DEVELOPMENT OF PAVEMENT MANAGEMENT PERFORMANCE MODEL: A CASE STUDY OF ETHIOPIAN ROADS ADMINISTRATION

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Development of Pavement Management Performance Model: A Case Study of Ethiopian Roads Administration

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DECLARATION

I, the undersigned declare that this thesis entitled "**Development of Pavement Management Performance Model A Case Study of Ethiopian Roads Administration"** is my original work, prepared under the guidance of **Dr. Asregdew Kassa.** All sources of material used for organizing this thesis have been dually acknowledged by proper citation. Moreover, this thesis has not been submitted by any other person in any university or Higher Educational Institute for an award of a degree.

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CERTEFICATE OF APPROVAL

This thesis is submitted to Ethiopian institute of Architecture, Building Construction, and City Development (EiABC) and to department of Infrastructure Technology Management in partial fulfillment of the requirement for the degree of Masters of Science in Construction Management.

We, the undersigned, members of the Board of Reviewers of the thesis open defense by **Seble Deginetu Bogale** have read and evaluated the thesis entitled **"Development of Pavement Management Performance Model: A Case Study of Ethiopian Roads Administration"** and assessed the understanding of the candidate about the thesis research. This is, therefore, to certify that the thesis is accepted.

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Abstract

According to United Nations Economic Commission for Africa "Road safety performance review of Ethiopia (2020)" Sustainable and vibrant transport systems can lead to long-term economic growth. If designed well, transport facilitates access to opportunities, education, medical services, and goods, and improves overall quality of life. Around $45 billion worth of road infrastructure has been destroyed over the previous 20 years due to poor maintenance, according to a World Bank study conducted in 85 developing nations. Less than $12 billion might have been spent on preventive maintenance to avoid this loss (Harral and Faiz, as cited by Regassa, 2015). This study's primary objectives are to evaluate the Ethiopian Road Administration's present pavement management practices and develop a pavement performance prediction model. A case study has been employed as a research methodology to carry out the investigation. Pavement condition assessment reports, document examination, and observation are the methods used to acquire data using regression analysis. The study's findings indicate that the road sector pavement management directorate planned and arrange strategies for timely maintenance of defective road but in reality the maintenance activity done after the road condition become sever condition. Which lead huge maintenance expense instead this loss could have been averted with less preventive maintenance cost. Performance models are used in pavement management systems (PMSs) to forecast pavement performance in the future by correlating pavement distress with traffic volume, age, traffic load, climate condition etc. But the study limited to correlating pavement distress with age of pavement as the other constraints (traffic volume, climatic condition, traffic load etc.) are not available during the study. The regression analysis model's result shows the maximum percentage difference between the actual and anticipated pavement distress is 4.2%, making it a good starting model. Ultimately, by reducing the most significant issues that are unique to the city, this study offers the municipal administration a logical way to enhance its road pavement management practices. By forecasting the road's future state, the pavement performance model is also anticipated to assist the local administration in carrying out prompt maintenance on damaged roads.

Key Word: Road pavement Management, Pavement Performance Prediction Model, Pavement Management System

Abbreviations

AACRA:	Addis Ababa City Road Administration
AMS:	Asset Management System
APWA:	American Public Works Association
EELPA:	Ethiopian Electric light and power Authority
ERA:	Ethiopian Road Administration
ETC:	Ethiopian Telecommunication Corporation
GDP:	Gross Domestic Product
LRS:	Location Referencing System
MoWUD:	Ministry of Work and Urban Development
OECD:	Organizational for Economic Cooperation and Development
PMS	Pavement Management System
PPP	Pavement Performance Prediction Model
RSDP:	Road Sector Development Program
RSDP	Road Sector Development Program
URRAP	Universal Rural Road Access Program

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CHAPTER ONE: INTRODUCTION

1.1 Background

One may argue that every aspect of development is impacted by construction. According to United Nations Economic Commission for Africa "Road safety performance review of Ethiopia (2020)" Sustainable and vibrant transport systems can lead to long-term economic growth. If designed well, transport facilitates access to opportunities, education, medical services, and goods, and improves overall quality of life. In addition to increasing manufacturing capacity, this sector is essential for building social infrastructure like hospitals and schools and for building economic infrastructure like highways and railroads. Additionally, by building and renovating dwellings, construction plays a major role in raising living standards.

The American Association of State Highway and Transportation Officials (AASHTO) defines pavement management as "…the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life cycle cost *(AASHTO, 2012).*" This concept of providing pavements and maintaining them in acceptable condition is as old as the first pavement. As pavement networks grew slowly in the first half of the twentieth century and then quickly in the 1950s and 1960s, simple procedures or experience that had worked previously was no longer able to manage these burgeoning networks. Instead, a more holistic systems approach was needed.

Originally described as "a systems approach to pavement design", the term "pavement management system (PMS)" came into popular use in the late 1960s and early 1970s to describe decision support tools for the entire range of activities involved in providing and maintaining pavements (OECD, 1987 and Peterson, 1987). Hudson et al. (1979) describe a "total pavement management system" as a coordinated set of activities, all directed toward achieving the best value possible for the available public funds in providing and operating smooth, safe, and economical pavements."

Performance models are used in pavement management systems (PMSs) to predict the state of the pavement in the future. As such, these models must be reliable and faithfully represent the real deterioration trends seen in the agency's pavements. (Abu-Lebdeh, G, Ahmed, K., and Lyles, R.W. ,2006). In order to forecast future pavement conditions, determine the best time for maintenance and rehabilitation, find the most economical treatment strategies for the pavement network, estimate statewide pavement requirements to meet agency-defined goals and constraints, and illustrate the implications of various pavement investment strategies, pavement prediction models are essential for a variety of pavement management tasks.

1.2 Problem Formulation

Around $45 billion in road infrastructure has been lost over the past 20 years as a result of inadequate maintenance, according to a World Bank research that included 85 developing countries. A preventative maintenance strategy that would have cost less than $12 billion may have avoided this loss (Harral and Faiz, as cited by Regassa, 2015). In order to optimize maintenance costs among pertinent organizations in Ethiopia, it is crucial to evaluate Road Pavement Management procedures and create models such as Public-Private Partnership (PPP).

Expanding road coverage is the Ethiopian Roads Administration (ERA) current priority. The problem, though, comes after new projects are finished. According to Temsgen Girmay (2016), ERA has planned yearly road maintenance operations after evaluating urban roadways; nevertheless, these maintenance initiatives are not being carried out efficiently. To extend the life of the roads, it is therefore essential to increase road coverage while also preserving the state of the current pavements.

On the other hand, a large number of recently built highways in the nation, especially those in Addis Ababa, do not last the full duration of their intended design. Every repaired part of these roads deteriorates within three to four months, despite multiple maintenance attempts to maintain them functional (Abate, 2015). The city road administration might carry out preventative maintenance and rehabilitation projects before serious distress arises if the nation possessed a pavement performance prediction model to predict the future state of its roads.

By assessing the Ethiopian Roads Administration's present road asset management procedures and creating a pavement performance prediction model to forecast the roads' future state, this study seeks to provide a logical solution.

1.3 Research Question

1. What is the current pavement management practice in Ethiopian Road Administration (ERA)? Mainly focus on (guidelines, process, technology and challenges of road asset management).

2. How to developing pavement performance model for Ethiopian Road Administration (ERA)?

1.4 Objectives of the Study

1.4.1 General Objectives

The main objectives of the study is to evaluate the current pavement management practice and develop a pavement performance model.

1.4.2 Specific Objectives

1. Assessing the current pavement management practice with respect to (guidelines, process, technology and challenges of road asset management) by taking Ethiopian Road Administration (ERA) as a case study.
2. Developing a pavement performance model for the Ethiopian Road Administration (ERA).

1.5 Scope and Limitations

1.5.1 Scope

Investigating current pavement management strategies, utilizing the ERA project as a case study, and developing a pavement performance model tailored for asphalt roads are the main goals. ERA have five road districts from them the study done on Alemgena district taking nine road sections for observing the current practice of pavement management and pavement perdition model done on Fiche to Gohatsion road which is part of Alemgenea district (Addis to Metema road).

1.5.2 Limitation

The pavement distress highly related to age traffic volume, climatic condition, temperature, traffic load, pavement material and others. But the study limited to correlating pavement distress with age of pavement as the other constraints (traffic volume, climatic condition, traffic load etc.) are not available during the study. And also the procedure of correcting arithmetic errors took a long time because the researcher faced many obstacles when collecting data on traffic conditions.

1.6 Significance of the Study

The study is about assessing the current pavement management practice and developing pavement performance model. By identifying the flaws in current approaches, this study seeks to help the ERA PMS to improve its road asset management procedures. Pavement performance models used to establish repair priorities based on available funds and to estimate future maintenance requirements and budgets. These models allow for the forecasting of future pavement conditions, which may then be utilized as inputs to the maintenance strategy to determine the necessary M&R (maintenance and rehabilitation) actions. Furthermore, it is expected that the pavement performance models will enhance overall performance by enabling prompt maintenance of failing roads by forecasting their future states.

1.7 Structure of the Thesis

The general outline of the thesis is as follows:

Chapter 1: Introduction

This chapter introduces the core issues to be addressed in the thesis. It gives a background to the subject matter, presents the problem statement, the objectives, and the scope & limitation of the study.

Chapter 2: Literature Review

Includes pertinent material on this topic to help readers comprehend the ongoing research. Both the research instrument's basis and the "best practices" reference base for the analysis and interpretation chapter are presented.

Chapter 3: Methodology

Includes the methodologies used in this research design, the study's subjects or participants (sample), the data sources, the instruments and tools used for data collecting, and the procedures for data gathering methods.

Chapter 4: Result & Discussion

The data is analyzed and interpreted in this chapter, and the results are compared with similar "international accepted practices" and theoretical explanations. In this chapter, the study's results are compiled, interpreted, and/or discussed.

Chapter 5: Conclusion and recommendations

This chapter comprises the conclusion; and recommendations for future study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Pavement Management System (PMS)

Pavement management systems (PMS) are a set of tools that help a road network administration make decisions about maintenance and repair (M&R) plans for keeping pavements in acceptable service condition. The network must be kept in good condition by timely and efficient road and bridge repair that is limited by money. For Road and Highway Departments to accomplish this, an effective Pavement Management System (PMS) is necessary (Kahn, 2005).

The current pavement quality is represented by combining data on pavement conditions into an index using prioritization methods. After that, all of the pavement portions are ranked and categorized using a priority-ranking criterion to sort the prioritization. Road class, traffic volume, pavement quality, and other factors are often used rating criteria. According to AASHTO (1993), PMS is a collection of instruments or techniques that help decision-makers identify the best ways to supply, assess, and keep pavements in a usable state throughout time. Additionally, they offer the data required to justify maintenance and rehabilitation plans and support financing requests Huang (quoted by Gebremedihin, 2016).

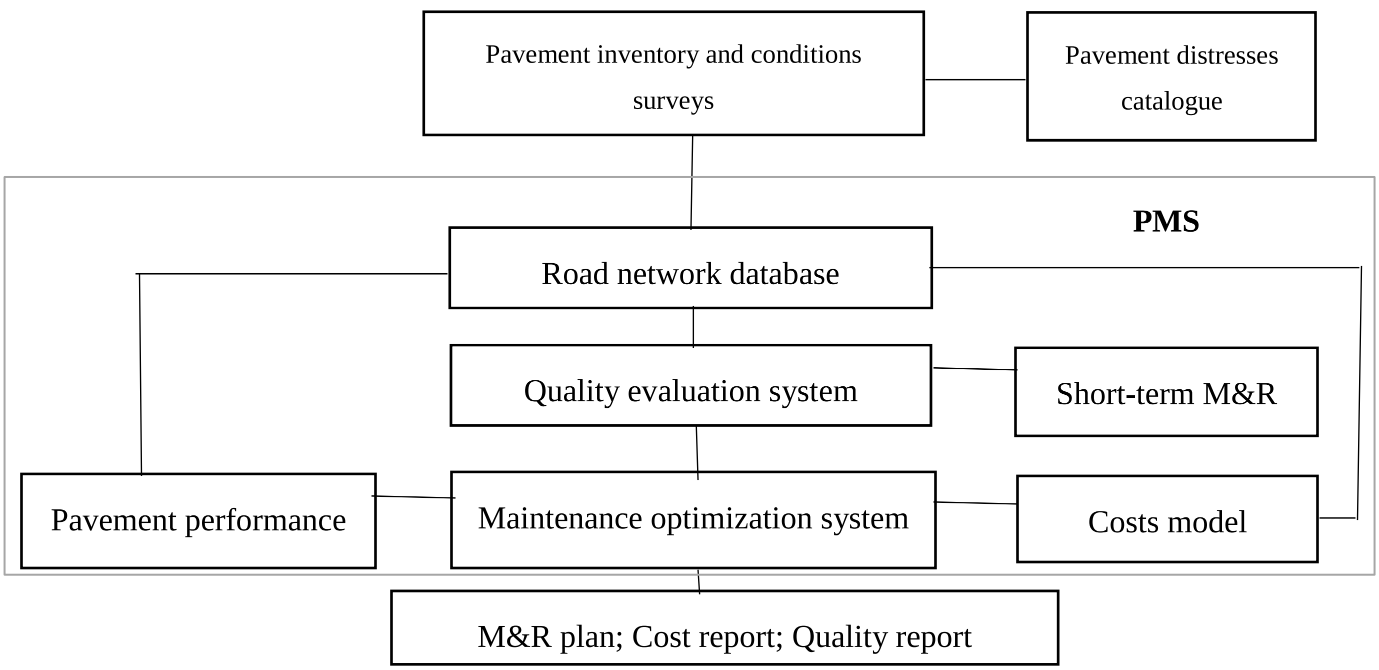


Figure 2.1. Structure of a PMS source; (Wong et al. 2003)

A PMS usually consists of five parts: a road network database, a quality evaluation system, a costs model, pavement performance models, and a decision-aid tool. One of the core components of a PMS is the process for selecting the best M&R plan while taking the expected changes in pavement condition into consideration. This methodology may be based on ranking or prioritization models (Wong et al. 2003).

To depict the current state of pavement quality, data on pavement conditions are compiled into an index using prioritization algorithms. The pavement portions are then ranked and categorized using a priority-ranking criterion in order to create a priority list. Road class, traffic volume, pavement quality, and other factors are frequently used as rating criteria.

2.1.1 Road Inventory and condition survey

A comprehensive collection of road characteristics, such as bridges and drainage systems, is referred to as a road inventory. Road networks, flyovers, underpasses, pedestrian amenities, drainage systems, intersections inside the right-of-way, etc. are all included. The physical components of the road system that do not significantly alter over time are described by inventory data.

Road inventories are used to determine the present state of the road network and its key characteristics, which aids in allocating funds for road maintenance and restoration. Additionally, it builds a database of roads and road characteristics for use in legal matters, research, and other contexts. Once a road in the road network has been inventoried, it doesn't need to be done again until there are significant changes to the system, such as new road construction. Therefore, the first and most important stage in determining the present state of the road network system is to conduct an inventory of the roads (Abell, 2000).

The major information required to complete inventory of a road network are; link name/road name, functional class of the road, length of the road ,width of the road, owner of the road, location of the road (Zone, Woreda, Kebele or others) and surface type of the road.

2.1.2 Road Condition Survey

In order to diagnose the physical deterioration of a pavement and determine whether maintenance or rehabilitation is necessary, a road condition survey is necessary. It is used to create the annual work program and to plan and measure the necessary road network maintenance. It can also be used to draw attention to periodic and ongoing maintenance needs. Either automated equipment or manual labor can be utilized to conduct distress surveys. In either scenario, the pavement's surface is examined and assessed to identify the kind, degree, and extent of the distress. The type of distress will help identify the likely reason or causes of the distress and, in the end, aid in choosing a rehabilitation approach that is appropriate for fixing and preventing the issue from happening again.

The harshness and extent of the manuals vary in their ranges. For instance, the ERA handbook (2002) shows the state of a road's surface at a specific point in time and identifies areas of equivalent quality using three damage levels: low, medium, and high. The "1" level, often known as "low severity," indicates that while the distress type has manifested, it is not now posing an issue, The "2" level, which denotes "medium or moderate severity," usually means that a pavement needs to be repaired or may soon become problematic. In general, a high or heavy severity, or "3," level denotes that the suffering is so severe that maintenance is either urgently required or ought to have been completed previously.

2.1.2.1 Pavement deterioration

Alligator/Fatigue Cracking

Fatigue or alligator cracking is a series of interconnected cracks caused by the HMA surfaces' (or stabilized base's) fatigue failure under repeated traffic strain. In thin pavements, cracking begins at the bottom of the HMA layer, where the tensile stress is highest, and progresses to the surface as one or more longitudinal cracks. Whiteoak (2003) states that the longitudinal cracks gradually unite under repeated stress to produce many-sided, sharply angled fragments that finally resemble the back of a crocodile or alligator.

Minimal Severity: Crack width less than the hairline
Medium Severity: hairline < 0.25-inch crack width
High severity: crack width > 0.25 inch

The length of distress at each severity level is then measured.

Rating Severity

There can be no spalling and only one crack in a low severity crack. Single or more cracks with significant spalling can be classified as moderately severe cracks. Single or numerous cracks with extensive spalling can make up high severity cracks.

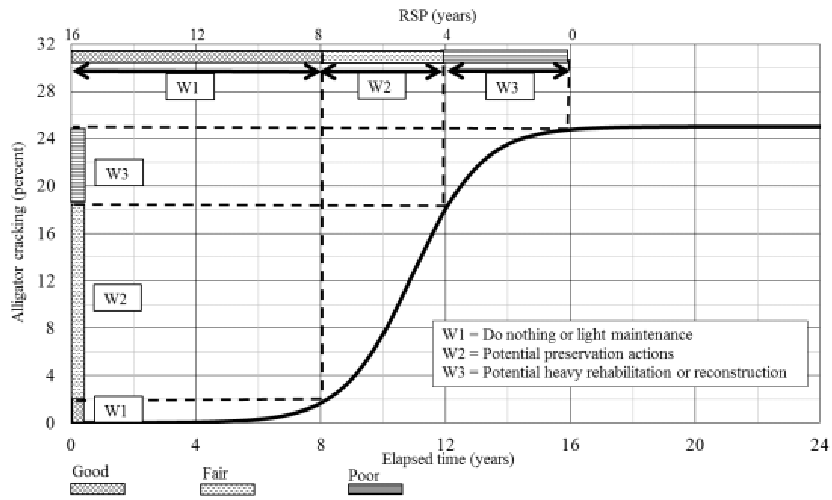


Figure 2.2 Graph. Idealized S-shaped curve for alligator cracking showing three windows (threshold values) for various treatment actions (Whiteoak , 2003).

Significant chipping and breaking of the crack margins is referred to as spalling. Completely sealed cracks are classified as mild severity. According to the inspection requirements, cracks that are not completely sealed are rated. Please be aware that cracks with intact or completely effective sealant are to be classed as low severity for network level surveys. A crack should be assessed in accordance with the inspection requirements if it has not been sealed or if it has been sealed but it is now clear that the crack sealer is no longer effective.

Alligator cracking, distortion, raveling, and bleeding have only moderate and high severity levels; there is no such thing as low severity. The averaged rut depth measurements for the left and right wheel paths are used to determine the rutting severity rating. Surface raveling should be easily distinguished from low severity potholes. Potholes should not be classified as small depressions that are less than 15 cm in diameter and 25 mm deep.

Pavement Edge Cracking (PEC)

Cracks that appear inside or outside of the pavement edge line marking, parallel to it, and within 300 mm of it. It is brought on by frost action, insufficient pavement width, poor drainage at the pavement edge and shoulder, high traffic loads, and inadequate pavement structural support at the pavement edge, among other factors.

Severity level

Level	Description
Low	Single crack with no spalling, means crack width < 5mm
Moderate	Single or multiple crack , moderate spalling, crack width 5-20mm
High	Single or multiple crack, sever spalling crack width >20mm

Transverse Cracking (TC)

Cracks that run perpendicular to the centerline or laydown direction of the pavement are known as transverse or thermal cracking, and they are typically a form of thermal cracking. Possible causes include frost action, reflection cracks, low-temperature-induced surface shrinkage, and the asphalt cement binder's sensitivity to high temperatures in asphalt mixtures.

Rutting

Shear distortion of bituminous layers, wear of the surface layer, deformation of the subgrade and unbound layers, and post-compaction are all components of surface rutting. The local climate and traffic patterns, in addition to the properties of the pavement materials, are crucial elements affecting pavement layer deformation.

Permanent vertical shear forces brought on by large vehicles, binder characteristics, and aggregate phase characteristics specifically, aggregate size distribution and their mechanical and morphological attributes are the main factors that influence the development of rutting. In this instance, surface depressions in the wheel path are caused by the pavement settling into the subgrade ruts.

Shoving (SHV)

Longitudinal displacement of localized area of the pavement surface generally caused by stop and starts of vehicles at intersection, heavy traffic on steep downgrades or upgrades, low stability asphalt mix, lack of bond in asphalt surface and underlying layer and unstable granular base etc.

Bleeding

A bright, glass-like reflective surface that feels sticky to the touch can be produced by applying too much bituminous binder to the pavement surface. Bleeding frequently happens along the wheel path due to flaws in the mix design, where an excessive amount of asphalt in relation to voids causes more asphalt to be driven to the surface by driving, especially on hot days.

Potholes (POT)

Potholes are tiny, bowl-shaped depressions that are typically smaller than one meter in diameter and appear on the base course or pavement surface. Near the top of the hole, they typically have vertical sides and sharp edges. Free water accumulating inside the whole speeds up their growth. When tiny fragments of pavement surface are worn away by vehicles, potholes are created. The pavement then keeps crumbling due to extensive alligator cracking, weak places in the base or subgrade, or poor surface quality. The majority of potholes are caused by structural distress, which is distinct from weathering and raveling.

Reveling (REV)

A rough surface that is susceptible to weather damage because to the gradual loss of pavement material from the surface downward. caused by clay-coated aggregate, wet aggregate, inadequate compaction that allows water and salts to seep in and encourage asphalt stripping, segregated mix used during construction and weathering, and poor aggregate adhesion brought on by insufficient asphalt content, among other factors.

