation more pronounced and easily noticed. Ride qualities are good to acceptable. Rutting is less than ½”.

Condition – Poor

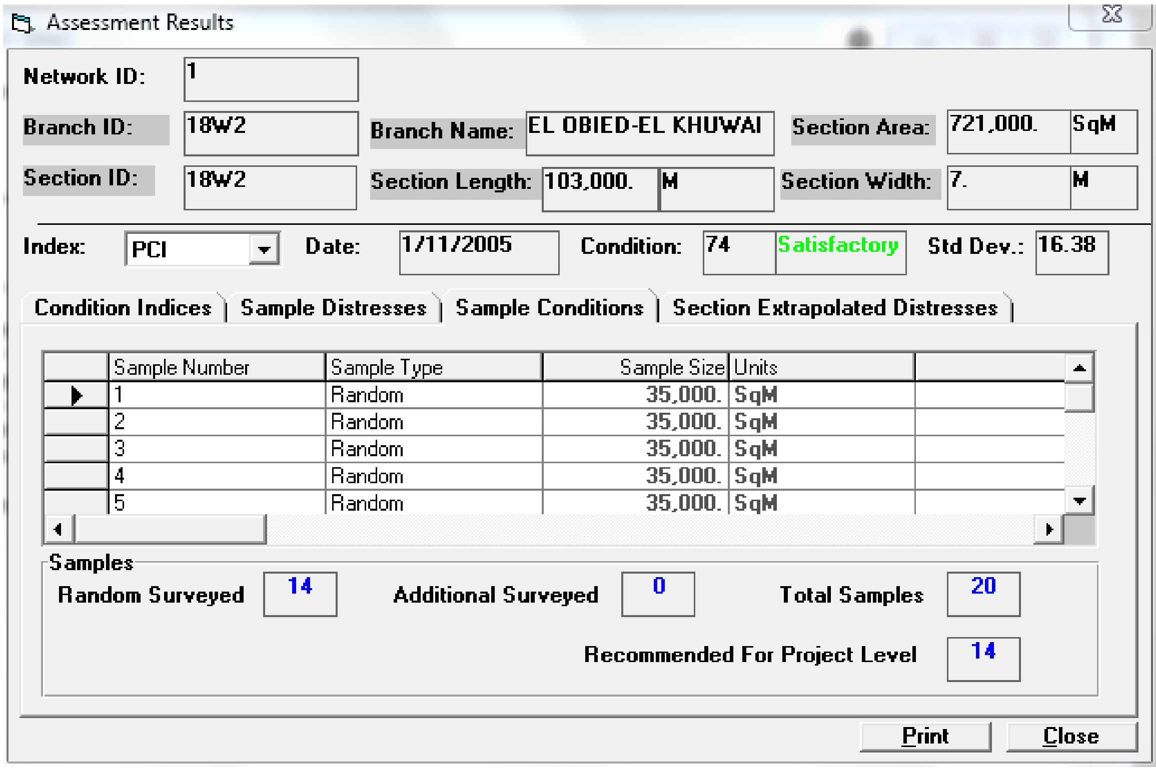
Pavement has areas of instability, marked evidence of structural deficiency, large crack patterns (alligatoring), heavy and numerous patches. Deformation is very noticeable. The riding qualities range from acceptable to poor. When rutting is present, rut depth is greater than ¾"

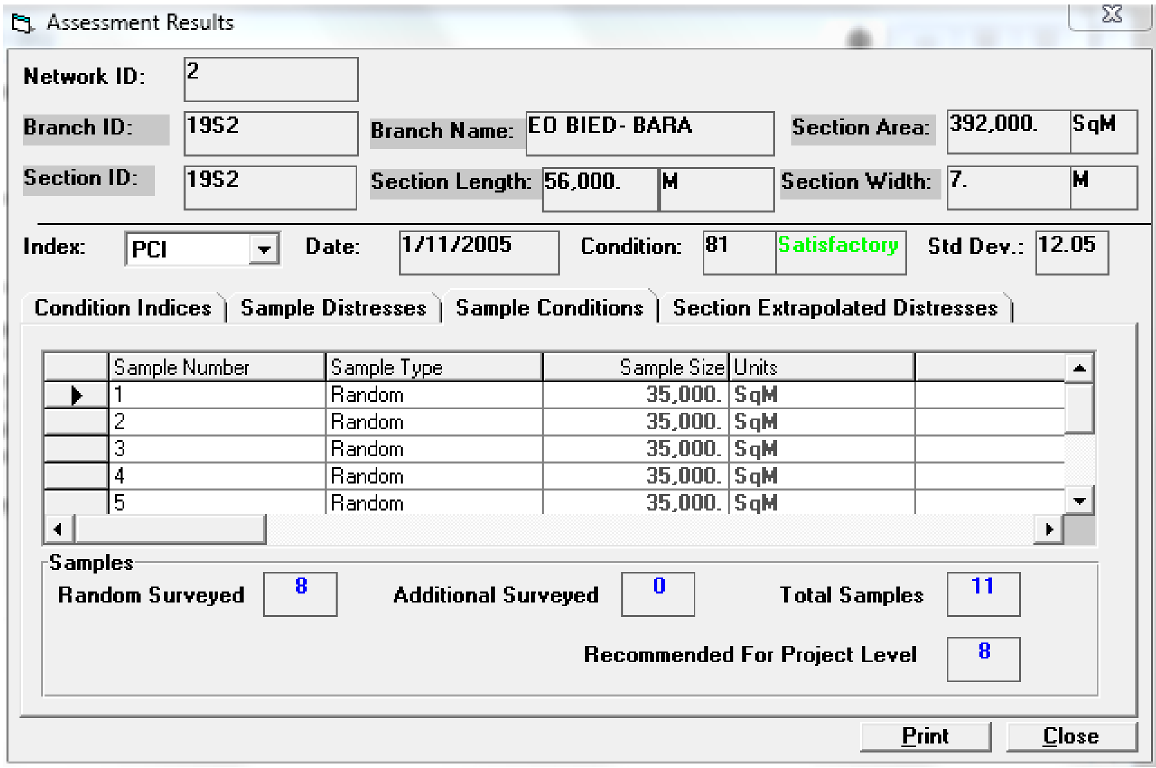
Condition – Very Poor

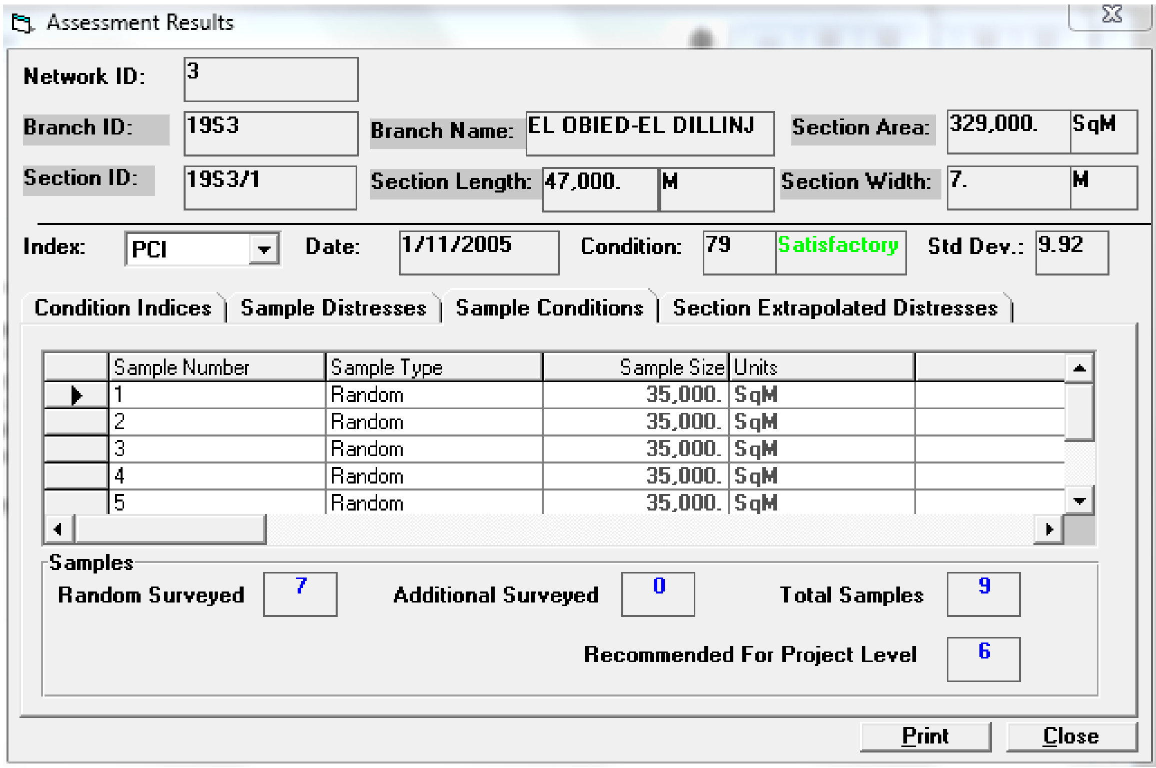
Pavement is in extremely deteriorated condition. The numerous of areas are instability. The majority of section showing are structural deficiency. Ride quality is unacceptable (probably should slow down).