2.1 Table summary of severity of pavement performance indicators(ERA PMS manul 20012)

Distress type	Severity level	Density measure	Bases of calculation and acceptable density value
Longitudinal wheel path cracking	L-M-H		Total length of crack divided by segment length multiple by two
Pavement edge cracking	L-M-H	Linear	Total length of crack divided by segment length
Bleeding	M-H		Total length of bleeding in each wheel path over combined 100m wheel path length
Transvers cracking	L-M-H	Number	0% - none 5%- few(1-2 cracks) 35%- frequent (3-10 cracks) 90%- throughout (>10 cracks)

Potholes	L-M-H		0% - none 5%- few(1-2 potholes) 35%- frequent (3-9 potholes) 90%- throughout (>10 potholes)
Alligator cracking	M-H	Area	0% - none 5%- few 15%- intermittent 35%- frequent 65%- extensive 90%- throughout
Rutting	L-M-H	Segment	0%- none 35%- only wheel path rut depth >3mm 90%- both wheel path rut depth >3mm

2.2 Pavement Condition Survey Equipment

Among the tools used for pavement condition surveys are

Roughness, distress, rutting, noise, and pavement cracking are all assessed using Profiler.

The purpose of Skid Trailer_ is to calculate pavement friction. Layer Thickness is determined using GPR_.

Falling Weight Deflector meters (FWD),

Which have been commonly used in the United State since the 1980s, measure the deflection caused by an impact load at different distances from the load source

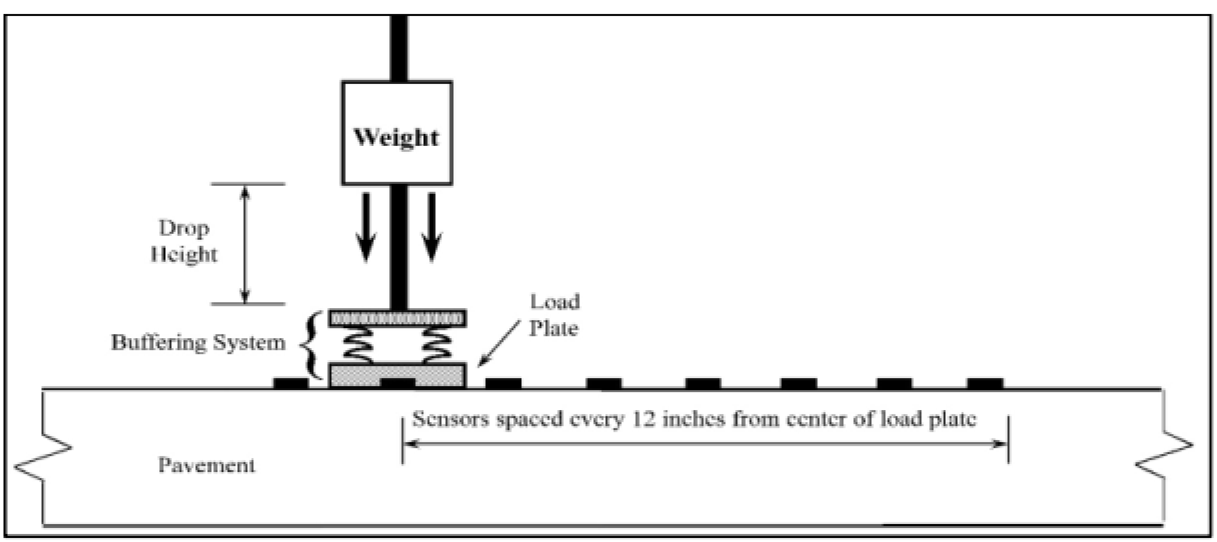


Figure 2.3 Schematic of FWD (Smith et al., 2017)

Data Analysis

Data analysis comes next when data collecting is finished. The following types of data analytics are performed in asset management systems: Analysis of the condition information gathered about each asset separately, determining which therapies are "optimal. Life-cycle cost calculation, setting maintenance treatment priorities in relation to funds.

The AMS's recognized and accepted accounting principles will be used to determine the assets' worth. Management solutions for individual assets typically do not contain the ability to calculate the asset's worth. Technical, financial, and general data analysis are all possible, although not all organizational levels will employ each sort of analysis equally (Dawson, T.A. (2012).

Table 2.2; Typical data analyses carried out by a road administration(source; asset management for the road sector, 2001)

Type of analysis	Analysis
Technical	Condition of the asset
	Causes of maintenance
	Age and degradation of the asset
	Use of the network
Economic	Budget required
	Budget allocations (e.g. budget breakdown)
	Variations in unit prices
	Deviations between out-turns and estimated costs
	Maintenance costs of assets
	Total costs and budget
General	Comparison of prioritization with political preferences
	Comparison of detailed and outline technical plans
	Changes in performance monitoring statistics
	Comparison of regional performance monitoring statistics

2.3 Pavement Maintenance Optimization System

One of the key tools used by road administrations for the study, planning, management, and evaluation of road maintenance, improvements, and investment decisions is the Highway Development and Management Model Four (David et al. 2006).

HDM-4 supports business-level decisions, such as technical and economic appraisals of road investment projects, standards, and strategies. The software helps determine the most economically efficient maintenance and improvement strategy for a road network.

However, it is twenty years since the last major upgrade, and the HDM 4 software is missing some of the coverage and functionality demanded by clients in the 21st Century in terms of: Climate Change; Resilience; Greenhouse gas emissions; Road safety benefits; Tertiary roads; Changes in the Vehicle Fleet; Wider economic impacts; Indexing of the real value of time and life; and Changing to a cloud-based service.

HDM-4 is being upgraded by the World Bank and its partners, the Asian Development Bank, the European Investment Bank, the United Kingdom Foreign Commonwealth Development Office, and the World Road Congress. A new version of HDM-4 is expected to be made accessible in 2025.

The Japan-Bank Program for Mainstreaming in Developing Countries, which is funded by the Japanese government and receives technical assistance from the World Bank Tokyo Disaster Risk Management Hub, is providing financial support for the HDM-4 Upgrade program.

The HDM-4 performance models were implemented using the Microsoft Visual Studio programming language (Randolph and Gardner 2008).

Objective	Minimization of total costs (construction costs; maintenance costs; user costs; residual value of pavements)
Data and models	Number of years of the planning period Discount rate Areas and volumes Structural and functional quality Performance models M&R actions and unit agency costs User costs model Residual value model Minimum quality levels to guarantee Annual budgets
Constraints	Verifying the minimum quality levels Using only the M&R actions defined by the infrastructure manager Not exceeding the available budget Not exceeding the maximum number of M&R actions during the planning period
Results	Maintenance and rehabilitation plan Costs report Structural and functional quality report

Figure 2.4. Maintenance optimization system components source: (David et al. 2006)

Table 2. 3 Warning levels by distress type (Ferreira 2001)

Distress type	Warning level
Cracking	Area = 20.0%
Surface disintegration	Area = 20.0%
Rutting	Mean rut depth = 20 mm
Longitudinal roughness	IRI = 5500 mm/km
Present serviceability index	PSI = 1.5

Table 2.4 Types of M&R action (Ferreira 2001)

M&R action	Description	Cost (€)
1	Do nothing	0.00/m²
2	Crack sealing	1.50/m²
3	Rut levelling	91.78/m³
4	Patching	91.78/m³
5	Longitudinal roughness levelling	91.78/m³
6	Anti-reflective cracking membrane	2.50/m²
7	Asphalt concrete layer (5 cm)	5.94/m²
8	Two asphalt concrete layers (5 cm + 5 cm)	10.25/m²
9	Two asphalt concrete layers (5 cm + 8 cm)	12.83/m²

2.3.1 Determining the Type of Maintenance

The density and overall state of the cracks frequently determine the best kind of repair for cracked pavement. Chip seals, slurry sealing, and similar techniques may be the most effective way to treat cracks that are numerous (i.e., high in density) and do not show significant edge deterioration. Crack repair techniques like partial-depth patching or spot patching might be justified if the cracks are low to moderate in density and have usually advanced to a point of high edge degeneration. Last but not least, sealing or filling procedures may be used to successfully cure cracks with a moderate density and mild to nonexistent edge degradation (Gardner 2008).

Crack sealing and filling

Although there hasn't been much differentiation between crack sealing and crack filling in the past, it is important to understand the roles and objectives of each in order to apply the most economical and durable treatment.

Crack sealing is the process of applying specialty materials in specific combinations above or inside active cracks to stop water and incompressible materials from leaking in.

Crack filling is the process of putting materials into non-working cracks to strengthen the nearby pavement and significantly lessen water intrusion. Crack movements that are larger than or equal to 0.1 in (2.5 ram) horizontally and/or vertically are referred to as working; movements that are less than 0.1 in (2.5 mm) are referred to as nonworking. This handbook assumes that the right repair technique or strategies will be explored when cracks show noticeable vertical deflections. (Randolph 2008)

Crack Characteristics	Crack Treatment Activity	
	Crack Sealing	Crack Filling
Width. in'	0.2 to 0.75	0.2 to 1.0
Edge Deterioration (i.e., spalls. secondary cracks)	Minimal to none (:>. 25 percent of crack length)	Moderate to none (:>. 50 percent of crack length)
Annual Horizontal Movement, in	> 0.1	< 0.1
Type of Crack	Transverse thermal cracks Transverse reflective cracks Longitudinal reflective cracks Longitudinal cold-joint cracks	Longitudinal reflective cracks Longitudinal cold-joint cracks Longitudinal edge cracks Distantly spaced block cracks

1 in = 25.4 mm (source pavement maintenance manual 2001)

Transverse reflecting fissures in AC-overlaid concrete pavements manifest 1–3 years after resurfacing, whereas flexible pavements show up 2–7 years after construction.

There are two advantages to caulking cracks in temperatures that are relatively chilly. In order to accommodate enough material in the fracture in the event that cutting is not done, cracks are first partially opened. Second, the crack channel's width is almost in the middle of its operating range, whether it is cut or not. Because the sealant material won't have to go through severe extension or contraction, this is crucial to its performance.

The majority of crack-filling tasks can be completed at any time of the year. Nonetheless, they frequently occur in cool or somewhat cool conditions (35 to 55°F [2 to 13°C]). Cracks are mostly or completely open at these temperatures, allowing for the application of more material.

Types of Asphalt Surface (Flexible Pavements) Treatment

Asphalt Surface Treatments refer to the reconditioning of the wearing (surface) course of older existing asphalt pavements. The term may also be applied to the final phases of new asphalt pavement construction. Surface treatments are installed by placing a layer of new asphalt binder on the existing pavement.

Fog Seal

Fog Seal is a spray application of a special asphalt emulsion (a thin liquid oil) to an existing asphalt pavement surface. It seals narrow cracks and narrow pores, restores surface color of the pavement, and preserves the underlying pavement structure.

Fog Seal contains globules of paving asphalt, water, an emulsifying agent or surfactant, and sometimes a rejuvenator. Soap is a common form of a surfactant. A rejuvenator is an asphalt additive that when applied to the existing pavement will slightly soften the pavement it is applied to creating a better bond. (AASHTO maintenance manual 2002)

Slurry Seal

Slurry Seal is the mixture of water, asphalt emulsion, well-graded fine aggregate, and some additives. It is applied in a thin layer of 3- to 6-mm layers to seal the pavement. And prevent some minor distresses such as raveling, minor/narrow cracks, crack joints, mat tearing, etc. However, it provides no structural strength. A Slurry Seal is similar to a Fog Seal except the slurry seal has aggregates as part of the mixture.

Chip Seal

Chip Seal is a rapid setting emulsion sprayed onto the pavement followed by rolling in the high-quality, washed, crushed, and single-sized aggregate typically 9.5 or 6.7 mm. A Chip Seal is named after the chips or the small crushed rock on the surface. A Chip Seal seals the narrow cracks, helps bind the cracked pavement together, provides a wearing surface, and prevents reflective cracking.

Asphalt emulsions used in Chip Seal applications contain globules of paving asphalt, water, an emulsifying agent or surfactant, polymer, and sometimes a rejuvenator. (ERA, PMS manual 2012)

Cape Seal

Cape Seal is a chip or scrub seal that is applied first, and then slurry seal or micro surfacing is applied subsequently. The existing pavement's fissures are sealed and bound using a chip or scrub seal. The driving surface's smoothness and chip retention are enhanced by the Slurry Seal or Micro surfacing.

Coats

Prime Coat is a low-viscosity liquid asphalt or emulsified asphalt used to seal a granular surface prior to the placement of surface treatment. Tack Coat is an emulsified asphalt-diluted slow setting that is applied to existing pavement surfaces. The placing of Tack Coats ensures good bonding between the layers. (ERA, PMS manual 2012)

2.4 Pavement management practices for different countries

I. Uzbekistan road asset management systems

The definition of asset management in the paragraph above essentially means the same thing, with a small variation based on the objectives and tactics of each road agency. Effective and efficient utilization of cash to meet public demand are the important phrases in all definitions.

The suggested two-way asset management system monitoring approach is depicted in the blow figure. In order to meet public expectations, a road agency applies engineering concepts and good business practices when providing services.

To assess agency performance, road agencies keep an eye on key performance indicators including technical, economic, and others. Road users' feedback sheds light on how satisfied they are with the services they receive.

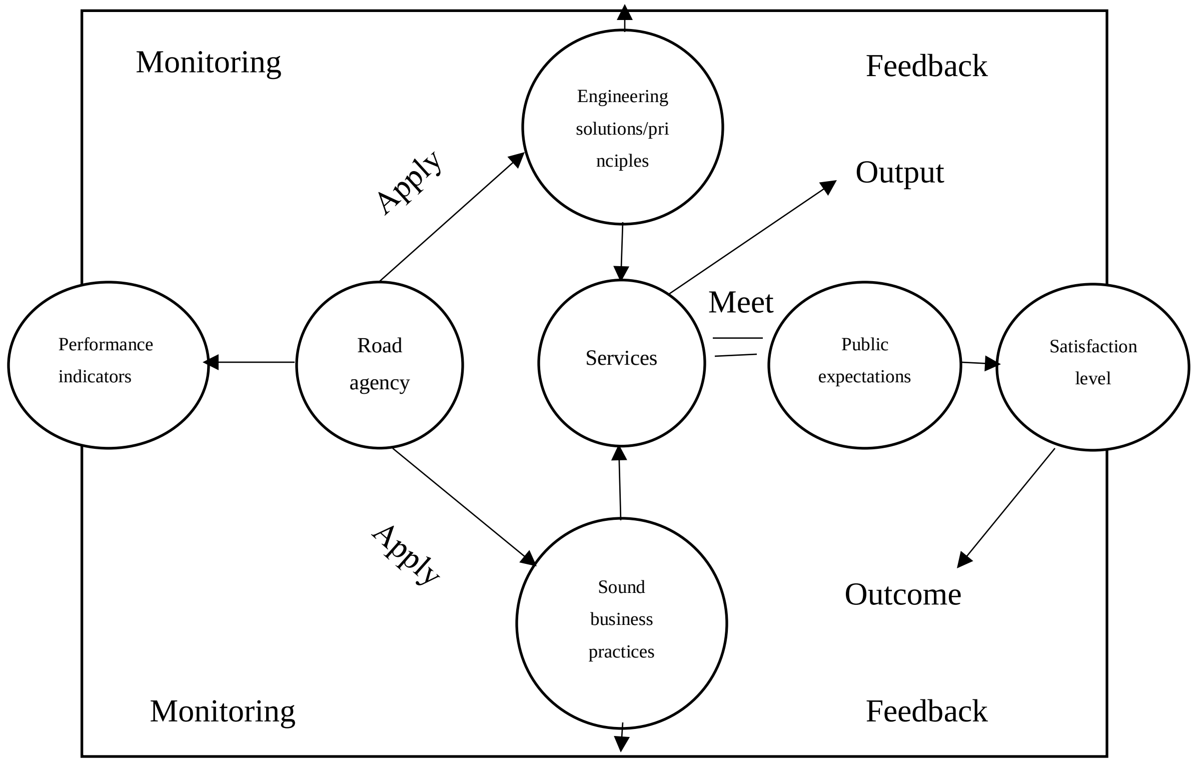


Figure 2.5 Two-way monitoring scheme for Road Asset Management System source; (Sodikov J.I. 2007)

Because automated road data collecting and data management systems are expensive, it is difficult to deploy the road asset management system that are now in place in wealthy nations in developing nations. From the perspective of new and inexpensive technologies like mobile, GIS, and the internet, which are developing quite quickly in this region of the world, the other side of the coin is the absence of standards, norms, and research in the field of road asset management systems. The process of modifying the current pavement management system so that road agencies may improve optimization through proper assessment, maintenance, and rehabilitation projects. More advanced methods and systems are being used by developed nations to forecast asset performance and improve budget optimization. ***(Sodikov J.I. 2007)***

II. Republic of Tajikistan, japan, 2016 PMS

In the Republic of Tajikistan, the Ministry of Transportation orders the commission to conduct an annual road inspection for national and international roads as well as railway crossings. This is done in coordination with MOT, SETM, SEHM, and the Traffic Police to ensure that traffic safety standards are being met. Inspection-found flaws are filed as maintenance orders to the appropriate authorities. In addition, the SEHM maintenance team keeps an eye on the state of roads every day.

It is the duty of road authorities like MOT, SETM, and SEHM to offer road users quality service all year round. Without a doubt, one of the most crucial tasks is maintenance. The pavement's lifespan can be extended by systematic maintenance that includes routine inspections and preventive repairs (see the figure below). This cycle helps to reduce both the amount of effort and the expense of maintenance. Using eye examination and the International Roughness Index (IRI), this guideline presents a pavement inspection approach. The purpose of these guidelines is to help road authorities manage pavement repair in a methodical manner.

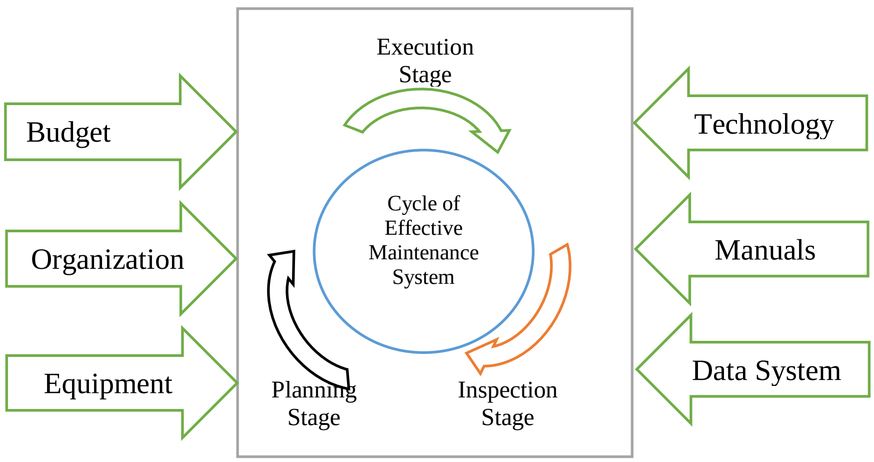


Figure 2.6 Road Maintenance Cycle (pavement inspection guide line, japan, 2016)

Cracks, rutting, smoothness, and potholes are the most significant types of pavement flaws that primarily affect pavement service (life, road safety, and driver comfort, etc.). Pavement inspection should adhere to a standard inspection approach in order to effectively monitor such defects.

Table 2.5 Typical Pavement Defect and Inspection Method (pavement inspection guide line, japan, 2016)

Inspection item	Method	Type of pavement defect				
		Crack		Rutting	Smoothness	Pothole
		Linier	Alligator			
IRI	Devise (ex.DRIMS)	Δ	○	Δ	◎	○
Crack	Visual	◎	◎	◎	Δ	-
Pothole	Visual	-	-	-	Δ	◎

◎ : Most applicable, ○ : Applicable, : Δ Less applicable

Using IRI, crack ratio, and pothole rank, RRI (Repair Requirement Index) calculates the necessity of pavement restoration.

Table 2.6 Standard Pothole Rank (pavement inspection guide line, japan, 2016)

Pothole Rank	Condition	Criteria	**A**
A	No Pothole	No pothole neither no repair patching	**1.0**
B	Few Potholes	1 to 5 potholes or patching per 100m	**1.0**
C	Several Potholes	5 to 20 potholes or patching per 100m	**1.1**
D	Many Potholes	More than 20 potholes or patching per 100m	**1.2**

Table 2.7 Standard Crack Rate (pavement inspection guide line, japan, 2016)

Crack Rate	Typical Condition	**B**
0% to 30 %	**New Pavement**	**1.0**
30 % to 50%	**Partial Crack** "Longitudinal Cracks 'Traverse Cracks	**1.0**
50% to 70%	**Jointed partial Crack** "Longitudinal crack and traverse crack joint and covers all surface	**1.1**
70% to 1OO%	**Dense Alligator Cracks** "Agitator crack smaller than 0.5x0.5m covers whole surface	**1.2**

Criteria for Prioritization

Pavement maintenance priority can be set by consideration of a large vehicle traffic volume and a current pavement condition.

Table 2.8 Group and Maintenance Priority (pavement inspection guide line, japan, 2016)

Prio1ity	Group	Maintenance Schedule	Budget Allocation Priority
1	Group 1	This Year	Highest
2	Group 2	Next Fiscal Year	2nd Highest
3	Group 3	ln 3 - 5 years	Less Priority
4	Group 4	In 5 - 10 years	Less Priority

III GHANA

The Ghana Highway Authority, the Department of Feeder of Federal Roads, and the Department of Urban Roads are the three agencies under the Ministry of Roads and Highways' management of Ghana's roads. Trunk road design, development, maintenance, and administration fall under the purview of, which has changed road maintenance over the past ten years from mostly using an in-house force account approach to at least 90% contracting out labor. In order to provide tools for successfully and efficiently managing road maintenance in Ghana, a computerized Road Maintenance and Management System is presently being developed as part of a Road Maintenance Project funded by both GHA and Gesellschaft für Technische Zusammenarbeit.

It is anticipated that this system will include elements for work execution, budgeting, and planning. Road inventory, road condition survey, and data storage system will be addressed under the planning and budgeting component; maintenance activities, performance standards, and work supervision will be taken into consideration under the work execution component. By reducing the amount of time needed for paperwork and improving the quality of the work, the use of sophisticated maintenance management systems, such as computerized road maintenance management systems, would boost performance and efficiency (GHA, 2007).