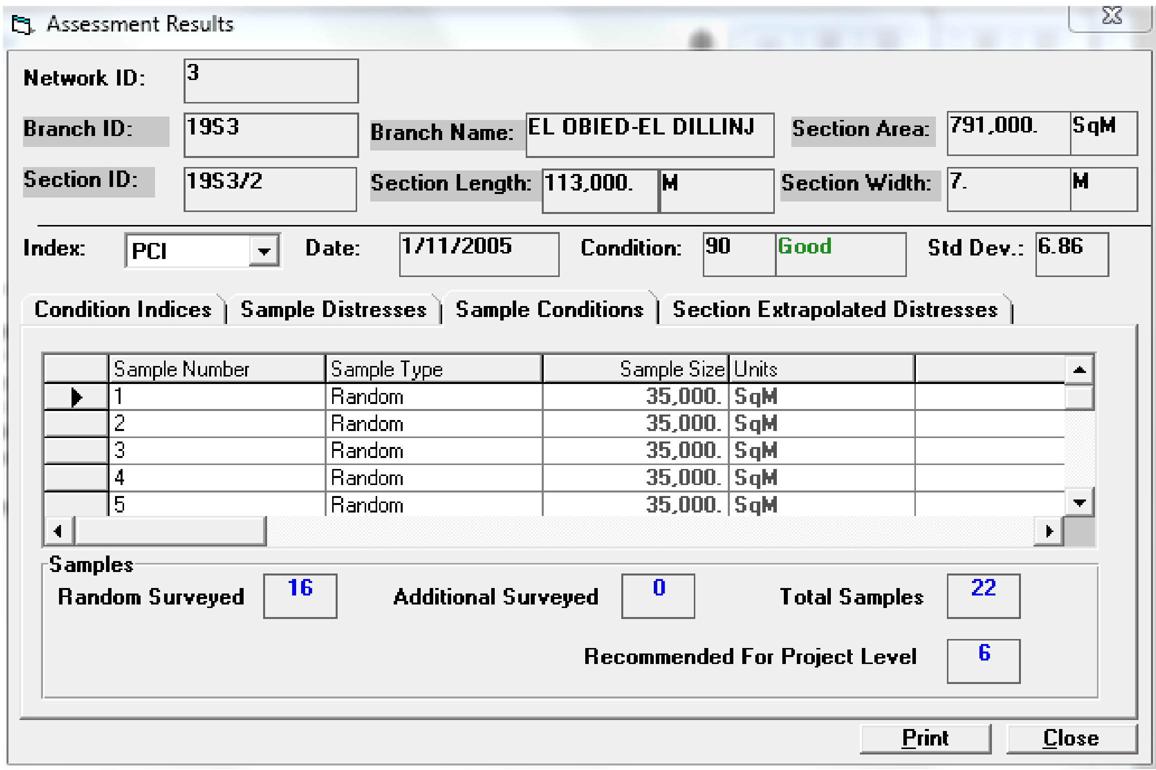
Appendix (2)