IV Ethiopian pavement management practice

Different PMS user guides are used to structure the ERA pavement management system. The PMS user handbook for PMS Operations, which covers every PMS procedure, is the most comprehensive of these user manuals. The operational steps required to support and maintain the data management of the ERA Pavement Management System (pavement management system) are outlined in this PMS User Manual. All of the ERA's PMS supporting documentation is described in the handbook. The HDM-4 software applications' customized ERA PMS systems are explained in the ERA PMS User Manual for HDM4 Operations.

Following a road survey using the HAWKEYE equipment, the steps to be taken are described in the ERA Manual for HAWKEYE Data PMS User Processing. Database operations in HDM-4 life cycle cost estimates are covered. In addition to providing guidance on how to further adjust the survey data for entry into ERA's DTIMS database, the handbook also explains how to process and export the distress and profile data.

The following information about the HDM-4 series is included in the official set of HDM-4 manuals: Applications Guide, Software Users Guide, Evaluating the Analytical Framework and Model Descriptions of the Ethiopian Roads Authority's (ERA) Pavement Management System (PMS), a Guide to Calibration and Adaptation, and Modelling Effects. User Manual for DTIMS V8 the DTIMS software application's official user manual was released in March 2011. It covers every facet of the DTIMS software program required to keep up a road network database in DTIMS. In his thesis, (Seid 2015) shown that the components of ERA's pavement management system operation are:

1. Equipment for Data Collection: The Hawkeye 2000 system is used to collect data for the PMS on paved roads, and the Hawkeye 1000 system is used on dirt roads. The Hawkeye 2000 system in the Mercedes Benz Vito gives information on paved roads, including potholes, drainage facilities, rutting, cracking, raveling, roughness, and structural issues. The Nissan Patrol station waggon is equipped with the Hawkeye 1000 system, which offers information about unpaved surfaces, including drainage status, roughness, and the quantity and quality of wearing courses.

All data are loaded into the DTIMS database after being processed in the Hawkeye Toolkit program, verified, and merged or mixed in the specialized pre-processing software application. After that, a specialized conversion application is run to transform the data into the HDM-4 input file specifications. Following life cycle strategic and program analysis, HDM-4 provides ERA Management with decision support about maintenance plans and long-term programs. In addition to the aforementioned tools, ERA also uses a Falling Weight Deflector-meter (FWD), which is hauled by a different Nissan patrol station wagon. Road pavement structural strength data is provided by the FWD. In order to depict the pavements' current strength, HDM-4 records the structural strength data.

2. Daily operations: Maintaining any PMS is a constant, ongoing undertaking. It involves tasks including analyzing survey data, importing data into Era DTIMS, and regularly updating it.

3. A new survey cycle has begun: ERA's road network to be surveyed should be listed together with paved and unpaved roads at the beginning of each survey cycle. After that, the surveyors and PMS staff who are in charge of overseeing the yearly surveys can receive the list of roads.

4. Traffic information in DTIMS from the "Traffic" perspective: The HDM-4 software's strategic study of ERA's road network heavily relies on traffic statistics. It affects road user costs in economic analyses, the rate at which roads deteriorate, and the strategic planning of road construction projects under budgetary constraints.

5. Falling Weight Deflection (FWD) data: ERA's DTIMS database's "FWD" perspective is where deflection data gathered from the FWD equipment should be kept. The HDM-4 analysis will automatically incorporate the FWD data that has been gathered for any segment of the road network after it has been entered into ERA's DTIMS database.

6. Information about the condition index: The state Index (CI) describes the overall condition of the road. The processed profile and distress data are used to calculate a single Condition Index (CI) that characterizes the overall condition of a road segment for a specific year. A road section in extremely poor condition is represented by a CI of 0, and a road segment in very good condition is represented by a CI of 100. It is calculated for each surveyed road segment.

A mediocre network the unpaved road network's average condition throughout a specific year is represented by CI. This average network CI is weighted by length. Five condition categories—very good, good, fair, poor, and very poor—can be used to categorize the state of the paved or unpaved road network using the CI. The accepted classifications are as follows: very good (86%) to 100%, good (71% to 85%), fair (51% to 70%), poor (36% to 50%), and very poor (0% to 35%).

The following problems that come up during the ERA pavement management system procedure were noted by Seid (2016) in his thesis: Lack of trained personnel (i.e., only one employee with PMS training), Road data: inaccurate and difficult to maintain in a systematic fashion; in this respect, the PMS standard handbook is not fully implemented. Only level 1 calibration of HDM-4 has been carried out by ERA since the new PMS was introduced in 2011; level 2 and level 3 calibrations have not yet been completed. Delays in maintaining data collector equipment and its breakdowns, Ignorance of data collector personnel , Inadequate PMS performance , An error occurred, causing the system to freeze, Why the profiler's status remains "not connected" even after all required modules have been launched., The Hawkeye 1000 Series and FWD hydraulic system failure

The ERA pavement management system's implementation level is impacted by the aforementioned issues. Therefore, in order to improve the current pavement management system, issues must be addressed.

Road prioritization

One commonality is that any maintenance project prioritization is dependent on the budget allocation derived from the network view and only considers the upcoming fiscal year. When maintenance management aims to maximize benefit, prioritization becomes an effective tool to support decision-making. Vanier (1999) lists the following six "what's" of asset management in order of importance: What do you own? What is its worth?, What is its condition?, What is the remaining service life? And what is the maintenance required?

Roads can be prioritized using a variety of methods. For instance, Reddy and Veeragaven (2004) created a system that assigns a priority index to various sections determined by their overall distress index model and traffic adjustment parameters carried out a study using the architectural analytical hierarchy method to prioritize the upkeep of UN-paved roads in northeastern Brazil.

Road maintenance plan

Roads are designated for maintenance based on their maintenance ranking and financial availability. Depending on the state of the roads and the amount of money available, the maintenance engineer and his team conduct field inspections to ascertain what needs to be done.

Following the identification of a list of maintenance tasks and their locations, the estimated quantities of each task are measured, and the estimated cost of execution is calculated using market rates. This is done in order to prevent deviations while doing maintenance tasks (Robinison, 2011).

2.5 Pavement Performance Modeling

An accurate performance prediction model is necessary for the pavement management system (PMS) to be implemented successfully in order to optimize maintenance and rehabilitation plans across the pavement service life. "A mathematical description of the expected values that a pavement attribute will take during a specified analysis period" is the definition of the pavement performance prediction model, which is referred to as an engine in a pavement management system (Hudson et al., 2008).

Pavement performance models can be used to establish repair priorities based on available funds and to estimate future maintenance requirements and budgets. These models allow for the forecasting of future pavement conditions, which may then be utilized as inputs to the maintenance strategy to determine the necessary M&R (maintenance and rehabilitation) actions. The way that pavement deteriorates over time is another way to define pavement performance (Lytton, 1987, Miller 2002). Agency engineers can use prediction models to determine what, when, and where maintenance should be performed (George, 2000). The behavior of an existing pavement segment in projecting its future performance is depicted in the image below.

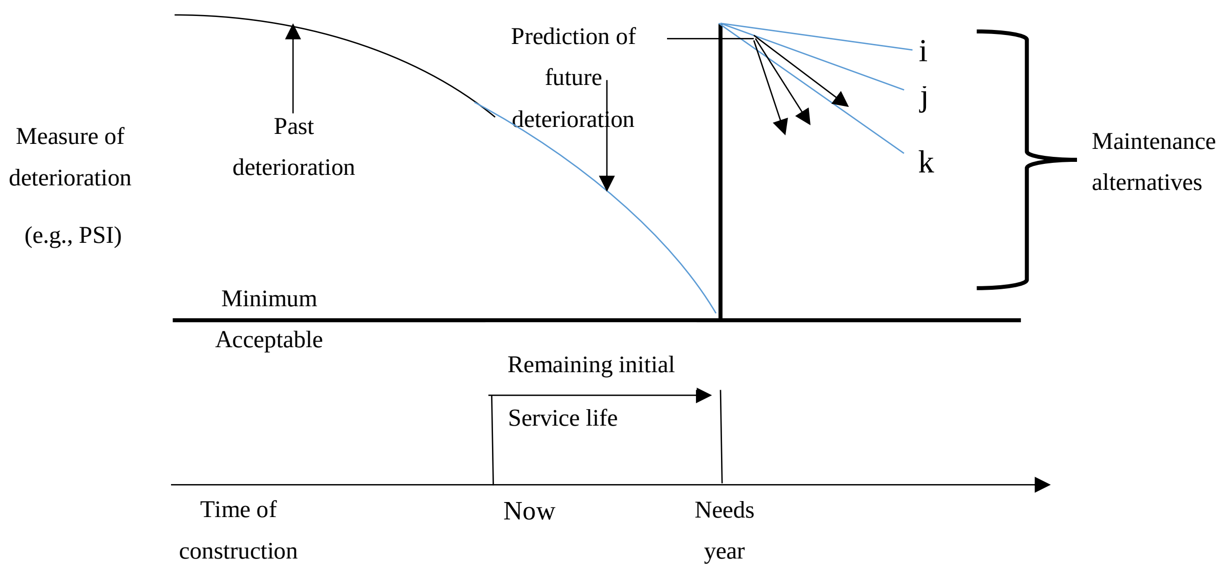


Figure 2.7 Illustration of pavement performance over time (Haas et al., 1994)

To decide on maintenance and rehabilitation plans, a prediction model can be used at the network and project management levels. The prediction model can forecast a pavement's future state, the necessary budget, and the order of projects at the network level. At the project level, pavement performance prediction models are used to prioritize projects, calculate life cycle costs, and identify several options for maintenance and rehabilitation for each potential project. By predicting pavement performance based on traffic loading, environmental conditions, and structural characteristics, transportation agencies are able to prioritize their projects and distribute funds (Hong and Prozzi, 2006).

Pavement management systems rely heavily on performance prediction models for the following tasks: estimating future pavement conditions; determining when maintenance and rehabilitation actions should be taken; identifying the most economical treatment plan for a pavement network; estimating the amount of money needed to meet agency goals; and assessing the effects of various pavement investment strategies (AASHTO, 2012).

The PPP models should be carefully chosen. If not, they can increase the cost of the road infrastructure system and make it hard to schedule projects, design the pavement, and select the best restoration methods (Attoh-Okine 1999). In early PMS, there were no PPP models available; instead, they only evaluated the pavement's condition. Pavement age was the only predictive feature taken into account in later, simplified PPP models. According to Kulkarni and Miller (2002), these models were frequently based on engineering judgements on the projected design life of various M&R actions.

2.5.1 Modeling Techniques

Pavement performance was developed using a variety of methods. The expert system, probabilistic model, mechanistic model, empirical (regression) model, and mechanic-empirical model are some of these methods. Regression models were determined to be very appropriate for this research because the given data lacked certain crucial elements (Attoh-Okine 1999).

Regression analysis was straightforward, easy to construct, and incredibly practical. These factors led to the use of this technique in the analysis to derive pavement performance curves. The literature also underlined how crucial it is to comprehend the underlying ideas of each model in order to choose the appropriate model type and shape. The availability of the data required to create the models and their ongoing updating in response to developments are crucial. Understanding each model's restrictions is also essential to preventing its use outside of its intended range. These suggestions serve as the foundation for the creation of trustworthy performance models throughout time, and each of these requirements is covered in further detail in the sections that follow (Miller (, 2002).

There are two types of pavement performance modelling: deterministic and stochastic. Deterministic and stochastic performance prediction models differ primarily in their modelling development principles, modelling technique or formulation, and model output format (Li et al. 1996). This paper discusses the advantages and disadvantages of several deterministic and stochastic pavement performance modelling approaches.

2.5.2 Deterministic Models

Deterministic models frequently forecast a single dependent value (such as pavement condition) using one or more independent variables (such as pavement age, historical cumulative traffic, environment, and pavement design attributes). Most deterministic pavement performance models are based on regression analysis, which uses two or more variables in a mathematical equation to predict the dependent variable (performance measure) as a function of the independent variable. To reduce the difference between the regression line and the real data, the coefficients of the equations are evaluated using least squares regression.

In order to choose the model that best fits the data, linear least squares regression estimates coefficients by minimizing the sum of the squared variances between the observed and predicted values. The deterministic model forms must be restricted in such a way that conditions continuously deteriorate with increasing time and/or traffic in order to produce accurate forecasts in the PMS.

1. A dependent variable's behavior is explained by the independent variable's behavior in a linear regression model.

$y = b0 + b1x$ (1-1) source: (***Li et al. 2006)***

Where:

y = dependent variable

x = independent variable

b0 and b1 = coefficients

An S-shaped degradation curve is frequently the basis for the regression equation. Equations 1-2 illustrate higher order (polynomial) regressions, which produce curvilinear correlations between the independent and dependent variables.

$y = b0 + b1x + \ldots + bnx\ n$ (1-2)

Where:

y = dependent variable

x = independent variable

b0, b1, …bn = coefficients

The primary distinctions between the two regression techniques are that the multiple variable regression model can take on a more complex equation structure and that the coefficients are no longer linear.

A power function, like the one employed by the Washington State Department of Transportation, is another common deterministic equation form for pavement management. Equation 1-3 provides an illustration of the equation's power form.

$y = b0 – b1x1^{b2}$ (1-3)

where:

y = dependent variable

x1 = independent variable

b0, b1, b2 = coefficients

The following picture illustrates how the three model forms linear, polynomial, and power could forecast the pavement's condition in relation to its age.

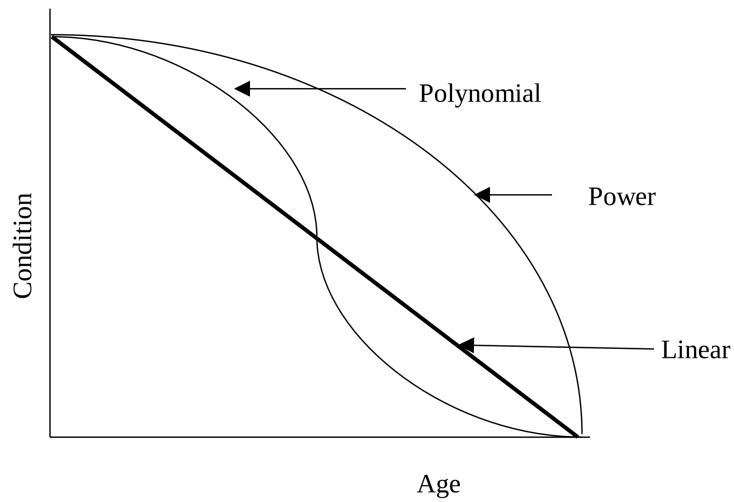


Figure 2.8 Different form of regression model. (**Li **et al. 2006)

Some organizations think about using numerous variables in addition to developing regression equations based on a single variable. The performance of a dependent variable is estimated using the behaviors of numerous independent variables in a multiple regression model. Equation 1-4 displays the equation's general form, which is an enlarged version of the linear least squared regression equation.

y = b0 + b1x1 + b2x2 + … bnxn (1-4)

where:

y = dependent variable

x1, x2, …xn = independent variables

b0, b1, b2, …bn = coefficients

Because there are several independent factors, agencies might want to find out how some of the variables interact with one another. In addition to incorporating these variables separately, variables that combine two independent variables can be created in order to assess the interactions between the terms. The product of the two variables may also be included in the equation and added as another term (x1*x2) in equations 1-4, for instance, if pavement thickness and traffic are both included as independent variables. Each of these variables may be represented as x1 and x2 in the equation. Because it increases the number of variables included in the study, incorporating these kinds of interactions makes the regression analysis even more difficult. Multiple regression can be a somewhat time consuming process because the variables included in the final multiple regression equation must be determined through a step-wise addition and deletion process or the use of statistical software to automate this process (Miller (2002).

However, because there are more variables unique to a section, using numerous variables (as opposed to just one) may improve the estimation of that section's performance. Two sections from the same family will have the same expected performance if they have the same beginning condition if a single variable, like age, is employed. However, you need to be sure of a variable's value if you're using it to forecast performance.

The most widely utilized models in pavement management are probabilistic and deterministic models. Deterministic models are used by most SHAs. For instance, the Arizona Department of Transportation (ADOT) has used non-linear regression analysis to create deterministic pavement performance models based on polynomial functions that provide an S-shaped curve. Two main types of pavement performance models are used by ADOT: one is based on the degree of cracking at a specific age, and the other is based on the Pavement Serviceability Rating (PSR), which is determined by the International Roughness Index (IRI). ADOT groups pavements with comparable qualities into a single category using a family-based approach. The following categories are considered for the development of the family classifications: last rehabilitation activity, pavement type, environmental conditions, traffic, subgrade conditions, and structural thickness (Li et al. 2006). Primary response, structural performance, function performance, and damage models are examples of deterministic models. There are three distinct kinds of deterministic models: regression, mechanistic, and mechanistic-empirical models.

A. Mechanistic models

Response characteristics including stress, strain, and deflection are related to each other in the mechanistic models (Li et al. 1996).

B. Empirical (Regression) Models

An empirical association between two or more variables was established using this approach. The mean of each variable as well as the lowest and maximum variation limits were provided. The most widely used approach for creating a deterministic empirical model is regression analysis. The chosen set of characteristics served as the independent variables in the regression models, with pavement condition (PCI) serving as the dependent variable. The components that should be included as independent variables were chosen using a statistical technique. Depending on the connection between the independent and dependent variables, the regression models may be either linear or non-linear. (Luo, Z. (2006)

Building Regression Models Using the Available Database

Various factors can affect pavement performance. The factors considered in the present study were roadway class, present pavement condition, pavement age, traffic level, and maintenance type.

1. Roadway Class

Riyadh Municipality classifies the roadways into two classes, main and secondary streets. Roadway class can affect the maintenance policy and criteria to a high extent, for example, the critical serviceability for main streets may be higher.

2. Pavement Age

The deterioration of paved roads is partly related to pavement age. Over time, the hardening of asphalt increases, thus making it more brittle and susceptible to cracking. In the pavement performance model development, pavement age was measured from the date of construction or from the date of the last major maintenance.

3. Traffic Level

Pavement deterioration is highly affected by traffic volume and vehicle types.

4. Maintenance Type

The type of M&R performed affects the pavement performance. Four maintenance strategies were considered in this project: no maintenance, basic routine maintenance (low, normal, and high), overlay, and reconstruction.

C. Mechanistic-empirical models

The relationship between roughness, cracking, and traffic loading is illustrated by mechanistic-empirical models. On the other hand, regression models show how a performance measure (like the riding comfort index, or RCI) and a predictive parameter (like pavement thickness, pavement material characteristics, traffic loading, and age) are related (Li et al. 1996). Many deterministic models, such as generalized models, time-related models, traffic-related models, and interactive-time-related models, have been developed for regional or local PMSs (Attoh-Okine 1999).

2.5.3 Pavement Performance Modeling Practices of different countries

I. United State

The evolution of pavement condition or distress over time is frequently used to represent the performance of a pavement segment. When compared to the threshold value, the performance level at any particular moment is equal to the pavement condition or discomfort level at that moment. Thus, the amount of service over time or the accumulation of damage over time determines a pavement segment's performance over its service life. Desaraju, P., and Gilliland, D. (2005). Most State transportation departments collect pavement condition and distress data. Some use the data to observe the condition of the pavement, while others use the time-series pavement condition and distress data to predict future pavement conditions. The combination of both practices allows the development of current and future strategies for management of the pavement network.

Using historical pavement performance data, numerous state transportation departments have investigated the efficacy of different pavement treatments. The minimum and maximum treatment service lifetimes for each treatment type were published in the various sources listed based on the various studies. These approximated averages are sufficient for use in network-level analysis. More precise estimations are needed for analysis at the project level. By modeling pavement condition and distress data before and after treatment to develop pavement performance curves, such assessments could be based on projections of past and future pavement conditions.

Table 2.9 Estimated and reported pavement treatment service life. (Desaraju, P., and Gilliland, D. (2005).

Treatment Type	**Estimated treatment service life expectancy (years)**		
	Minimum	**Average**	**Maximum**
Thin (< 2.5-inch) hot-mix asphalt (HMA) overlay	2	8	12
Thick (≥ 2.5-inch) HMA overlay	6	10	17
Single chip seal	1	6	12
Double chip seal	4	9	15
Thin (< 2.5-inch) mill and fill	4	8	20
Thick (≥ 2.5-inch) mill and fill	6	10	17
Cold-in-place HMA recycling	5	10	20
Crack sealing	2	3	10
Micro surfacing	4	6	10

1 inch = 25.4 mm.

Ordinary least squares regression is the most often used technique for modelling pavement condition and distress data as a function of time. It should be mentioned that in order to model the nonlinear data, at least three time series data points are needed. The sum of squared errors is minimized in order to establish the parameters of the chosen mathematical formula.

This approach is effective when the pavement segment's data shows deterioration over time. Other models would be needed if the approach fails to account for the way that a condition or discomfort develops over time. Z. Luo (2006).

$$RD = \gamma t^{\omega}$$ Rut depth equation

$$IRI = \alpha e^{\beta t}$$

RII equation

$$Crack = \frac{k}{1 + exp[-\theta(t - \mu)]}$$

Crack equation

Where:

RD = Rut depth; *k*, , and = Regression parameters; *Crack* = Crack length, area, or percent; *t* = Elapsed time in years.

The amount of time until a particular threshold value is reached can be estimated using such models. The threshold is a predetermined condition or degree of distress that, depending on the level at which the predetermined threshold value is established, indicates that the pavement segment requires repair, preservation, or rehabilitation because the undesirable pavement condition or distress has been reached. Originally developed by Spathe and subsequently updated by others, the cluster wise regression algorithm is another technique for modelling pavement condition and distress data (Luo, Z. (2006)). Splitting the data into subgroups according to their features and fitting distinct models to each segment is known as cluster-wise regression.

II. The Department of Transportation in North Dakota (NDDOT)

For pavement families with recurring deterioration patterns, the NDDOT creates a multiyear prioritized program using the pavement performance models. To choose the best rehabilitation therapies for different functional classes, condition levels, and geometric scenarios, decision matrices are created. To ascertain the quantity and timing of rehabilitation that offers the agency the most cost-effective plan during the analysis period, the NDDOT uses the BCR (Paterson, 1987).

A number of transportation-related topics are addressed by the U.S. transportation authorities in the RIAMS, including the evaluation of investment strategies using performance data and systematic processes. This makes it possible for transport agencies to successfully respond to government initiatives aimed at increasing efficiency and raising customer expectations as well as budgetary restrictions (FHWA, 2012).

Both asset management efficiency and the accountability of the transportation agencies are improved by the integration of LCCA into the RIAMS. The adopted RIAMS assesses the annual percentage of depreciation paid and accounts for any unfunded depreciation as an agency liability in order to determine the financial sustainability of the investment programs (FHWA, 2012). The assessment of the relative benefits of capital and operating investments, risk-based estimation, dynamic traffic loads during the pavement's lifespan, and the identification of various failure-related costs have not yet been considered by the transportation agencies.

III Australian approaches

Several performance metrics are used by the Australian internal, and lower levels of management. National performance indicators, such as road safety, registration and licensing, road construction and maintenance, environment, program and project assessment, travel time, lane occupancy rates, and user charges, are published annually by the transportation agencies at the highest level (OECD, 2001).

Program efficiency, user satisfaction, road-user costs, freight movement and heavy vehicle access, route reliability with regard to flooding, levels of private investment from developers and on toll-ways, environmental performance, contracting performance, administrative overheads, and stakeholder acceptance of the road implementation program are just a few of the performance indicators that agencies use at the internal management level. The trend in road pavement or bridge condition, as well as measurement parameters for a route, sub-network, road category, or area, are among the performance indicators used by local transportation agencies (OECD, 2001).

IV Portuguese approach

The Portuguese RIAMS has significant shortcomings, including faulty empirical models and a dearth of historical data. The conventional empirical models are flawed in two ways. Initially, the direct modelling of transition probabilities has proven to be expensive and ultimately fruitless. Second, these approaches don't address how to manage the overall budget restrictions without requiring pointless subjective trade-offs between road types or how to incorporate engineering information into models (Golabi & Pereira, 2003).

The Portuguese Pavement Management System (PPMS) was proposed by Golabi and Pereira (2003). This system successfully tackles the following issues: (1) how to handle incomplete data; (2) how to close the gap between network optimization and real-world projects; (3) how to accurately integrate engineering knowledge into models; and (4) how to handle overall budget constraints without needless subjective trade-offs among road categories.

The Pavement Rehabilitation and Improvement Strategic Model (PRISM), a GIS, the data bank, and the Pavement Quality Evaluation Model (PQEM) are some of the components that make up the PPMS (Golabi & Pereira, 2003). Although it doesn't require any prior data to begin, the PPMS may readily include engineering opinion and use historical data. For both short-term and long-term planning horizons, the PPMS system offers an interactive budget planning paradigm that lets users add flexibility to budgetary and performance-level limitations. After that, the system will choose the best option among workable possibilities (Golabi & Pereira, 2003).

V Japanese approaches

The technical and in-depth debates on defining the RIAMS and road infrastructure are only getting started in Japan. The performance of the road network and transport system cannot yet be measured using any general-objective metrics. The roughness, rutting, and cracking of pavement surfaces are used to calculate a Maintenance Control Index (MCI). Roughness is used to compute the RCI (OECD, 2001).

Comparative evaluation

Since it involves more stakeholder perspectives, broader objectives, and longer time horizons, managing road infrastructure systems is a challenging undertaking (Zeb et al., 2013). Assessing the degree to which current RIAMS methods achieve maturity is challenging.

The generally relevant "must do" items for asset management are included in ISO 55000 (Woodhouse, 2013). The ISO 55000's main themes are: (1) organizational goals that are clearly aligned with asset management strategies, goals, plans, and daily operations; (2) asset management planning throughout the entire lifecycle and interdisciplinary collaboration to attain the best value combined outcome; (3) risk management and risk-based decision-making; and (4) the development of a discipline at various learning, innovation, and feedback levels (Woodhouse, 2012; 2013).

Nevertheless, according to Woodhouse (2013), the ISO 55000 makes little effort to specify "how to" carry out the "must do" components of an asset management system. Technical, accounting, or financial guidance for managing particular asset categories is not included in ISO 55000 (Woodhouse, 2013).

Zeb et al. (2013) established the Infrastructure Management-Process Maturity Model (IM-PMM), which is used in this study to compare and quantify RIAMS procedures and determine the extent of improvements. Asset inventory management, condition management, service life analysis, LCCA, risk analysis, and decision-making analysis are the components that make up the IM-PMM framework (Vanier et al., 2009; Zeb et al., 2013).

The five stages of maturity, which represent escalating degrees of formalization or process maturity, are used to evaluate the IM-PMM's aforementioned functions. The specific role of the IM-PMM has not yet begun, or has begun, but only at a very basic level, during the infancy period. The function has only been defined; it is not being used. As the definition is documented but still in its early stages of practice, the preliminary stage suggests that the function is at the beginning level. The definitions of the functions in the reactive stage are situation-specific and not recorded for future use.

They are dynamic and constantly evolving in relation to context and time. The function definitions are standardized and recorded for future use during the Proactive step. The functions are actively controlled in accordance with the standardized process definitions during the integrated stage. Continuous improvements are sought after, and data is gathered to assess the functions' efficacy and success (Zeb et al., 2013).

Table 2.10 Comparative evaluation of PM model for different countries

Functions	Details	Approaches						
		U.S.	Canadian	Australian	New Zealand	Portuguese	Japanese	Polish
Inventory management	Enumerating, listing and storing of the information	Integrated	Proactive	Proactive	Proactive	Preliminary	Proactive	Proactive
Condition assessment	Evaluation of the existing condition based on the historical data, engineering model and customer priorities	Proactive	Reactive	Proactive	Proactive	Preliminary	Infancy	Proactive
Service life analysis	Determination of the remaining or residual life of the assets based on the prevailing condition assessment of the asset	Integrated	Reactive	Integrated	Integrated	Preliminary	Infancy	Preliminary
Life-cycle cost analysis (LCCA)	Assessment of the cost over the life cycle of the asset based on proposed maintenance scenarios	Integrated	Preliminary	Integrated	Integrated	Preliminary	Infancy	Preliminary
Risk analysis	Evaluation of the risks associated with the asset over its life cycle	Proactive	Preliminary	Reactive	Reactive	Infancy	Reactive	Infancy
Decision making analysis	Analysis of proposed alternatives and selection of the best alternative for M&R of the asset including the agency cost, road user costs and socio-economic developments	Reactive	Preliminary	Reactive	Reactive	Infancy	Infancy	Preliminary

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 Introduction

According to Easterby-Smith et al. (2001), a research methodology is a set of methods used to investigate a problem and provide conclusions. It covers the methods by which the researcher gathers information about the phenomenon being studied and draws conclusions. A critical research process design would be necessary for the selection of the best research methodology, approach, and operationalization of the same. The research endeavor should be directed by methodically planned methods that reinforce one another in order to produce high-quality results.

A research methodology is a set of methods used to investigate the topic being studied and come to a conclusion; in other words, the set of methods utilized to carry out the research. Probably the most crucial phase in a research study technique is defining the research topics. This study's primary goal is to assess PMS's present practice, create models for predicting pavement performance using data on pavement conditions over the last eight years, and forecast pavement performance over the next five years. Age, weather, traffic volume, and pavement thickness will all be factors in the pavement prediction model. Other than age, the researcher is unable to discover sufficient information.

Therefore, the connection cannot be reliable in the absence of enough and accurate data. Roughness, rutting, vertical deformation, potholes, patching, shoving, edge break, and pavement cracking are therefore associated with pavement age, according to the study.

Accordingly, a research study is concerned with both the topics it examines (the problems, the data, and the findings) and the methods used to gather the data and draw its conclusions (the methodologies) (Fellows and Liu, 2008).

3.2 Research design

A research design is a logical step that connects the empirical data of a study to the research question and, eventually, to the conclusion (Yin, 2003). Its steps include deciding which question to study, identifying pertinent data, developing mechanisms, collecting data, and analyzing the data to reach a conclusion (Philliber et al., 1980).

With a primary focus on the rules, procedures, and technology utilized in road asset management, the study examines the pavement management practices now employed by the Ethiopian Road

Administration (ERA). Models for forecasting future pavement performance of road conditions will be created based on data gathered from ERA in order to optimize cost and schedule maintenance.

The pavement performance prediction model will be developed using data on pavement conditions from the past and present. Regression analysis is used in this work to forecast the likelihood of future pavement conditions. More than ten years' worth of pavement condition data should be used to obtain precise and reliable PPP results. The study's producer is depicted in Figure 3.1.

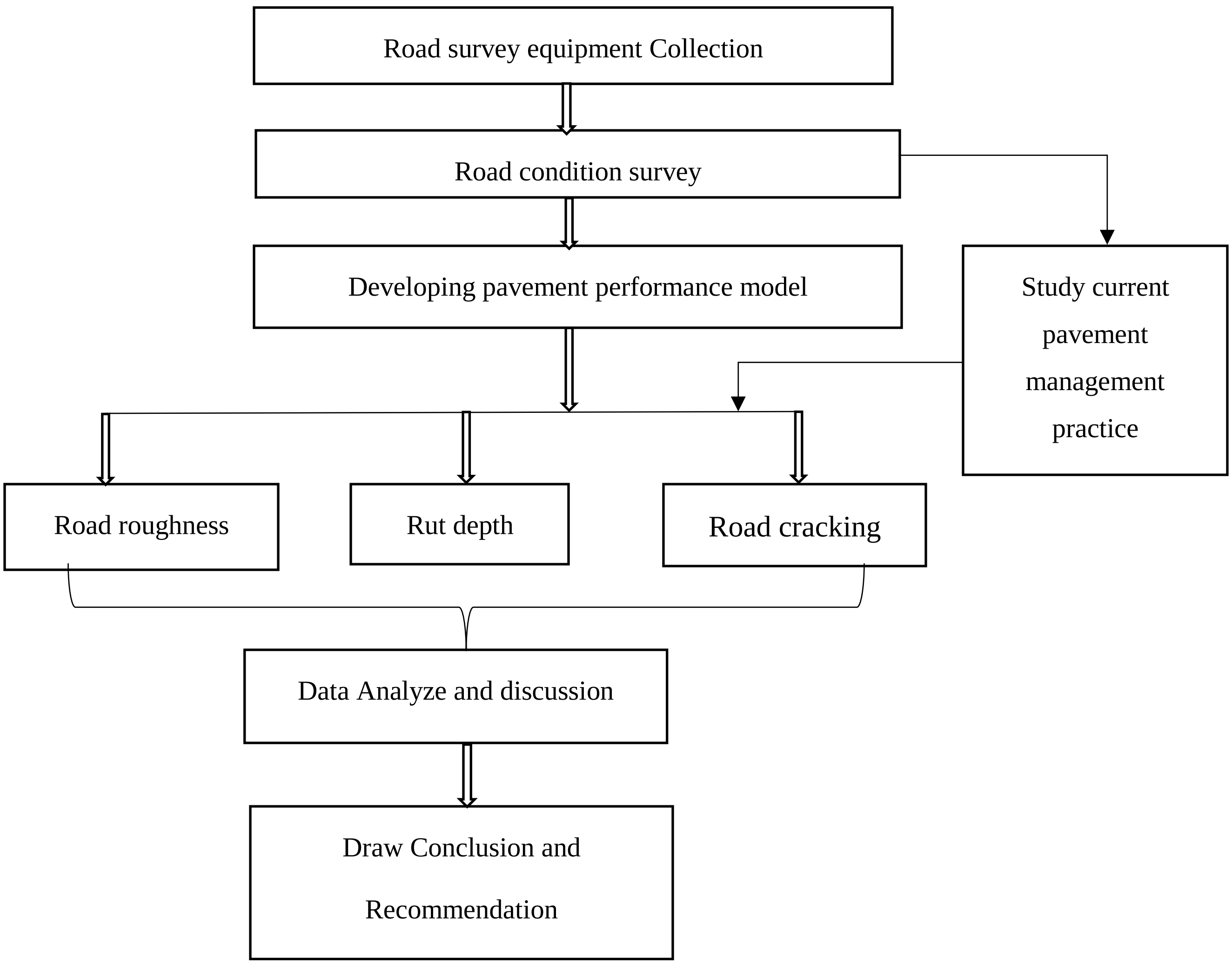


Figure 3.1 Research design

3.2.1 Case study

A common approach of qualitative analysis is the case study method, which is a thorough and meticulous examination of an individual, family, institution, cultural group, or even the entire community. It is an approach to study that focusses on depth rather than scope. The case study focusses more on thoroughly examining a small set of circumstances or occurrences and how they relate to one another. The processes that occur and their interactions are the subject of the case study. Therefore, a case study is basically a thorough examination of the specific unit being studied. Finding the elements that explain the behavior patterns of the specified unit as an integrated whole is the goal of the case study technique.

Since there is sufficient data and information on the condition of the pavement, Alemgena districts major Fitch Road is used as a case study in this study.

3.3 Data collection method

The population is the total collection of instances from which the sample is taken. Sampling strategies assist lower the number of instances because there is not enough time or money to analyse the complete population (Taherdoost, 2016). The process of choosing components of a population the entire membership of a specific class of individuals, things, or events for inclusion in a research study is known as sampling. According to O'Leary (2017), samples are deemed representative if their distribution and characteristics enable the findings to be extrapolated to the pertinent population.

To gather data, the researcher used document analysis, and observation. The data from the pavement condition survey that was previously gathered by the Road Asset and Data Base Management Directorate using manual procedures, observation, and relevant literature are considered secondary data.

3.4 Study population and sampling techniques

Investigating contemporary pavement management practices and creating a pavement performance prediction model for the Ethiopian Road Administration (ERA) are the primary goals of this work. Thus, the sampling frame is the 102–177 km Ftche to Gohathion route, and the target population is the Ethiopian road Administration/Alemgena district. Three road segments were purposefully chosen by the researcher to serve as a case study. 102–103 kilo meters, case one, 119–120 km for case two, and 139–140 km for case three.

The goal of sampling, according to Fellows and Liu (2015), is to offer a workable way to carry out the data gathering and processing aspects of research while guaranteeing that the sample offers a good representation of the population.

3.5 Data Collection Equipment and Methodology for Pavement Condition Assessment

For a variety of reasons, the pavement condition data is crucial to the creation of efficient maintenance and rehabilitation plans. Information about the pavement, such as its thickness, present state, traffic, climate, etc., is necessary to determine the best options for maintenance and repair. Numerous elements are included in the pavement data, such as the pavement's materials, thicknesses, traffic information, geometry, present condition, historical performance, and environmental data.Ethiopian Roads Authority collects various road condition data either by using an automated data collection system (Hawkeye 1000/2000 Digital Profiler) and manually rating the road network.

Every format and equipment required, including laptop computers, GPS, cameras, straight edges, reflective jackets and warning signs, condition manuals, etc. Following the ERA-PMS handbook and guide as well as international practice, the survey team measured, gathered, and documented detail road pavement condition data during the detail condition survey. This data included surface cracking, raveling, potholes, edge break, roughness, rutting, texture, and pavement strength data (deflection measurement).

3.6 Pavement Performance Indicators

Following the ERA-PMS handbook and guide as well as international practice, the survey team measured, gathered, and documented detail road pavement condition data during the detail condition survey. This data included surface cracking, ravelling, potholes, edge break, roughness, rutting, texture, and pavement strength data (deflection measurement). Obtaining performance data that is reliable, representative, and consistent enough to facilitate network level studies is the aim of the network level surveys. In order to identify pavements that are deficient based on specified levels of service and to track trends in highway condition, the Ministry will survey the state of the paved numbered highways as well as a representative sample of all paved side roads within its authority. In order to support strategic asset management planning, data is utilized to determine the overall demands for pavement repair and to evaluate the necessary levels of expenditure.

A. Pavement Condition Index (PCI)

The PCI uses an objective scale ranging from 0 to 100 to quantify pavement conditions. PCI ratings fall into five categories very poor (0-35); poor (36-50); fair (51-70); good (71-85); and excellent (86- 100). Following ERA- PMS manual and guide as well as international practice.

B. Rut Data

The Automated Distress Condition Surveying program gathers rut data. A summary of the distance between the pavement profiles and the bottom of the rut—a longitudinal distortion in the pavement cross-section—is given by the rut data, which are gathered at least every 30 feet. As demonstrated below, in accordance with international practice and the ERA-PMS manual and guide, a severity level is allocated to each sampling interval based on the average rut depth.

- Good or Low Severity: < 2mm
- Isolate; 2- 5 mm
- Medium Severity: 5- 15 mm
- Warning; 15- 25 mm
- High Severity: Average Rut Depth > 25mm

C. International Roughness Index (IRI)

Following a road condition survey using the Automated Road Analyzer (ARAN), a pavement's longitudinal profile will be measured to determine the International Roughness Index (IRI). Pavements are divided into three categories: poor (>170 in./mile), fair (95–170 in./mile), and good (95 in./mile). Observing international practice and the ERA-PMS handbook and guide.

- Sound or Low Severity: < 2IRI
- Isolate; 2- 3 IRI
- Medium problem: 3- 4.5 IRI
- Warning; 4.5- 6.5 IRI
- Severe: > 6.55 IRI

D. Potholes

0% - none, 5% - few (1 -2 potholes), 35% - frequent (3 to 9 potholes), 90% - throughout (> 10 potholes)

3.7 Method of data analysis

Regression

In order to anticipate pavement performance modelling, the study employed linear regression to evaluate the relationship between factors, demonstrating the extent to which independent variables influence dependent variables.

The regression formula

Y = mx+ b source: *(Li et al. 2006)*

Where y = the predicted variable of y

m = unstandardized regression coefficient or slope

x = the independent variable

b = y intercept

The pavement's age, traffic volume, and climate are the independent factors.

In the study, rutting, roughness, cracking, shoving, patching, and edge break were correlated with pavement age.

Rut depth, roughness, cracking, patching, edge break, shoving, vertical deformation, and pavement quality index are some of the dependent factors.

Lastly, this study uses linear regression analysis to show how age correlates with rutting, roughness, pothole, cracking, patching, edge break, and shoving.

CHAPTER FOUR: DISCUSSION ON FINDINGS

4.1 Introduction

The road network

Under the five road network management directorates there are a total of 12,655 km of road network length out of which 6,329 km is paved and the remaining 6,326 km is gravel surfaced. This system of road network consists of a wide range of condition, age and performance. However, the study is for paved roads and hence the current practice and the PPP model is for the paved roads only. The road network is organized in five road network management directorates.

Table 4.1 the Ethiopian road network

	Length (km)		Total (km)
District	Paved roads	Unpaved roads	
Alemgena	1,932	2,211	4,143
Kombolcha	1,689	1,138	2,827
Adigrat	1,456	771	2,227
Debremarkos	333	1,362	1,695
Gondar	919	844	1,763
Total	6,329	6,326	12,655

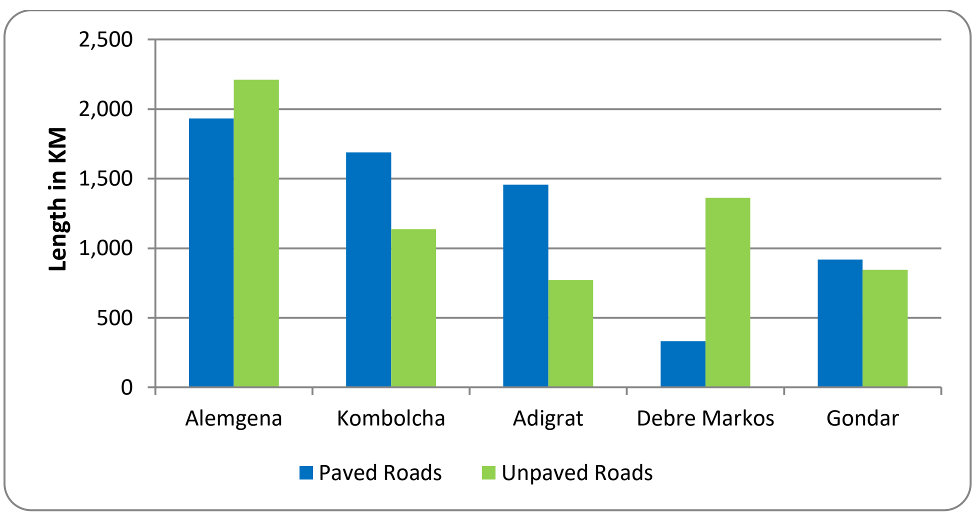


Figure 4.1: RNMDs Road Network

Table: 4.2; the road network according the road classification

Lot - 1 RNMDs Length in km				
Road Class		Paved	Unpaved	Total
Trunk	A	3,039.0	18.0	3,057.0
Link	B	1,210.0	1,248.0	2,458.0
Main Access	C	780.0	1,617.0	2,397.0
Collector	D	439.1	1,466.0	1,905.1
Feeder	E	866.0	1,972.2	2,838.2
Total		6,334.1	6,321.2	12,655.3

4.2 Pavement detail condition survey

During the detail condition survey the survey team measured, collect and record detail road pavement condition data that includes surface cracking, ravelling, potholes, edge break, roughness, rutting, Texture, pavement strength data (deflection measurement) on road pavement following ERA- PMS manual and guide as well as international practice.

Besides the training given, the survey teams relied on their experience, engineering judgment and the measured facts in identifying defects. Estimation of severity and extent of the defects was made on site based on the measurements which then are recorded on excel formats both on hard and soft copy.

Once the values of the condition attributes are determined ERA PMS Condition Index (CI) calculation formula is used to calculate pavement CI of each sub segment which is then weighed by length to determine the average road segment CI. Correspondingly, the same is done for determination of Sections and Directorate condition indices. The pavement condition index is a five stage percentage index rating ranging between 0, for pavement in Very Poor condition, to 100 percent representing a pavement in Very Good condition. The five categories are colour coded as shown in table 4.3 below.

Table: 4.3:- Condition Index Performance Categories (source: ERA PMS Condition Index (CI))

Descriptive Category	Condition Index	
	Range (%)	Colour Code
Very Good	86 – 100	
Good	71 – 85	
Fair	51 – 70	
Poor	36 – 50	
Very Poor	0 – 35	

Surface cracking, Rutting, Pothole, Ravelling, Edge Break, Drainage Detail Condition, Texture, Road Segment Location (Coordinates) data collection

All type of the above mentioned distresses are carefully identified and the area covered on pavement is measured by the survey team using appropriate tool such as meter, straight edge and rulers and record the data on field survey formats. Whenever necessary the team also take pictures which were very helpful for later office studies. Each and every distress following ERA PMS condition survey manual and recorded the data in prepared formats both with hard and soft copy.