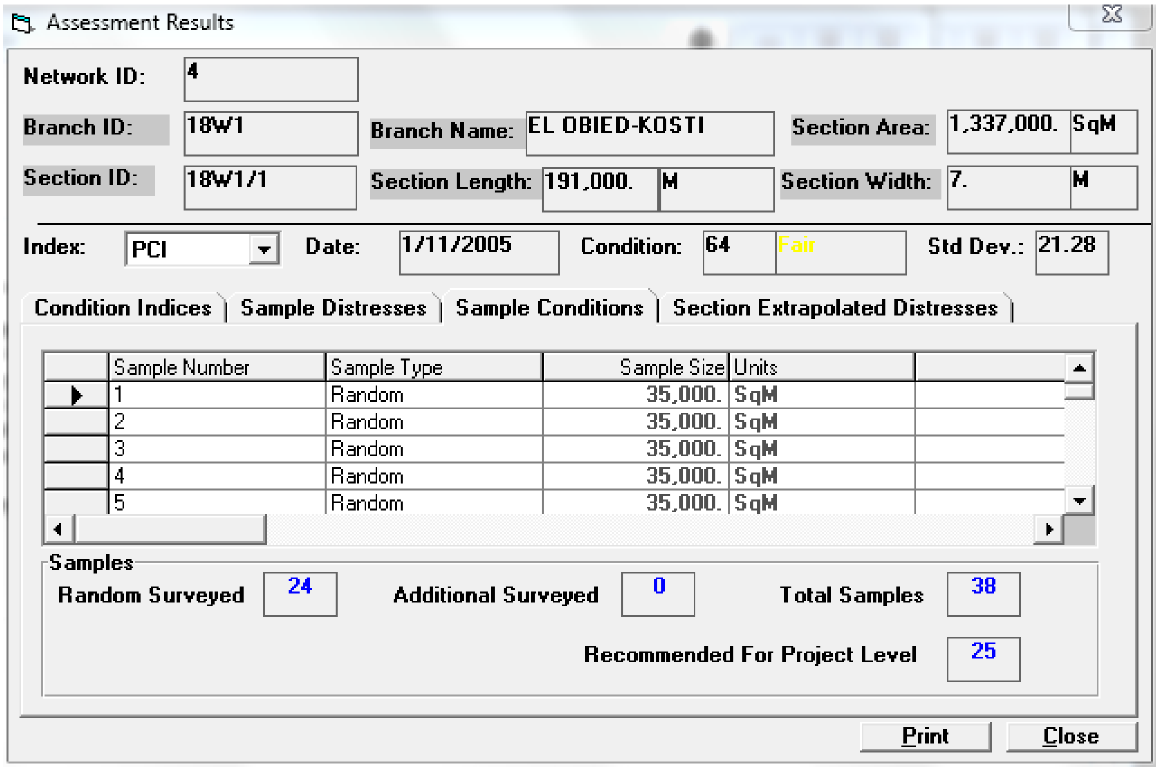
Pavement Condition Index Micro Paver Results for the Six Section