The survey team made a record of locations of road segments in collaboration with appropriate RNMD and recorded the GPS coordinates of road segments differentiating the Start and End of Road segments using Hand held GPS.

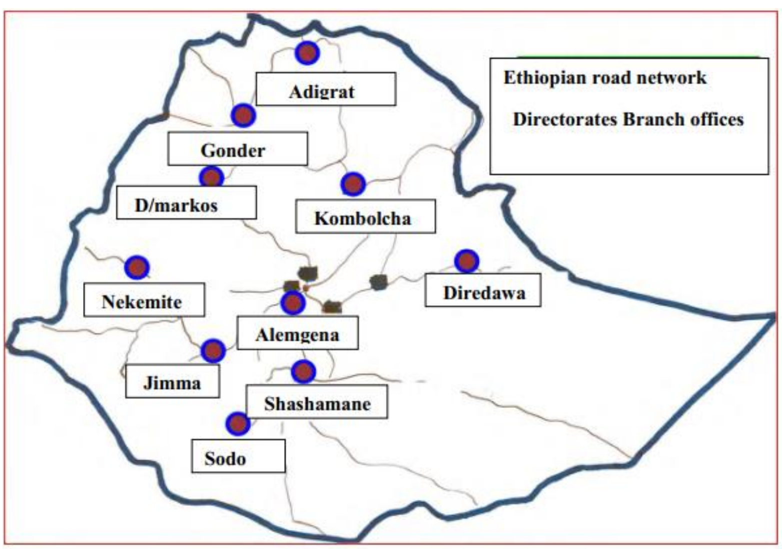
Table: 4.4:- Condition Index and Data range describing each problem category – paved roads

Distress	Attribute in Survey perspective	Data range describing each problem category – paved roads				
		Severe	Warning	Moderate	Isolated	None
Condition Index (CI) %	CI	0-35%	35-50%	50-70%	70-85%	85%+
Narrow Cracks (%)	P_CracksPerc_Narrow	>15%	10-14%	5-9%	1-4%	0%
Wide Cracks (%)	P_CracksPerc_Wide	>15%	10-14%	5-9%	1-4%	0%
Ravelling (%)	P_RavellingPerc	>15%	10-14%	5-9%	1-4%	0%
Potholes (No / km)	P_Pothole_Per_Km	>15	14-10	9-5	4-1	0

Roughness (IRI)	B_IRI	>6.5 IRI	4.5-6.5 IRI	3-4.5 IRI	2-3 IRI	< 2 IRI
Rut Depth (mm)	P_Rut	> 25 mm	15 – 25 mm	5 – 15 mm	2 – 5 mm	< 2 mm
Mean Texture Depth (mm)	P_MPD	< 0.3 mm	0.3-0.7 mm	0.7 – 1.0 mm	1 – 1.5 mm	> 1.5 mm
Edge Break (m2 / km)	P_EdgeBreakArea	>300m2	100-300 m2	10-100 m2	0-10 m2	0 m2
Side Drainage Condition (1-5)	P_DrainCondition	4	3	2	1	0

Excel format was developed, for the road condition detail assessment grouping each pavement distress type into five distress densities of **Severe, Warning, Moderate, Isolated** and **None (Sound)**.

Alemgena RNMD is found in the central part of Ethiopia, its network traverses through big cities and industrial establishments. It is the biggest of the ten directorates both in network expanse and traffic volume.



Source: ERA Road Asset Management Directorate

Figure: 4.2: Alemgena RNMD Road Map

Table: 4.5: Alemgena RNMD network by surface type

Item no.	Section	Road Segment No.	Surface Type & Length (km)		
			Paved	Unpaved	Total
1	Mojo	9	387.1	73.0	460.1
2	Debreberehan	9	149.1	151.0	300.1
3	Robit	10 *	181.2 *	134.0	315.2
4	Muketuri	12	311.4 *	220.0	531.4
5	Ambo	8	250.2	111.0	361.2
6	Woliso	9	176.1	193.0	369.1
7	Huruta	13	88.3	507.0	595.3
8	Butajira	12	345.8	191.0	536.8
9	Endiber	8	244.5*	88.0	332.5
Total		90	2,133.7	1,668.0	3,801.7

4.4 Paved road Network Condition

The current condition of the paved roads in Alemgena RNMD is described in terms of roughness, rutting, and overall Condition Index (CI) according to the detailed condition survey as indicated here below.

Roughness

Pavement roughness can be expressed as the extent of the non-existence or existence of surface irregularities that affect the ride quality of road users. The International Roughness Index (IRI) is the roughness index most commonly obtained from measured longitudinal road profiles. The roughness of the roads in this survey was measured using Hawkeye 1000 road profiler equipment provided by ERA. The survey team consisting of an Engineer, a technician and driver who were assigned to perform the task after making sure that the equipment is appropriately calibrated and serviced to make it fit for the task. The activity commenced from Alemgena road Network Management Directorate's network.

According to this survey (Year 2016) the average roughness of the roads in Alemgena RNMD by road segment is as shown in table below.

Table: 4.6: Alemgena RNMD Roughness (IRI) Distribution by Road Segment

Section	Road Name	Length	Roughness IRI	Problem Category
Modjo	Arerti kesem wonze	25.26	4.90	Warning
	Metehara Awash	39.80	2.76	Isolated Problems
	Mojo Addis	49.94	4.10	Moderate Problems
	Mojo Ejere Arerti	61.38	4.30	Moderate Problems
	Mojo Nazrete	19.83	3.00	Isolated Problems
	Nazrete Metehara	98.00	3.26	Moderate Problems
	Zeway Mojo	92.92	3.80	Moderate Problems
	Total	387.13	3.71	Moderate Problems
Debrebrehan	Addis Aleltu	38.91	3.00	Isolated Problems
	Aleltu Sembo	34.96	3.00	Isolated Problems
	Debrebrehan-Gudo beret	33.49	2.80	Isolated Problems
	Sembo Debrebrehan	41.71	3.00	Isolated Problems
	Total	149.07	2.96	Isolated Problems
Robit	Debresina Robit	31.97	2.90	Isolated Problems
	Gundobret Debresina	29.28	2.90	Isolated Problems
	Robit Ataye	47.90	2.93	Isolated Problems
	Total	109.15	2.91	Isolated Problems
Muketuri	Abay Wenze Dejen	22.07	11.35	Severe
	Addis Chancho	29.72	3.50	Moderate Problems
	Chagel Debrelibanos	5.14	4.10	Moderate Problems
	Chancho Commando	76.83	3.50	Moderate Problems
	Commando-Fitche	5.03	3.40	Moderate Problems
	Commando-G.Gurach	46.87	4.50	Moderate Problems
	G.Gurach Abay Wenze	52.77	11.00	Severe
	Total	238.43	6.09	Warning
Ambo	Addis Holota	27.30	2.90	Isolated Problems
	Addis Tatek	13.94	5.50	Warning
	Ambo Gedo	69.38	4.60	Warning
	Ginchi Ambo	37.45	3.40	Moderate Problems
	Holeta Muger	57.60	2.20	Isolated Problems
	Holota Ginchi	44.57	3.20	Moderate Problems
	Total	250.24	3.48	Moderate Problems
Woliso	Addis Tulubollo	66.80	3.86	Moderate Problems
	Tullu Bollo Weliso	35.68	3.80	Moderate Problems
	Weliso Welkite	42.48	3.66	Moderate Problems
	Welkite Gibe Wonze	31.16	3.87	Moderate Problems
	Total	176.12	3.80	Moderate Problems
Huruta	Eteya Asela	28.78	2.30	Isolated Problems
	Melkasa Eteya	34.20	2.30	Isolated Problems
	Melkasa Sodere	7.43	6.40	Warning
	Nazrete Melkasa	17.85	2.40	Isolated Problems
	Total	88.26	2.67	Isolated Problems
Butajira	Alemgena Lemen	43.75	5.50	Warning
	Butajera Wolbareg	55.20	4.60	Warning

Section	Road Name	Length	Roughness IRI	Problem Category
	Butajera Zeway	54.79	5.10	Warning
	Hosina Areka	71.04	5.60	Warning
	Hosina Wolbareg	44.50	5.50	Warning
	Lemen Butajera	76.47	5.10	Warning
	Total	345.75	5.22	Warning
Endeber	Bojeber Gubre	54.18	4.60	Warning
	Butajira Bojeber	29.05	4.70	Warning
	Kose - Gilgel Gibe II	36.14	6.50	Warning
	Welkite - Mazoria	56.19	2.80	Isolated Problems
	Total	175.56	4.43	Moderate Problems
Alemgena Total		1,919.71	4.17	Moderate Problems

The Detailed Road Condition Assessment findings shown in table 4.5 reveals that the overall paved road roughness value for Alemgena RNMD is 4.17 IRI which places the overall problem category for roughness in the Moderate Problems Category.

The assessment also indicates that the Roughness Distress on paved road network under three sections (Debreberehan, Robit and Huruta) is in Isolated Problem category, while that for the other four sections (Mojo, Ambo, Woliso, and Endibir) is in Moderate Problem category. The remaining two sections (Butajira and Muketuri) have a roughness distress in the Warning Problem category.

Rearranging the data shown above one can see that the length of road in each Problem category is as shown in the following table.

Table: 4.7:- Alemgena RNMD Roughness (IRI) Distribution by Problem Category

Roughness	Road Length (Km)	Average Roughness	% Proportion
Sound: <2 IRI	0.00	0.00	0.00
Isolated Problems: 2-3 IRI	539.77	2.74	28
Moderate Problems: 3-4.5 IRI	723.97	3.73	38
Warning: 4.5-6.5 IRI	581.13	5.15	30
Severe: >6.55 IRI	74.84	11.10	4
Alemgena Total	1,919.71	4.17	100

Out of the total length of 1,919.7 km long road surveyed directorate wide about 28 %, 38 %, 30 % and 4 % are found to be in Isolated Problem, Moderate Problem, Warning and Severe Problem Category, with an average Roughness of 2.74 μm/km, 3.73 μm/km, 5.15 mμ/km and 11.10 μm/km respectively. The critical parts that need closer attention are the road length in Warning and Severe Problem category with length of nearly 656 km, which is about 34 % of the network.

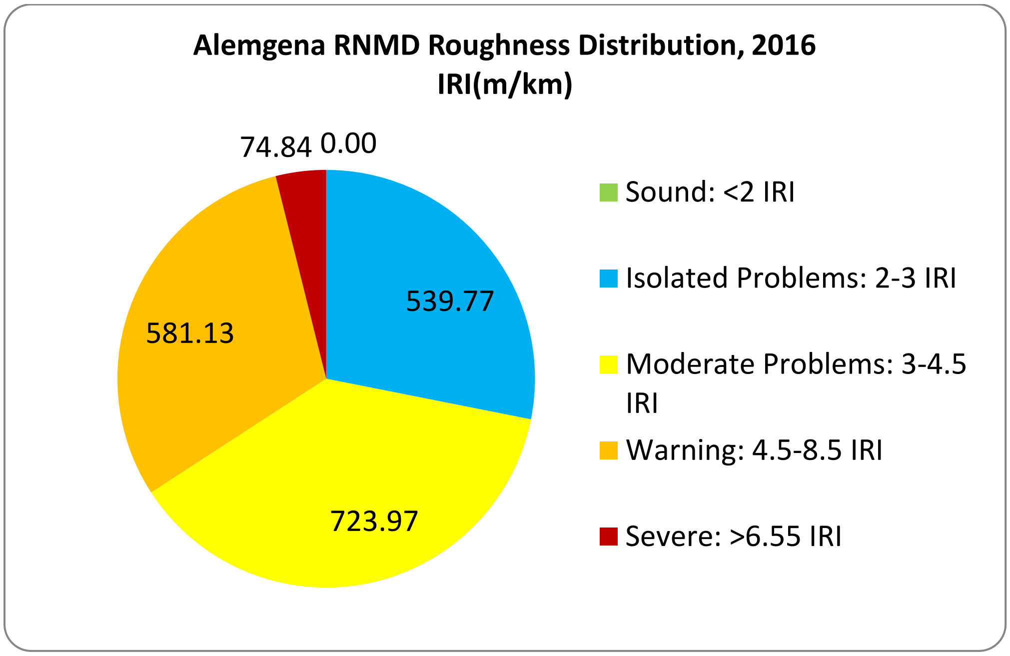


Figure 4.3: Alemgena RNMD Roughness Distribution, 2016

Rutting

Rut depth is measured manually in both wheel tracks by placing a straight edge over the depressions. The distribution of mean rut depth in this district is summarized as follows

Table 4.8:- Alemgena RNMD Rutting (mm) Distribution by Road Segment, 2016

Section	Road Name	Length	Rut Depth (mm)	Problem Category
Modjo	Arerti kesem wonze	25.26	2.34	Isolated Problems
	Metehara Awash	39.80	2.56	Isolated Problems
	Mojo Addis	49.94	8.38	Moderate Problems
	Mojo Ejere Arerti	61.38	2.13	Isolated Problems
	Mojo Nazrete	19.83	4.89	Isolated Problems
	Nazrete Metehara	98.00	3.54	Isolated Problems
	Zeway Mojo	92.92	7.61	Moderate Problems
	Total	387.13	4.81	Isolated Problems
Debrebrehan	Addis Aleltu	38.91	2.05	Isolated Problems
	Aleltu Sembo	34.96	2.00	Sound

Section	Road Name	Length	Rut Depth (mm)	Problem Category
	Debrebrehan-Gudo beret	33.49	2.00	Sound
	Sembo Debrebrehan	41.71	2.00	Sound
	Total	149.07	2.01	Isolated Problems
Robit	Debresina Robit	31.97	5.91	Moderate Problems
	Gundobret Debresina	29.28	2.22	Isolated Problems
	Robit Ataye	47.90	3.89	Isolated Problems
	Total	109.15	4.03	Isolated Problems
Muketuri	Abay Wenze Dejen	22.07	34.90	Severe
	Addis Chancho	29.72	8.79	Moderate Problems
	Chagel Debrelibanos	5.14	8.61	Moderate Problems
	Chancho Commando	76.83	8.42	Moderate Problems
	Commando-Fitche	5.03	5.00	Moderate Problems
	Commando-G.Gurach	46.87	11.17	Moderate Problems
	G.Gurach Abay Wenze	52.77	20.12	Warning
	Total	238.43	13.98	Moderate Problems
Ambo	Addis Holota	27.30	3.96	Isolated Problems
	Addis Tatek	13.94	4.56	Isolated Problems
	Ambo Gedo	69.38	5.25	Moderate Problems
	Ginchi Ambo	37.45	3.93	Isolated Problems
	Holeta Muger	57.60	2.00	Sound
	Holota Ginchi	44.57	3.63	Isolated Problems
	Total	250.24	3.84	Isolated Problems
Woliso	Addis Tulubollo	66.80	5.15	Moderate Problems
	Tullu Bollo Weliso	35.68	5.01	Moderate Problems
	Weliso Welkite	42.48	4.75	Isolated Problems
	Welkite Gibe Wonze	31.16	3.68	Isolated Problems
	Total	176.12	4.76	Isolated Problems
Huruta	Eteya Asela	28.78	2.89	Isolated Problems
	Melkasa Eteya	34.20	2.61	Isolated Problems
	Melkasa Sodere	7.43	6.52	Moderate Problems
	Nazrete Melkasa	17.85	2.78	Isolated Problems
	Total	88.26	3.06	Isolated Problems
Butajira	Alemgena Lemen	43.75	5.42	Moderate Problems
	Butajera Wolbareg	55.20	3.53	Isolated Problems
	Butajera Zeway	54.79	3.18	Isolated Problems

Section	Road Name	Length	Rut Depth (mm)	Problem Category
	Hosina Areka	71.04	4.47	Isolated Problems
	Hosina Wolbareg	44.50	5.04	Moderate Problems
	Lemen Butajera	76.47	6.13	Moderate Problems
	Total	345.75	4.68	Isolated Problems
Endeber	Bojeber Gubre	54.18	2.00	Sound
	Butajira Bojeber	29.05	2.00	Sound
	Kose - Gilgel Gibe II	36.14	7.22	Moderate Problems
	Welkite - Mazoria	56.19	2.26	Isolated Problems
	Total	175.56	3.16	Isolated Problems
Alemgena Total		1,919.71	5.30	Moderate Problems

The Detailed Road Condition Assessment findings shown in Table 4.7 above reveals that the overall paved road rutting value for Alemgena RNMD is 5.3 mm, this places the RNMD's paved road overall category for rutting in the Moderate Problems Category. The assessment also indicates that the Rutting Distress on paved road network under eight of the nine sections of Alemgena RNMD (Mojo, Robit, Ambo, Woliso, Huruta, Endibir, Woliso and Butajira) is in Isolated Problem category while that of Muketuri section is in Moderate Problem category. Rearranging the data shown above the length of road in each Problem category is as shown in the following table.

Table 4.9:- Rutting (mm) severity level (ERA maintenance manual)

Rut Depth	Road Length (Km)	Rut Depth(mm)	% Proportion
Sound: <2mm	250.99	2.19	13
Isolated Problems: 2-5 mm	875.31	3.31	46
Moderate Problems: 5-15 mm	718.57	6.88	37
Warning: 15-25 mm	52.77	20.12	3
Severe: >25 mm	22.07	34.90	1
Alemgena Total	1,919.71	5.30	100.00

Out of the total length of 1,919.7 km long paved road surveyed directorate wide about 13%, 46%, 37%, 3% and 1% are found to be in Sound, Isolated Problem, Moderate Problem, Warning and Severe Problem Category with mean rut depth of 2.19 mm, 3.31 mm, 6.88 mm, 20.12 mm and 34.90 mm respectively. The critical parts that need closer attention are the road length in Warning and Severe Problem category with length of nearly 75 km, which is just about 4 % of the network.

Condition Index (CI)

The collected distress data is used to determine a single Condition Index (CI) describing the overall condition of a road segment in the RNMD for the year 2016. This CI, calculated for each surveyed road segment, is a percentage index ranging between 0 and 100; 0 representing a road segment in very poor condition and 100 representing a road segment in very good condition. Table 4.9 below shows the pavement CI for 2016 for each road segment in Alemgena RNMD.

Table 4.10: Summary of the Detailed Road Condition Assessment Finding, 2016

Section	Road Name	Length	Roughness	Condition Category
Modjo	Arerti kesem wonze	25.26	61	Fair
	Metehara Awash	39.80	70	Fair
	Mojo Addis	49.94	36	Poor
	Mojo Ejere Arerti	61.38	63	Fair
	Mojo Nazrete	19.83	62	Fair
	Nazrete Metehara	98.00	66	Fair
	Zeway Mojo	92.92	36	Poor
	Total	387.13	54.33	Fair
Debrebrehan	Addis Aleltu	38.91	74	Good
	Aleltu Sembo	34.96	74	Good
	Debrebrehan-Gudo beret	33.49	75	Good
	Sembo Debrebrehan	41.71	74	Good
	Total	149.07	74.22	Good
Robit	Debresina Robit	31.97	62	Fair
	Gundobret Debresina	29.28	71	Good
	Robit Ataye	47.90	64	Fair
	Total	109.15	65.29	Fair
Muketuri	Abay Wenze Dejen	22.07	17	Very Poor
	Addis Chancho	29.72	53	Fair
	Chagel Debrelibanos	5.14	41	Poor
	Chancho Commando	76.83	54	Fair
	Commando-Fitche	5.03	64	Fair
	Commando-G.Gurach	46.87	28	Very Poor
	G.Gurach Abay Wenze	52.77	13	Very Poor
	Total	238.43	36.20	Poor
Ambo	Addis Holota	27.30	71	Good
	Addis Tatek	13.94	41	Poor
	Ambo Gedo	69.38	46	Poor
	Ginchi Ambo	37.45	67	Fair
	Holeta Muger	57.60	80	Good
	Holota Ginchi	44.57	69	Fair
	Total	250.24	63.51	Fair
Woliso	Addis Tulubollo	66.80	51	Fair
	Tullu Bollo Weliso	35.68	58	Fair
	Weliso Welkite	42.48	62	Fair

Section	Road Name	Length	Roughness	Condition Category
	Welkite Gibe Wonze	31.16	50	Poor
	Total	176.12	54.89	Fair
Huruta	Eteya Asela	28.78	68	Fair
	Melkasa Eteya	34.20	77	Good
	Melkasa Sodere	7.43	31	Very Poor
	Nazrete Melkasa	17.85	68	Fair
	Total	88.26	68.37	Fair
Butajira	Alemgena Lemen	43.75	45	Poor
	Butajera Wolbareg	55.20	58	Fair
	Butajera Zeway	54.79	56	Fair
	Hosina Areka	71.04	45	Poor
	Hosina Wolbareg	44.50	49	Poor
	Lemen Butajera	76.47	49	Poor
	Total	345.75	50.22	Fair
Endeber	Bojeber Gubre	54.18	61	Fair
	Butajira Bojeber	29.05	62	Fair
	Kose - Gilgel Gibe II	36.14	30	Very Poor
	Welkite - Mazoria	56.19	74	Good
	Total	175.56	58.94	Fair
Alemgena Total		1,919.71	55.82	Fair

The Detailed Road Condition Assessment findings shown in table 4.9 above reveal that the overall paved road condition index of Alemgena Road Network Management Directorate is about 55.82 % which is lower side of the fair category. The assessment also indicate that condition index of paved road network under seven of the nine sections (Mojo, Robit, Ambo, Woliso, Huruta, Endibir and Butajira) is in Fair condition category while that of Debreberehan and Muketuri sections is in Good and Poor condition category respectively.

Summary of Distress information for Alemgena road district

The district Paved road network can also be categorised in terms of the different distresses that were rated, e.g. narrow cracks, wide cracks, drain condition, etc.

Table 4.11 the different types of distresses measured in this survey

Alemgena RNMD	IRI	NC (%)	WC(%)	DC (0-5)	EB(m^2/Km)	Texture	Pothole (No/km)	Raveling (%)	Rut Depth (mm)
Severe	74.84	-	142.86	-	-	-	7.43	71.04	22.07
Warning	581.13	46.87	67.30	13.94	-	-	-	252.65	52.77
Moderate	723.97	57.91	195.22	-	105.49	352.01	154.36	376.98	718.57
Isolated	539.77	795.47	873.30	190.13	848.88	1,156.90	1,094.24	886.86	875.31
Sound	-	1,019.46	641.03	1,715.64	965.34	410.80	663.68	332.18	250.99
	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71

The distresses are measured during the detailed condition survey and each has been used to determine the Condition Index of road segments which are then used to calculate the overall Section and Condition Index in proportion to the road segment length.

The observation shows that the dominant distresses affecting roads in Severe and Warning problem categories are Roughness (IRI), Ravelling, Wide Crack and Rutting impacting 34 %, 17 %, 11 % and 4% of the RNMD's paved road network, respectively.

4.5 Pavement performance prediction model (ppp model) a Case study of Alemgena road disrrict (Fiche to Gohatsion road)

4.5.1 Project Description

The project road is part of the road segment from Addis Ababa – Metema, particularly being part of the Addis Ababa – Debere Markos trunk road which has high traffic volume and load as it is the main corridor of Port Sudan, and additional traffic load arising from traffic generated as a result of industrial developments along the road corridor.

The project road is located in Oromia Regional State and is part of the main road from Addis Ababa to Gondar through Fiche, Dejen, Debremarkos and Bahirdar from Fiche to Gohatsion (from km 102+000 to km 177+147).

Climatic condition

The project area is located on the highlands of the Ethiopian plateau, i.e. having altitude over 2000. Therefore the project area is considered Dega. The effective temperature is lower than $27C^0$, which is good and most of the time comfortable for constructions.

Table 4.12 Mean Monthly Rainfall (mm) of the Project Area

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	17.6	39.7	68.5	91.3	77.3	119.2	253.6	279.6	172.9	39.2	8.1	9.2

Table 4.13 Monthly Maximum and Minimum Temperature (0C) for the Area

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Max.	25.1	26.0	27.0	27.2	270 9	24.4	22.3	21.3	23.1	24.4	24.7	24.4
Min.	4.7	5.5	8.7	9.4	9.7	8.9	9.1	9.3	8.7	6.5	4.7	4.7

The mean monthly rainfall is maximum during the months of July and August i.e. 253.6 mm and 279.6 mm and it is minimum during the months of November and December i.e. 8 mm and 9 mm respectively. Moreover, the monthly temperature is maximum during the months of March through May, about 27 0c, and it is minimum in the months of November through January, 4.7 0c.

4.5.2 Case study: PPP preliminary model the case of Alemgena road district (Fiche to Gohatsion road)

Pavement performance prediction model (ppp model) done for case one (102km - 104km), case two (119-121km) and case three from (139km – 141km)

I. Case study one from (102km-104km)

A. preliminary PPP regression model for Rutting

year	rutting
2016	2928.1
2017	3201.8
2018	3664.2
2019	3961.3
2020	4896.9
2021	5324.8
2022	5675.5
2023	6091
2024	6604.92
2025	7078.75
2026	7552.58
2027	8026.41
2028	8500.24

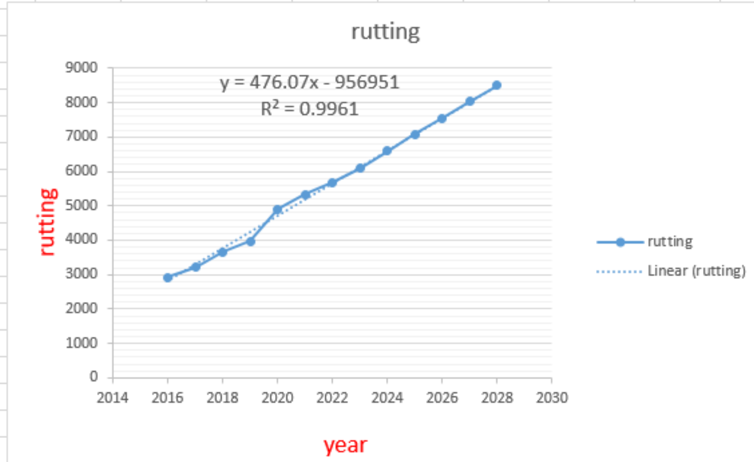


Figure 4.4 preliminary ppp regression model for rutting

Ppp regression model done for rutting by correlating pavement age with pavement rutting having R^2 value of 0.9961 that means rutting and pavement age is highly correlated. The correlation of age and rutting is based on the past eight years rut data and predict the future five years rut information.

The past eight years rut data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of rut depth on 2024 GC will be 6604.92 m^2 and the actual rut data on 2024 is 6545.1m^2.

Using the percentage difference formula the difference between the actual and the predicted rut depth will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 6604.92- 6545.1 = 59.82m^2

The average value is (6604.92 + 6545.1)/2 = 6575m^2

The percentage deference is = (59.89/6575) * 100% = 0.9%

The study shows the actual rut depth is 59.82m^2 less than the predicted value which is expressed in percentage of 0.9%

B. Preliminary PPP regression model for cracking

year	cracking
2016	438.7
2017	511.1
2018	551.4
2019	576.5
2020	609.9
2021	651.8
2022	691.3
2023	718.2
2024	764.464
2025	802.4
2026	840.336
2027	878.272
2028	916.208

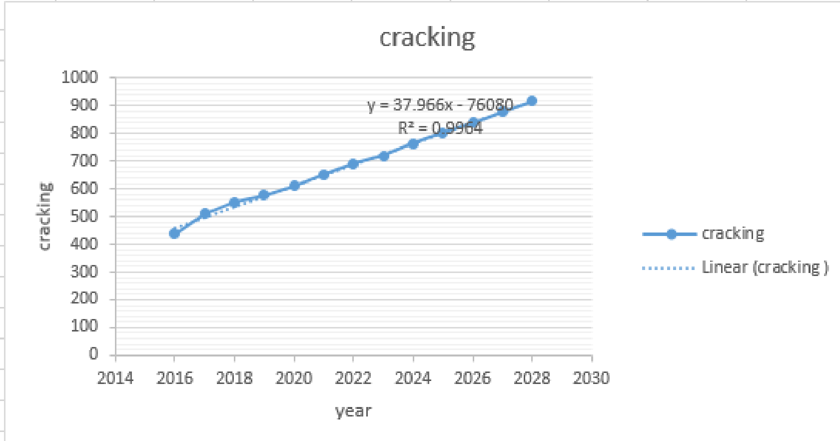


Figure 4.5 preliminary PPP regression model for cracking

Ppp regression model done for cracking by correlating pavement age with pavement cracking having R^2 value of 0.9964 that means cracking and pavement age is highly correlated. The correlation of age and cracking is based on the past eight years crack data and predict the future five years crack information.

The past eight years crack data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of crack on 2024 GC will be 764.5m^2 and the actual crack data on 2024 is 769.4m^2.

Using the percentage difference formula the difference between the actual and the predicted crack will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 769.4- 764.5 = 5m^2

The average value is 769.4 + 764.5)/2 = 766.95m^2

The percentage deference is = (5/766.95) * 100% = 0.65%

The study shows the actual crack is 5m^2 greater than the predicted value which is expressed in percentage difference of 0.65%

C. Preliminary PPP model for patching

year	paching
2016	477.73
2017	540.45
2018	563.4
2019	603.1
2020	648.1
2021	697.7
2022	743.3
2023	790.3
2024	829.808
2025	873.3
2026	916.792
2027	960.284
2028	1003.776

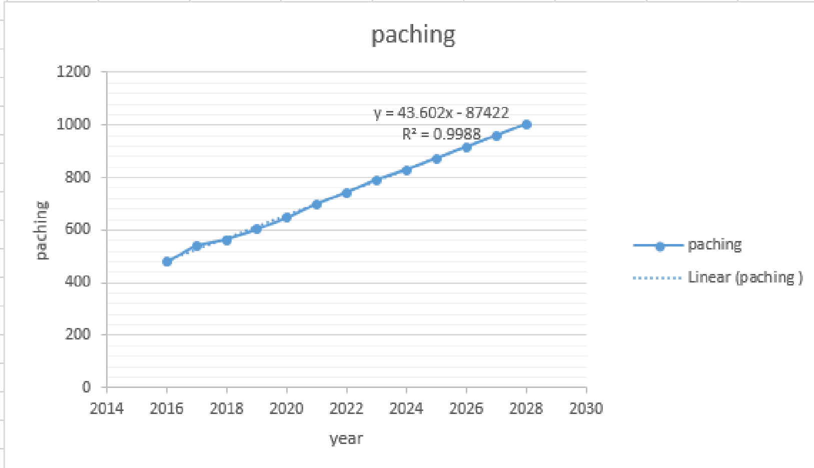


Figure 4.6 preliminary PPP regression model for patching

Ppp regression model done for patching by correlating pavement age with pavement patching having R^2 value of 0.9988 that means patching and pavement age is highly correlated. The correlation of age and patching is based on the past eight years patch data and predict the future five years patch information.

The past eight years patch data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of patch on 2024 GC will be 829.8m^2 and the actual patch data on 2024 is 843.1m^2.

Using the percentage difference formula the difference between the actual and the predicted patching will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 843.1- 829.8 = 13.3m^2

The average value is 843.1 + 829.8)/2 = 836.45m^2

The percentage deference is = (13.3/836.45) * 100% = 1.60%

The study shows the actual patching is 13.3m^2 greater than the predicted value which is expressed in percentage difference of 1.60%

D. Preliminary PPP model for edge damage

year	edge damage
2016	25.28
2017	31.82
2018	36.32
2019	43.56
2020	46.3
2021	53.36
2022	64.71
2023	72.79
2024	76.3
2025	82.8
2026	89.391
2027	95.95
2028	102.51

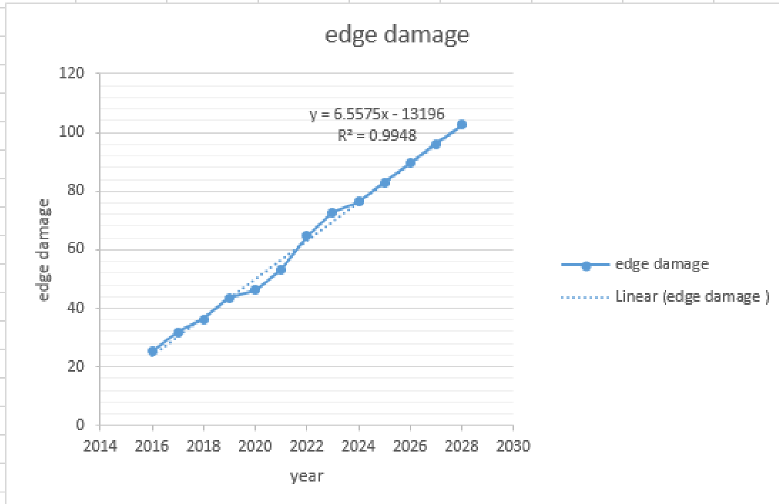


Figure 4.7 PPP regression model for edge damage

Ppp regression model done for edge damage is by correlating pavement age with pavement edge damage having R^2 value of 0.9948 that means edge damage and pavement age is highly correlated. The correlation of age and edge damage is based on the past eight years edge damage data and predict the future five years edge damage information.

The past eight years edge damage data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of edge damage on 2024 GC will be 76.3m^2 and the actual crack data on 2024 is 78.29m^2.

Using the percentage difference formula the difference between the actual and the predicted edge break will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 78.29- 76.3 = 2m^2

The average value is 78.29 + 76.3)/2 = 77.29m^2

The percentage deference is = (2/77.29) * 100% = 2.6%

The study shows the actual edge damage is 2m^2 greater than the predicted value which is expressed in percentage difference of 2.6%

II. Case study two from (119km – 121km)

Pavement performance prediction model (ppp model) done for case two (119km - 121km),

A. Preliminary Ppp regression model for rutting

year	rutting
2016	1789.5
2017	1893.5
2018	1952.2
2019	2050.6
2020	2138.2
2021	2240.5
2022	2383
2023	2550.9
2024	2695.28
2025	2815.5
2026	2935.72
2027	3055.94
2028	3176.16

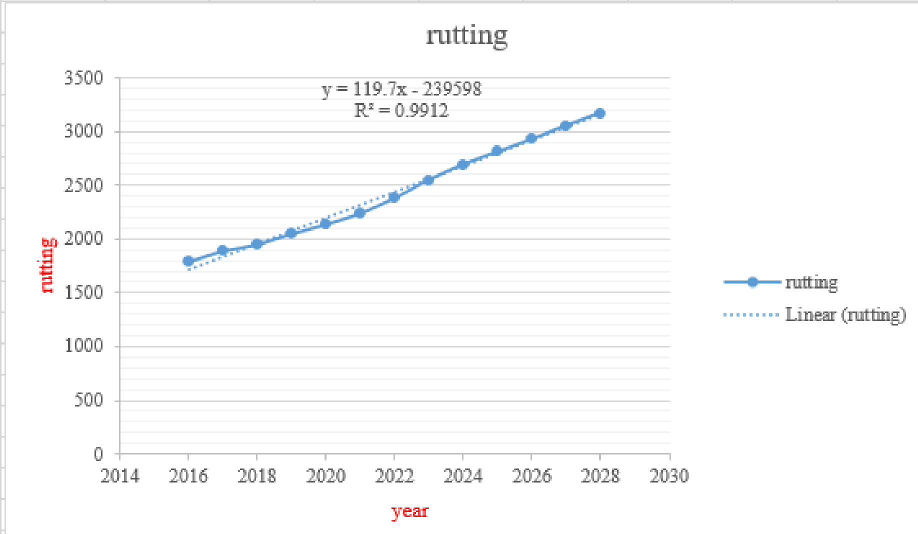


Figure 4.8 PPP regression model for rutting from 119km-121km

Ppp regression model done for rutting by correlating pavement age with pavement rutting having R^2 value of 0.9912 that means rutting and pavement age is highly correlated. The correlation of age and rutting is based on the past eight years rut data and predict the future five years rut information.

The past eight years rut data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of rut depth on 2024 GC will be 2695.28m^2 and the actual rut data on 2024 is 2775m^2.

Using the percentage difference formula the difference between the actual and the predicted rut depth will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 2775 – 2695.28 = 80m^2

The average value of actual and predicted rut data is (2775 + 2695.28)/2 = 2735m^2

The percentage deference is = (80/2735) * 100% = 2.9%

The study shows the actual rut depth is 80m^2 greater than the predicted value which is expressed in percentage of 2.9%

B. Preliminary PPP regression model for cracking

year	cracking
2016	1562.2
2017	1649.8
2018	1746
2019	1883
2020	1970.24
2021	2027.72
2022	2132.55
2023	2207.7
2024	2319.048
2025	2412.675
2026	2506.302
2027	2599.929
2028	2693.556

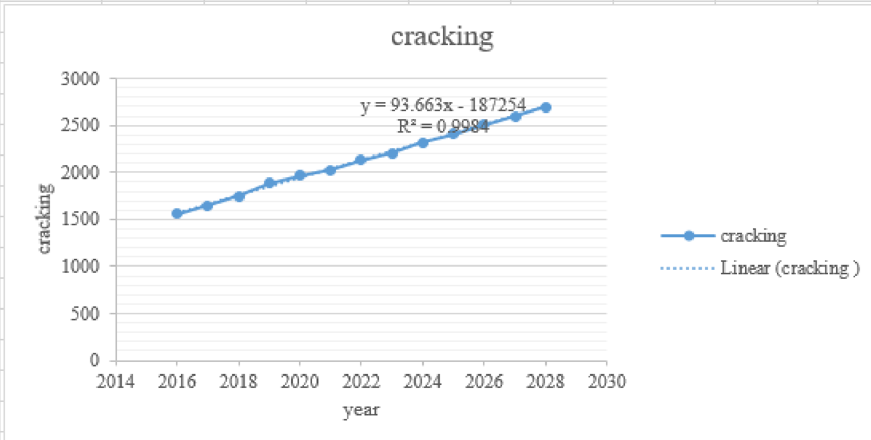


Figure 4.9 PPP regression model for cracking from 119km-121km

Ppp regression model done for cracking by correlating pavement age with pavement cracking having R^2 value of 0.9984 that means cracking and pavement age is highly correlated. The correlation of age and cracking is based on the past eight years crack data and predict the future five years crack information.

The past eight years crack data from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of crack on 2024 GC will be 2319m^2 and the actual crack data on 2024 is 2358.3m^2.

Using the percentage difference formula the difference between the actual and the predicted crack will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 2358 - 2319 = 39m^2

The average value is 2358 + 2319)/2 = 2338.5m^2

The percentage deference is = (39/2338.5) * 100% = 1.67%

The study shows the actual pavement crack is 39m^2 greater than the predicted value which is expressed in percentage difference of 1.67%

C. Preliminary PPP model for patching

year	paching
2016	427.52
2017	491.17
2018	520.38
2019	542.92
2020	601.55
2021	664.14
2022	781.86
2023	873.61
2024	883.416
2025	943.725
2026	1004.034
2027	1064.343
2028	1124.652

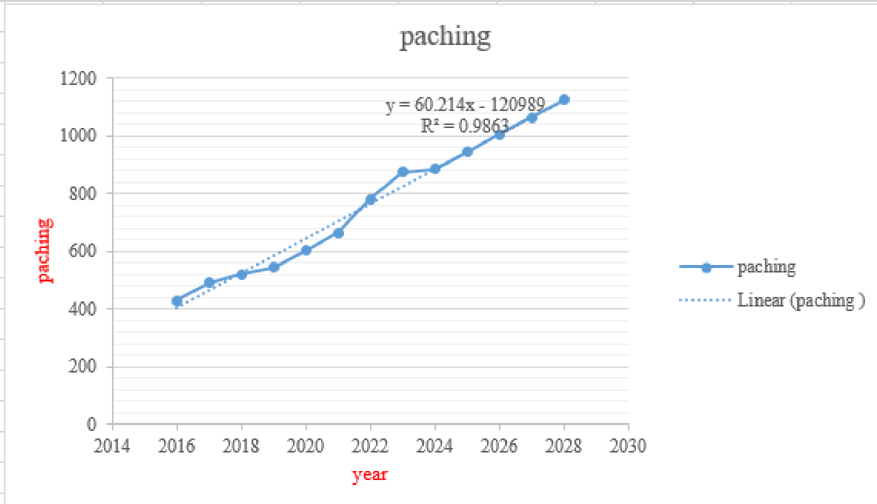


Figure 4.10 preliminary PPP regression model for patching

Ppp regression model done for patching by correlating pavement age with pavement patching having R^2 value of 0.9863 that means patching and pavement age is highly correlated. The correlation of age and patching is based on the past eight years patch data and predict the future five years patch information.

The past eight year's pavement patch data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of pavement patch on 2024 GC will be 883.4m^2 and the actual patch data on 2024 is 911.8m^2.

Using the percentage difference formula the difference between the actual and the predicted patching will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 911.8 – 883.4 = 28.4m^2

The average value is 911.8 + 883.4)/2 = 897.45m^2

The percentage deference is = (28.4/897.45) * 100% = 3.16%

The study shows the actual patching is 28.4m^2 greater than the predicted value, which is expressed in percentage difference of 3.16%

D. Preliminary PPP model for edge damage

year	edge damage
2016	26.7
2017	34.44
2018	45
2019	57
2020	68.64
2021	85.96
2022	103
2023	132
2024	132.968
2025	147.425
2026	161.882
2027	176.339
2028	190.796

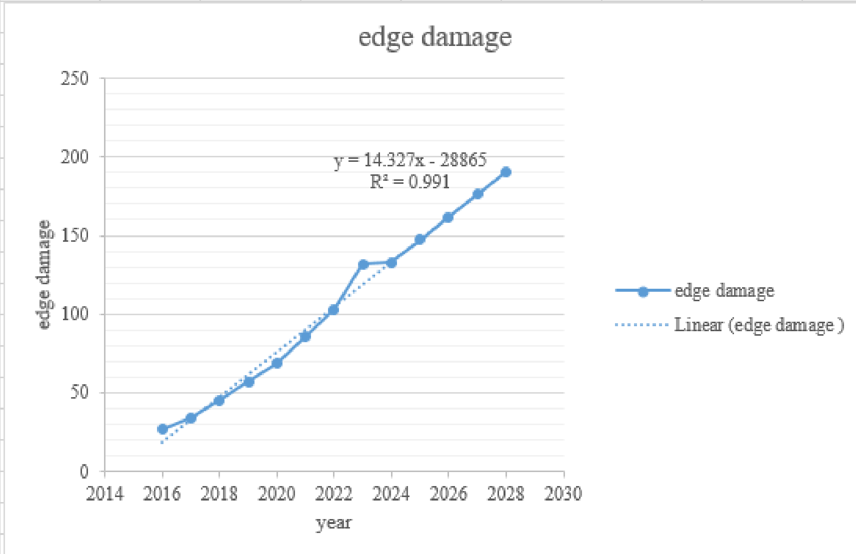


Figure 4.11 Preliminary PPP regression model for edge damage

Ppp regression model done for edge damage is by correlating pavement age with pavement edge damage having R^2 value of 0.991 that means edge damage and pavement age is highly correlated. The correlation of age and edge damage is based on the past eight years edge damage data and predict the future five years edge damage information.

The past eight years edge damage data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of edge damage on 2024 GC will be 132.9m^2 and the actual crack data on 2024 is 136.6m^2.