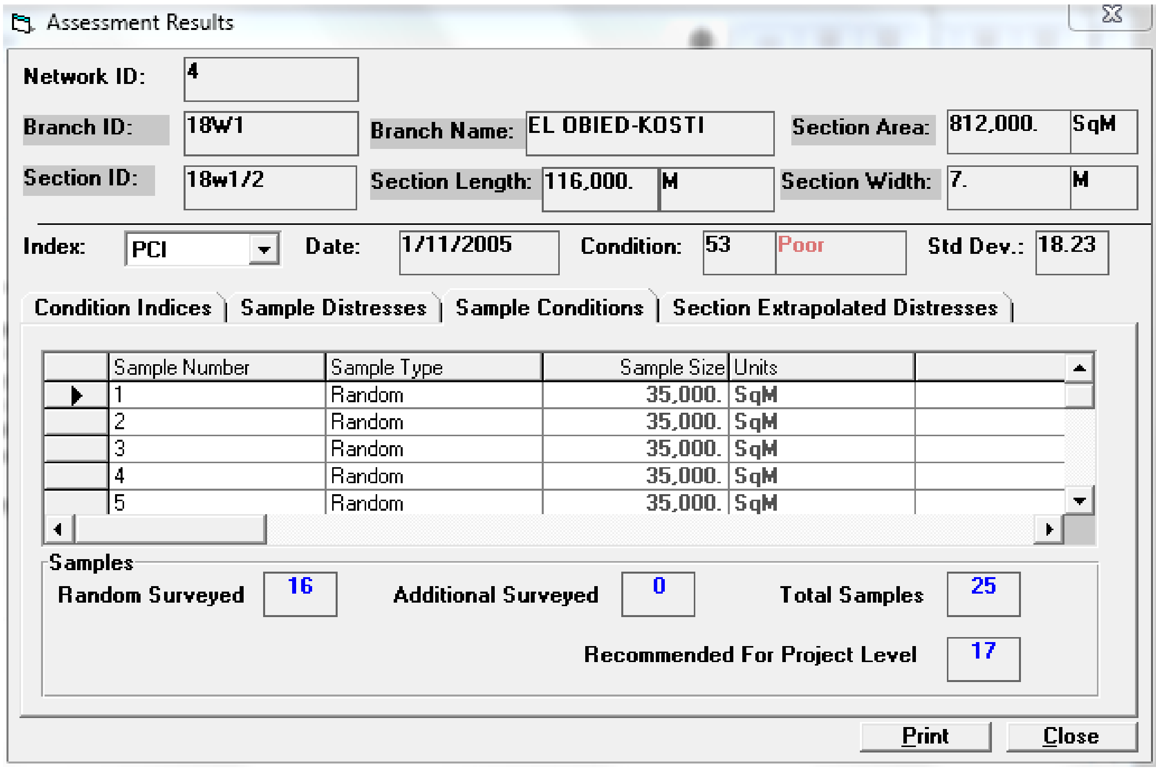





Assessment Results
Network ID: 3
Branch ID: 19S3
Branch Name: EL OBIED-EL DILLINJ
Section Area: 329,000. SqM
Section ID: 19S3/1
Section Length: 47,000. M
Section Width: 7. M
Index: PCI
Date: 1/11/2005
Condition: 79 Satisfactory
Std Dev.: 9.92
Condition Indices
Sample Distresses
Sample Conditions
Section Extrapolated Distresses
Sample Number | Sample Type | Sample Size | Units
1 | Random | 35,000. | SqM
2 | Random | 35,000. | SqM
3 | Random | 35,000. | SqM
4 | Random | 35,000. | SqM
5 | Random | 35,000. | SqM
Samples
Random Surveyed 7
Additional Surveyed 0
Total Samples 9
Recommended For Project Level 6
Print
Close


Assessment Results
Network ID: 3
Branch ID: 19S3
Branch Name: EL OBIED-EL DILLINJ
Section Area: 791,000. SqM
Section ID: 19S3/2
Section Length: 113,000. M
Section Width: 7. M
Index: PCI
Date: 1/11/2005
Condition: 90 Good
Std Dev.: 6.86
Condition Indices
Sample Distresses
Sample Conditions
Section Extrapolated Distresses
Sample Number | Sample Type | Sample Size | Units
1 | Random | 35,000. | SqM
2 | Random | 35,000. | SqM
3 | Random | 35,000. | SqM
4 | Random | 35,000. | SqM
5 | Random | 35,000. | SqM
Samples
Random Surveyed 16
Additional Surveyed 0
Total Samples 22
Recommended For Project Level 6
Print
Close


Assessment Results
Network ID: 4
Branch ID: 18W1
Branch Name: EL OBIED-KOSTI
Section Area: 1,337,000. SqM
Section ID: 18W1/1
Section Length: 191,000. M
Section Width: 7. M
Index: PCI
Date: 1/11/2005
Condition: 64 Fair
Std Dev.: 21.28
Condition Indices
Sample Distresses
Sample Conditions
Section Extrapolated Distresses
Sample Number
Sample Type
Sample Size
Units
1 Random 35,000. SqM
2 Random 35,000. SqM
3 Random 35,000. SqM
4 Random 35,000. SqM
5 Random 35,000. SqM
Samples
Random Surveyed 24
Additional Surveyed 0
Total Samples 38
Recommended For Project Level 25
Print
Close


Assessment Results
Network ID: 4
Branch ID: 18W1
Branch Name: EL OBIED-KOSTI
Section Area: 812,000. SqM
Section ID: 18w1/2
Section Length: 116,000. M
Section Width: 7. M
Index: PCI
Date: 1/11/2005
Condition: 53 Poor
Std Dev.: 18.23
Condition Indices
Sample Distresses
Sample Conditions
Section Extrapolated Distresses
Sample Number
Sample Type
Sample Size
Units
1 Random 35,000. SqM
2 Random 35,000. SqM
3 Random 35,000. SqM
4 Random 35,000. SqM
5 Random 35,000. SqM
Samples
Random Surveyed 16
Additional Surveyed 0
Total Samples 25
Recommended For Project Level 17
Print
Close