Using the percentage difference formula the difference between the actual and the predicted edge break will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 136.6- 132.9 = 3.7m^2

The average value is 136.6 + 132.9)/2 = 134.75m^2

The percentage deference is = (3.7/134.75) * 100% = 2.7%

The study shows the actual edge damage is 3.7m^2 greater than the predicted value which is expressed in percentage difference of 2.7%

E. Preliminary Ppp regression model for pothole

year	pothole
2016	70.29
2017	81.86
2018	97.11
2019	99
2020	137.98
2021	149.56
2022	179.56
2023	220.17
2024	222.432
2025	243.075
2026	263.718
2027	284.361
2028	305.004

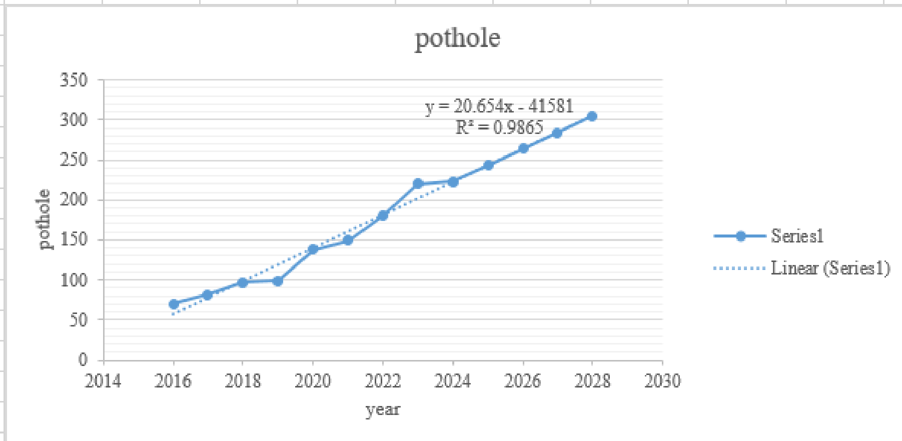


Figure 4.12 preliminary PPP regression model for pothole

Ppp regression model done for pothole is by correlating pavement age with pavement pothole having R^2 value of 0.9865 that means pothole and pavement age is highly correlated. The correlation of age and pothole is based on the past eight year's pothole data and predict the future five years pothole information.

The past eight year's pothole data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of pothole on 2024 GC will be 222.4m^2 and the actual pothole data on 2024 is 232m^2.

Using the percentage difference formula the difference between the actual and the predicted pothole will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 232- 222.4 = 9.6m^2

The average value is 232 + 222.4)/2 = 227.2m^2

The percentage deference is = (9.6/227.2) * 100% = 4.2%

The study shows the actual edge damage is 9.6m^2 greater than the predicted value which is expressed in percentage difference of 4.2%

F. Preliminary Ppp model for pavement shoving

year	shoving
2016	184.1
2017	196.2
2018	228.32
2019	258.62
2020	296.58
2021	313.94
2022	346
2023	376
2024	403.032
2025	431.45
2026	459.868
2027	488.286
2028	516.704

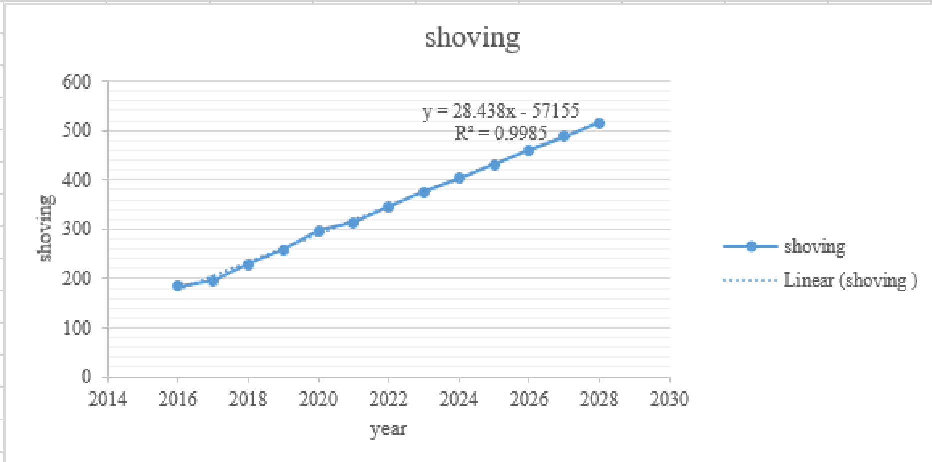


Figure 4.13 preliminary PPP regression model for shoving

Ppp regression model done for shoving is by correlating pavement age with pavement shoving having R^2 value of 0.9985 that means shoving and pavement age is highly correlated. The correlation of age and shoving is based on the past eight years shoving data and predict the future five years shoving information.

The past eight years shoving data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of shoving on 2024 GC will be 403m^2 and the actual shoving data on 2024 is 397.5m^2.

Using the percentage difference formula the difference between the actual and the predicted shoving will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 403 – 397.5 = 5.5m^2

The average value is 403 + 397.5)/2 = 400.25m^2

The percentage deference is = (5.5/400.25) * 100% = 1.37%

The study shows the actual shoving is 5.5m^2 less than the predicted value which is expressed in percentage difference of 1.37%

III case study three from (139km – 141km)

Pavement performance prediction model (ppp model) done for case three (139km - 141km),

A. Preliminary Ppp regression model for rutting

year	rutting
2016	1236.2
2017	1384.6
2018	1405.5
2019	1470.9
2020	1674
2021	1997.9
2022	2190
2023	2341.5
2024	2440.88
2025	2604.5
2026	2768.12
2027	2931.74
2028	3095.36

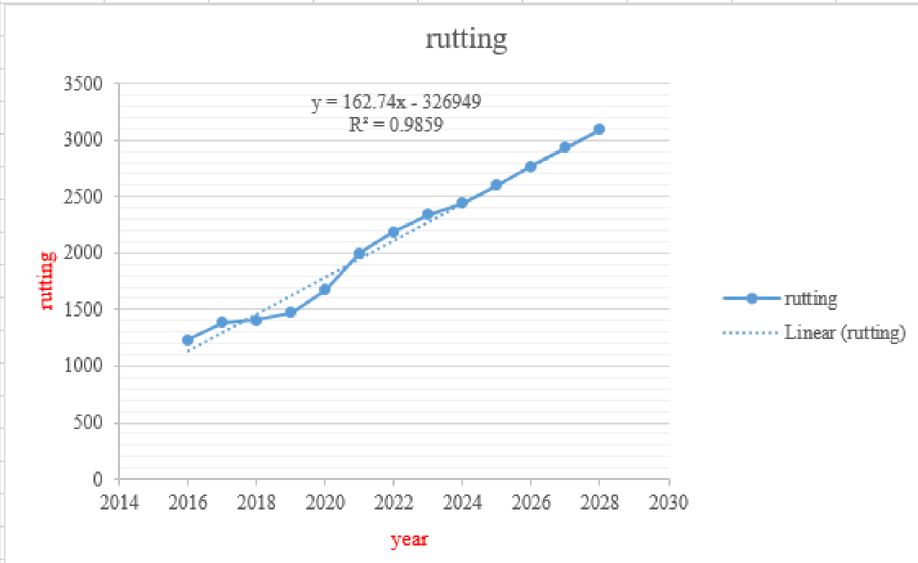


Figure 4.14 PPP regression model for rutting from 139km-141km

Ppp regression model done for rutting by correlating pavement age with pavement rutting having R^2 value of 0.9859 that means rutting and pavement age is highly correlated. The correlation of age and rutting is based on the past eight years rut data and predict the future five years rut information.

The past eight years rut data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of rut depth on 2024 GC will be 2440.8m^2 and the actual rut data on 2024 is 2431m^2.

Using the percentage difference formula the difference between the actual and the predicted rut depth will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 2440.8 – 2431 = 9.8m^2

The average value of actual and predicted rut data is (2440.8 + 2431)/2 = 2435.9m^2

The percentage deference is = (9.8/2435.9) * 100% = 0.4%

The study shows the actual rut depth is 9.8m^2 less than the predicted value which is expressed in percentage of 0.4%

B. Preliminary PPP regression model for cracking

year	cracking
2016	405.6
2017	443
2018	459.4
2019	472.3
2020	503
2021	552.7
2022	567
2023	571
2024	608.688
2025	633.55
2026	658.412
2027	683.274
2028	708.136

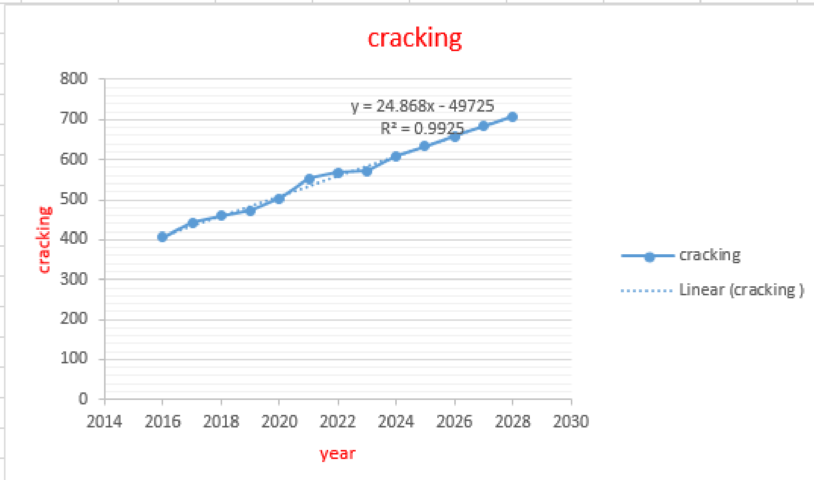


Figure 4.15 PPP regression model for cracking from 119km-121km

Ppp regression model done for cracking by correlating pavement age with pavement cracking having R^2 value of 0.9925 that means cracking and pavement age is highly correlated. The correlation of age and cracking is based on the past eight years crack data and predict the future five years crack information.

The past eight years crack data from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of crack on 2024 GC will be 608.6m^2 and the actual crack data on 2024 is 593m^2.

Using the percentage difference formula the difference between the actual and the predicted crack will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 608.6 - 593 = 15.6m^2

The average value is 608.6 + 593)/2 = 600.8m^2

The percentage deference is = (15.6/600.8) * 100% = 2.59%

The study shows the actual pavement crack is 15.6m^2 less than the predicted value which is expressed in percentage difference of 2.59%

C. Preliminary PPP model for patching

year	paching
2016	798.14
2017	887.5
2018	911.56
2019	941.2
2020	977
2021	1025.44
2022	1088
2023	1106.5
2024	1157
2025	1199.125
2026	1241.25
2027	1283.375
2028	1325.5

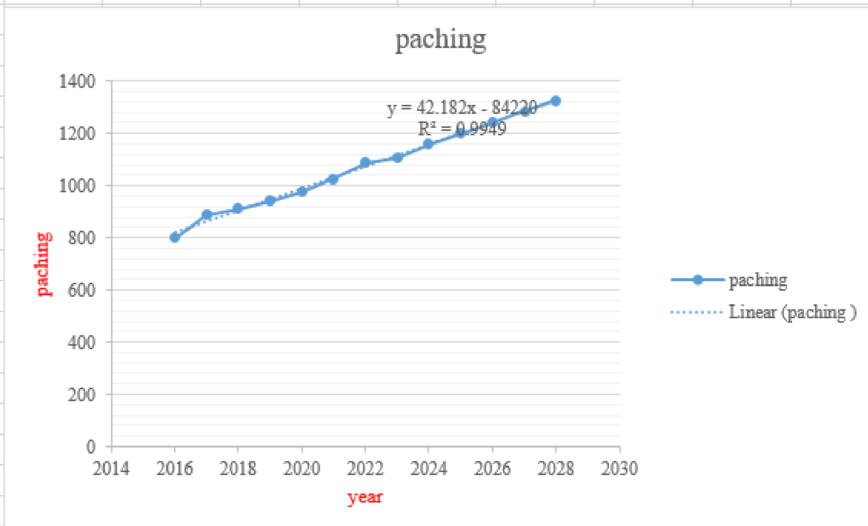


Figure 4.16 preliminary PPP regression model for patching

Ppp regression model done for patching by correlating pavement age with pavement patching having R^2 value of 0.9949 that means patching and pavement age is highly correlated. The correlation of age and patching is based on the past eight years patch data and predict the future five years patch information.

The past eight-year's pavement patch data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of pavement patch on 2024 GC will be 1157m^2 and the actual patch data on 2024 is 1165.6m^2.

Using the percentage difference formula the difference between the actual and the predicted patching will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 1165.6– 1157 = 8.7m^2

The average value is 1165.6+ 1157)/2 = 1161.3m^2

The percentage deference is = (8.7/1161.3) * 100% = 0.75%

The study shows the actual patching is 8.7m^2 greater than the predicted value which is expressed in percentage difference of 0.75%

D. Preliminary PPP model for edge damage

year	edge damage
2016	4.2
2017	11.2
2018	13.2
2019	15.6
2020	23
2021	23.8
2022	28.2
2023	30
2024	33.772
2025	37.4
2026	41.028
2027	44.656
2028	48.284

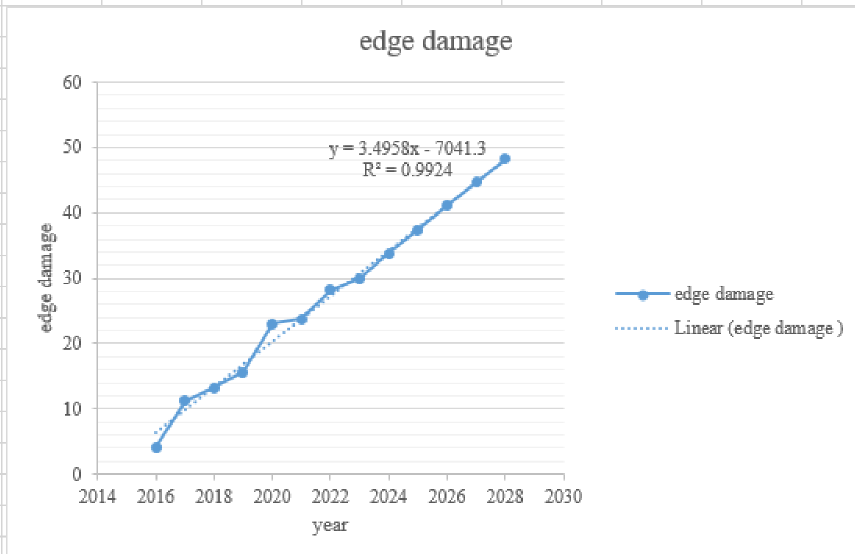


Figure 4.17 Preliminary PPP regression model for edge damage

Ppp regression model done for edge damage is by correlating pavement age with pavement edge damage having R^2 value of 0.9924 that means edge damage and pavement age is highly correlated. The correlation of age and edge damage is based on the past eight years edge damage data and predict the future five years edge damage information.

The past eight years edge damage data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of edge damage on 2024 GC will be 33.7m^2 and the actual crack data on 2024 is 35m^2.

Using the percentage difference formula the difference between the actual and the predicted edge break will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 35- 33.7 = 1.3m^2

The average value is 35 + 33.7)/2 = 34.35m^2

The percentage deference is = (1.3/34.35) * 100% = 3.78%

The study shows the actual edge damage is 1.7m^2 greater than the predicted value which is expressed in percentage difference of 3.78%

E. Preliminary Ppp regression model for pothole

year	pothole
2016	190.71
2017	201.35
2018	212.76
2019	214
2020	217.4
2021	230.5
2022	231
2023	236.8
2024	245.3152
2025	251.595
2026	257.8748
2027	264.1546
2028	270.4344

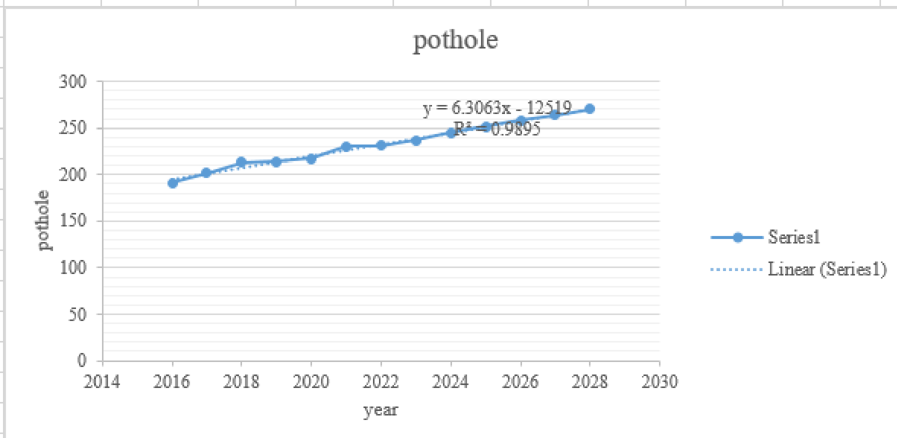


Figure 4.18 PPP regression model for pothole

Ppp regression model done for pothole is by correlating pavement age with pavement pothole having R^2 value of 0.9895 that means pothole and pavement age is highly correlated. The correlation of age and pothole is based on the past eight year's pothole data and predict the future five years pothole information.

The past eight year's pothole data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of pothole on 2024 GC will be 245.3m^2 and the actual pothole data on 2024 is 247.8m^2.

Using the percentage difference formula the difference between the actual and the predicted pothole will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 247.8- 245.3 = 2.5m^2

The average value is 247.8 + 245.3)/2 = 246.55m^2

The percentage deference is = (2.5/246.55) * 100% = 1.0%

The study shows the actual edge damage is 2.5m^2 greater than the predicted value which is expressed in percentage difference of 1.0%

F. Preliminary Ppp model for pavement shoving

year	shoving
2016	76
2017	86.9
2018	93.1
2019	111
2020	124.5
2021	167
2022	172
2023	174.2
2024	198.176
2025	214.225
2026	230.274
2027	246.323
2028	262.372

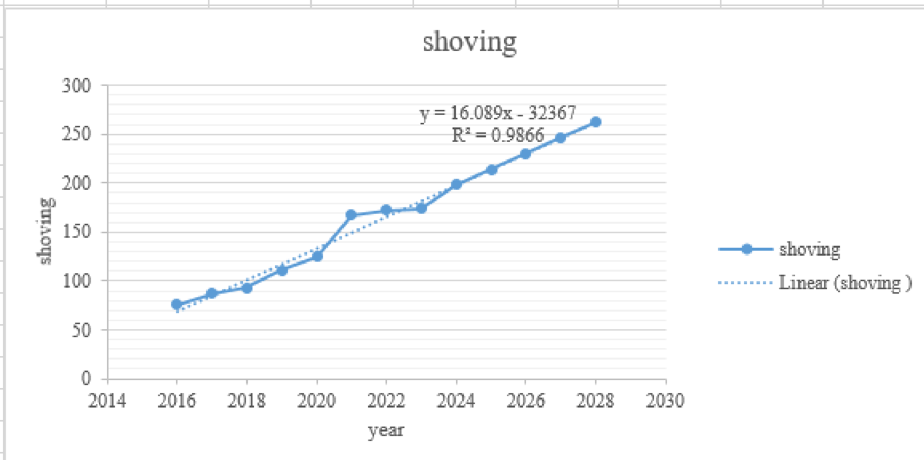


Figure 4.19 preliminary PPP regression model for shoving

Ppp regression model done for shoving is by correlating pavement age with pavement shoving having R^2 value of 0.9866 that means shoving and pavement age is highly correlated. The correlation of age and shoving is based on the past eight years shoving data and predict the future five years shoving information.

The past eight years shoving data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of shoving on 2024 GC will be 198.17m^2 and the actual shoving data on 2024 is 194.8m^2.

Using the percentage difference formula the difference between the actual and the predicted shoving will be calculated as below.

The percentage difference is the ratio of the difference between the actual and the predicted values of any quantity after a change to their average value multiplied by 100.

The difference is 198.17 – 194.8 = 3.37m^2

The average value is 198.17 + 194.8)/2 = 196.48m^2

The percentage deference is = (3.37/196.48) * 100% = 1.7%

The study shows the actual shoving is 3.37m^2 less than the predicted value which is expressed in percentage difference of 1.7%

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The purpose of this thesis was to assess the state of pavement management practices and create a pavement performance prediction model using the Ethiopian Road Administration as a case study. The major problem in road sector development is inadequate maintenance of defective road. The road sector pavement management directorate planned and arrange strategies for timely maintenance of defective road but in reality the maintenance activity done after the road condition become sever condition. Which lead huge maintenance expense instead this loss could have been averted with less preventive maintenance cost. Pavement performance models can be used to establish repair priorities based on available funds and to estimate future maintenance requirements and budgets. These models allow for the forecasting of future pavement conditions, which may then be utilized as inputs to the maintenance strategy to determine the necessary maintenance and rehabilitation actions. Pavement management department can use prediction models to determine what, when, and where maintenance should be performed. The study's findings indicate that the regression analysis model's maximum percentage difference between the actual and anticipated pavement distress is 4.2%, making it a good starting model. In this case it is very necessary to evaluate Road pavement Management practices and develop PPP model for optimizing the cost of maintenance in the pertinent organizations in Ethiopia. Additionally, the country's budget and the severity of the road conditions are given priority in the repair activities.

5.2 RECOMMENDATION

Subgrade with high swell should be avoided in future road design and construction, or it should be properly treated by excavating and replacing expansive inset subgrade to a depth where moisture variation is minimal and sufficient cover is provided to overcome the swell pressure caused by moisture increase under subgrade.

To reduce unnecessary expenses, the pavement management team should do routine maintenance before the road sustains significant damage. HDM-4 software is used by the Ethiopian road administration pavement management section to aid with maintenance tasks. However, the department has yet to implement the PPP model. Actually the maintenance department did pavement maintenance strategies according to the pavement design and service life of road but due to different reasons the pavement repaired after the road become detreated. So it is helpful that the department should use performance prediction model in order to forecast the future condition of road and arrange maintenance strategies before the road became totally destroyed.

5.3 RESEARCH GAPS

As a nation, pavement performance prediction models are a relatively recent field of study. Therefore, obtaining data on road conditions and various analysis techniques presents numerous challenges and uncertainties for the study.

ERA's PM section administers HDM-4, an efficient pp approach that uses about two hundred data points. For two key reasons, it is not practicable for a personal researcher to do study using HDM-4 software. First, only the department itself is permitted to utilize the software, and second, it is challenging to obtain two hundred data directly.

For the reasons listed above, the researcher used regression analysis alone to create the model as a preliminary study. This method is somewhat successful, but the research community needs to perform other ppp model analysis.

REFERENCE

Abu-Lebdeh, G, Ahmed, K., and Lyles, R.W. (2006) “Prediction of Pavement Distress Index With Limited Data on Causal Factors: an Auto-Regression Approach,” *The International Journal of Pavement Engineering*, *7*(1), p. 23–35, London, England.

Cain, C. (2003), *Building Down Barriers: A Guide to Construction Best Practice*, Spoon Press, London.

Chatti, K., Buch, N., Haider, S.W., Pulipaka, A.S., Lyles, R.W., Gilliland, D., and Desaraju, P. (2005) *LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements.* Web-Only Document 74 (Project 2050 [10/16]), National Cooperative Highway Research Program, Washington, DC.

C.R. Kothari, Research methodology method and technics (second edition), May 1990.

Applied pavement technology “Current practice in pavement management modeling (2010)

Ethiopian Roads Authority Drainage Design Manual, (2002).

Ethiopia Transportation System Improvement Project (TRANSIP) (February 2016).

ERA (2013), *Road Sector Development Program: 16 Years Performance Assessment*, Ethiopian Roads Authority, Addis Ababa.

FHWA (1997). ―Asset Management Primer‖, Federal Highway Administration, Office of Asset Management, Washington, DC.

Government of Western Australia, 2010. *Western Australian (Roman) Asset Management System.*

Hillebrandt, P. (1974), *Economic Theory*. London: Macmillan Press Ltd.

Khatta, M.J., G.Y. Baladi, Z. Zhang, and S. Ismail. 2008. *Review of Louisiana's Pavement Management System - Phase I.* Transportation Research Record, Volume 2084. Transportation Research Board, Washington, DC.

Khurshid, M.B.Irfan, M., and Labi, S. (2009) Service *Life of Thin HMA Overlay Using Different Performance Indicators*. Transportation Research Board Annual Meeting, Washington, DC.

Meraf Elias, assessment of drainage system in Adama, 2015.

Morton, R. (2002) *Construction UK: Introduction to the Industry*. Oxford: Blackwell Publishing.

MoWUD (2001) *Study for Capacity Building of the Construction Industry Ethiopia,* Ministry of Works and Urban Development, Addis Ababa.

NCHRP. Transportation Asset Management Guide. Project 20-24(11) for AASHTO. 2002.

Luo, Z. (2006) *Flexible Pavement Condition Model Using Cluster-wise Regression and Mechanistic-Empirical Procedure for Fatigue Cracking Modeling*. Doctoral Dissertation. The University of Toledo, Toledo, OH.

OECD (2001), Asset Management for the Roads Sector,‖ Program of Co-Operation in the Field of Research on Road Transport and Intermodal Linkages, Organization for Economic Cooperation and Development, Directorate.

Robert. K. yin, case study research and application, six edition, 2018. Statistic in plain English second edition

Winch, G.M. (2002), *Managing Construction Projects: An Information Processing Approach,* Blackwell Science Ltd, Oxford, UK.

Fiche – Gohatsion Road Overlay Project, through Admeasurements and Performance Based Road Contract Draft Engineering Design Review Report (2016)

United Nations Economic Commission for Africa "Road safety performance review of Ethiopia (2020)"

ANNEX: PUBLICATION ARTICLE (MANUSCRIPT)

Development of Pavement Management Performance Model: A Case Study of Ethiopian Roads Administration

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Abstract

According to reports, the road subsector, which creates a large number of job possibilities, accounts for roughly fifty-eight percent (58%) of Ethiopia's federal capital budget. It is important to stress that building roads is how Ethiopian development is accomplished. An estimated $45 billion worth of road infrastructure has been destroyed over the previous 20 years due to poor maintenance, according to a World Bank study conducted in 85 developing nations. Less than $12 billion might have been spent on preventive maintenance to avoid this loss. Performance models are used in pavement management systems (PMSs) to forecast pavement performance in the future. This study's primary goals are to evaluate the Ethiopian Road Administration's present pavement management practices and create a pavement performance prediction model. A case study will be employed as a research methodology to carry out the investigation. Previous pavement condition assessment reports, document examination, and observation are the methods used to acquire data. Following that, both qualitative and quantitative methods—primarily the regression method—are used to analyze and interpret the data. The study's findings indicate that the regression analysis model's maximum percentage difference between the actual and anticipated pavement distress is 4.2%, making it a good starting model. Ultimately, by reducing the most significant issues that are unique to the city, this study offers the municipal administration a logical way to enhance its road pavement management practices. By forecasting the road's future state, the pavement performance model is also anticipated to assist the local administration in carrying out prompt maintenance on damaged roads.

Key Word: Road pavement Management, Pavement Performance Prediction Model, Pavement Management System

1. Introduction

Our country's progress is significantly influenced by the construction industry. One may argue that every aspect of development is impacted by construction. According to United Nations Economic Commission for Africa "Road safety performance review of Ethiopia (2020)" Sustainable and vibrant transport systems can lead to long-term economic growth. If designed well, transport facilitates access to opportunities, education, medical services, and goods, and improves overall quality of life. In addition to increasing manufacturing capacity, this sector is essential for building social infrastructure like hospitals and schools and for building economic infrastructure like highways and railroads. Additionally, by building and renovating dwellings, construction plays a major role in raising living standards.

Performance models are used in pavement management systems (PMSs) to predict the state of the pavement in the future. As such, these models must be reliable and faithfully represent the real deterioration trends seen in the agency's pavements. (Abu-Lebdeh, G, Ahmed, K., and Lyles, R.W. ,2006). In order to forecast future pavement conditions, determine the best time for maintenance and rehabilitation, find the most economical treatment strategies for the pavement network, estimate statewide pavement requirements to meet agency-defined goals and constraints, and illustrate the implications of various pavement investment strategies, pavement prediction models are essential for a variety of pavement management tasks.

2. Methodology of the study

2.1 Research design

With a primary focus on the rules, procedures, and technology utilized in road asset management, the study examines the pavement management practices now employed by the Ethiopian Road Administration (ERA). Models for forecasting future pavement performance of road conditions will be created based on data gathered from ERA in order to optimize cost and schedule maintenance.

The pavement performance prediction model will be developed using data on pavement conditions from the past and present. Regression analysis is used in this work to forecast the likelihood of future pavement conditions. More than ten years' worth of pavement condition data should be used to obtain precise and reliable PPP results. The study's producer is depicted in Figure 2.1.

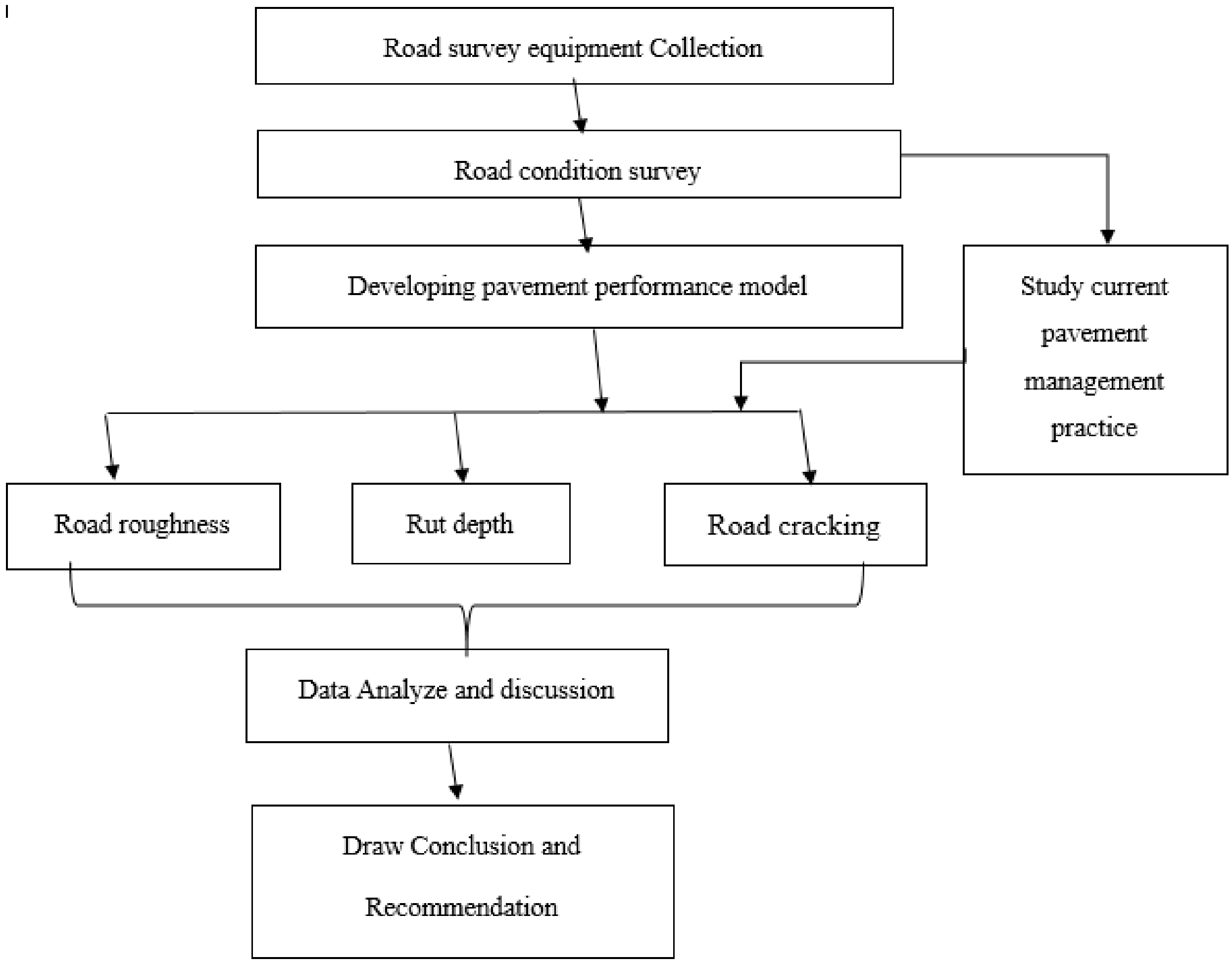

Figure 2.1 Research design

Probably the most crucial phase in a research study technique is defining the research topics. This study's primary goal is to assess PMS's present practice, create models for predicting pavement performance using data on pavement conditions over the last eight years, and forecast pavement performance over the next five years. Age, weather, traffic volume, and pavement thickness will all be factors in the pavement prediction model. Other than age, the researcher is unable to discover sufficient information.

Therefore, the connection cannot be reliable in the absence of enough and accurate data. Roughness, rutting, vertical deformation, potholes, patching, shoving, edge break, and pavement cracking are therefore associated with pavement age, according to the study.

2.1.1 Case study

The case study focusses more on thoroughly examining a small set of circumstances or occurrences and how they relate to one another. The processes that occur and their interactions are the subject of the case study. Therefore, a case study is basically a thorough examination of the specific unit being studied. Finding the elements that explain the behavior patterns of the specified unit as an integrated whole is the goal of the case study technique.

Since there is sufficient data and information on the condition of the pavement, Alemgena districts major Fitch Road is used as a case study in this study.

2.2 Data collection method

To gather data, the researcher used document analysis, and observation. The data from the pavement condition survey that was previously gathered by the Road Asset and Data Base Management Directorate using manual procedures, observation, and relevant literature are considered secondary data.

2.3 Study population and sampling techniques

Investigating contemporary pavement management practices and creating a pavement performance prediction model for the Ethiopian Road Administration (ERA) are the primary goals of this work. Thus, the sampling frame is the 102–177 km Fitch to Gohathion route, and the target population is the Ethiopian road Administration/Alemgena district. Three road segments were purposefully chosen by the researcher to serve as a case study. 102–103 kilometres for example one, 119–120 km for case two, and 139–140 km for case three.

The goal of sampling, according to Fellows and Liu (2015), is to offer a workable way to carry out the data gathering and processing aspects of research while guaranteeing that the sample offers a good representation of the population.

2.4 Pavement Performance Indicators

Following the ERA-PMS handbook and guide as well as international practice, the survey team measured, gathered, and documented detail road pavement condition data during the detail condition survey. This data included surface cracking, ravelling, potholes, edge break, roughness, rutting, texture, and pavement strength data (deflection measurement). The pavement condition index uses an objective scale ranging from 0 to 100 to quantify pavement conditions. PCI ratings fall into five categories very poor (0-35); poor (36-50); fair (51-70); good (71-85); and excellent (86- 100). Following ERA- PMS manual and guide as well as international practice.

2.5 Method of data analysis

In order to anticipate pavement performance modelling, the study employed linear regression to evaluate the relationship between factors, demonstrating the extent to which independent variables influence dependent variables. (Luo, Z. (2006)

The regression formula

$Y = mx + b$

Where y = the predicted variable of y

m = unstandardized regression coefficient or slope

x = the independent variable

b = y intercept

The pavement's age, traffic volume, and climate are the independent factors.
In the study, rutting, roughness, cracking, shoving, patching, and edge break were correlated with pavement age. Rut depth, roughness, cracking, patching, edge break, shoving, vertical deformation, and pavement quality index are some of the dependent factors. Lastly, this study uses linear regression analysis to show how age correlates with rutting, roughness, pothole, cracking, patching, edge break, and shoving.

3. Data analysis and discussion

3.1 Current pavement management practice for Alemgena road district

Ethiopian Roads Administration collects various road condition data either by using an automated data collection system (Hawkeye 1000/2000 Digital Profiler) or by manually rating the road network. This study is done the case of the paved road network of Alemgena district.

In order to have a better decision on allocation of the limited resource for the road maintenance and condition improvement and to minimize the negative impact of poor roads on road users, detailed condition data needs to be collected on a regular time frame, if possible annually.

Under the five road network management directorates there are a total of 12,655 km of road network length out of which 6,329 km is paved and the remaining 6,326 km is gravel surfaced. This system of road network consists of a wide range of condition, age and performance. However, the study is for paved roads and hence the current practice and the PPP model is for the paved roads only. The road network is organized in five road network management directorates.

Table 3.1 the Ethiopian road network

	Length (km)		Total (km)
District	Paved roads	Unpaved roads	
Alemgena	1,932	2,211	4,143
Kombolcha	1,689	1,138	2,827
Adigrat	1,456	771	2,227
Debremarkos	333	1,362	1,695
Gondar	919	844	1,763
Total	6,329	6,326	12,655

3.2 pavement condition survey

The pavement condition index is a five stage percentage index rating ranging between 0, for pavement in Very Poor condition, to 100 percent representing a pavement in Very Good condition. The five categories are colour coded.

Table: 3.2:- Condition Index Performance Categories (source: ERA PMS Condition Index (CI))

Descriptive Category	Condition Index	
	Range (%)	Colour Code
Very Good	86 – 100	
Good	71 – 85	
Fair	51 – 70	
Poor	36 – 50	
Very Poor	0 – 35	

Table: 3.3:- Condition Index and Data range describing each problem category – paved roads

Distress	Attribute in Survey perspective	Data range describing each problem category – paved roads				
		Severe	Warning	Moderate	Isolated	None
Condition Index (CI) %	CI	0-35%	35-50%	50-70%	70-85%	85%+
Narrow Cracks (%)	P_CracksPerc_Narrow	>15%	10-14%	5-9%	1-4%	0%
Wide Cracks (%)	P_CracksPerc_Wide	>15%	10-14%	5-9%	1-4%	0%
Ravelling (%)	P_RavellingPerc	>15%	10-14%	5-9%	1-4%	0%
Potholes (No / km)	P_Pothole_Per_Km	>15	14-10	9-5	4-1	0
Roughness (IRI)	B_IRI	>6.5 IRI	4.5-6.5 IRI	3-4.5 IRI	2-3 IRI	< 2 IRI
Rut Depth (mm)	P_Rut	> 25 mm	15 – 25 mm	5 – 15 mm	2 – 5 mm	< 2 mm
Mean Texture Depth (mm)	P_MPD	< 0.3 mm	0.3-0.7 mm	0.7 – 1.0 mm	1 – 1.5 mm	> 1.5 mm
Edge Break (m2 / km)	P_EdgeBreakArea	>300m2	100-300 m2	10-100 m2	0-10 m2	0 m2
Side Drainage Condition (1-5)	P_DrainCondition	4	3	2	1	0

Table 3.4 Alemgena RNMD network by surface type

Item no.	Section	Road Segment No.	Surface Type & Length (km)		
			Paved	Unpaved	Total
1	Mojo	9	387.1	73.0	460.1
2	Debreberehan	9	149.1	151.0	300.1

Item no.	Section	Road Segment No.	Surface Type & Length (km)		
			Paved	Unpaved	Total
3	Robit	10 *	181.2 *	134.0	315.2
4	Muketuri	12	311.4 *	220.0	531.4
5	Ambo	8	250.2	111.0	361.2
6	Woliso	9	176.1	193.0	369.1
7	Huruta	13	88.3	507.0	595.3
8	Butajira	12	345.8	191.0	536.8
9	Endiber	8	244.5*	88.0	332.5
Total		90	2,133.7	1,668.0	3,801.7

Paved road Network Condition

The current condition of the paved roads in Alemgena RNMD is described in terms of roughness, rutting, and overall Condition Index (CI) according to the detailed condition survey as indicated here below.

Roughness

The International Roughness Index (IRI) is the roughness index most commonly obtained from measured longitudinal road profiles. According to this survey (Year 2016) the average roughness of the roads in Alemgena RNMD by road segment is as shown in table below.

Table: 3.5: Alemgena RNMD Roughness (IRI) Distribution by Road Segment

Section	Road Name	Length	Roughness IRI	Problem Category
Modjo	Arerti kesem wonze	25.26	4.90	Warning
	Metehara Awash	39.80	2.76	Isolated Problems
	Mojo Addis	49.94	4.10	Moderate Problems
	Mojo Ejere Arerti	61.38	4.30	Moderate Problems
	Mojo Nazrete	19.83	3.00	Isolated Problems
	Nazrete Metehara	98.00	3.26	Moderate Problems
	Zeway Mojo	92.92	3.80	Moderate Problems
	Total	387.13	3.71	Moderate Problems
Debrebrehan	Addis Aleltu	38.91	3.00	Isolated Problems
	Aleltu Sembo	34.96	3.00	Isolated Problems
	Debrebrehan-Gudo beret	33.49	2.80	Isolated Problems
	Sembo Debrebrehan	41.71	3.00	Isolated Problems
	Total	149.07	2.96	Isolated Problems
Robit	Debresina Robit	31.97	2.90	Isolated Problems

Section	Road Name	Length	Roughness IRI	Problem Category
	Gundobret Debresina	29.28	2.90	Isolated Problems
	Robit Ataye	47.90	2.93	Isolated Problems
	Total	109.15	2.91	Isolated Problems
Muketuri	Abay Wenze Dejen	22.07	11.35	Severe
	Addis Chancho	29.72	3.50	Moderate Problems
	Chagel Debrelibanos	5.14	4.10	Moderate Problems
	Chancho Commando	76.83	3.50	Moderate Problems
	Commando-Fitche	5.03	3.40	Moderate Problems
	Commando-G.Gurach	46.87	4.50	Moderate Problems
	G.Gurach Abay Wenze	52.77	11.00	Severe
	Total	238.43	6.09	Warning
Ambo	Addis Holota	27.30	2.90	Isolated Problems
	Addis Tatek	13.94	5.50	Warning
	Ambo Gedo	69.38	4.60	Warning
	Ginchi Ambo	37.45	3.40	Moderate Problems
	Holeta Muger	57.60	2.20	Isolated Problems
	Holota Ginchi	44.57	3.20	Moderate Problems
	Total	250.24	3.48	Moderate Problems
Woliso	Addis Tulubollo	66.80	3.86	Moderate Problems
	Tullu Bollo Weliso	35.68	3.80	Moderate Problems
	Weliso Welkite	42.48	3.66	Moderate Problems
	Welkite Gibe Wonze	31.16	3.87	Moderate Problems
	Total	176.12	3.80	Moderate Problems
Huruta	Eteya Asela	28.78	2.30	Isolated Problems
	Melkasa Eteya	34.20	2.30	Isolated Problems
	Melkasa Sodere	7.43	6.40	Warning
	Nazrete Melkasa	17.85	2.40	Isolated Problems
	Total	88.26	2.67	Isolated Problems
Butajira	Alemgena Lemen	43.75	5.50	Warning
	Butajera Wolbareg	55.20	4.60	Warning
	Butajera Zeway	54.79	5.10	Warning
	Hosina Areka	71.04	5.60	Warning
	Hosina Wolbareg	44.50	5.50	Warning
	Lemen Butajera	76.47	5.10	Warning
	Total	345.75	5.22	Warning
Endeber	Bojeber Gubre	54.18	4.60	Warning
	Butajira Bojeber	29.05	4.70	Warning
	Kose - Gilgel Gibe II	36.14	6.50	Warning
	Welkite - Mazoria	56.19	2.80	Isolated Problems
	Total	175.56	4.43	Moderate Problems
Alemgena Total		1,919.71	4.17	Moderate Problems

The Detailed Road Condition Assessment findings shown in table 4.5 reveals that the overall paved road roughness value for Alemgena RNMD is 4.17 IRI which places the overall problem category for roughness in the Moderate Problems Category.

The assessment also indicates that the Roughness Distress on paved road network under three sections (Debreberehan, Robit and Huruta) is in Isolated Problem category, while that for the other four sections (Mojo, Ambo, Woliso, and Endibir) is in Moderate Problem category. The remaining two sections (Butajira and Muketuri) have a roughness distress in the Warning Problem category.

Rearranging the data shown above one can see that the length of road in each Problem category is as shown in the following table.

Table: 3.6:- Alemgena RNMD Roughness (IRI) Distribution by Problem Category

Roughness	Road Length (Km)	Average Roughness	% Proportion
Sound: <2 IRI	0.00	0.00	0.00
Isolated Problems: 2-3 IRI	539.77	2.74	28
Moderate Problems: 3-4.5 IRI	723.97	3.73	38
Warning: 4.5-6.5 IRI	581.13	5.15	30
Severe: >6.55 IRI	74.84	11.10	4
Alemgena Total	1,919.71	4.17	100

Out of the total length of 1,919.7 km long road surveyed directorate wide about 28 %, 38 %, 30 % and 4 % are found to be in Isolated Problem, Moderate Problem, Warning and Severe Problem Category, with an average Roughness of 2.74 µm/km, 3.73 µm/km, 5.15 mµ/km and 11.10 µm/km respectively. The critical parts that need closer attention are the road length in Warning and Severe Problem category with length of nearly 656 km, which is about 34 % of the network.

Rutting

Rut depth is measured manually in both wheel tracks by placing a straight edge over the depressions. The distribution of mean rut depth in this district is summarized as follows

Table 3.7:- Alemgena RNMD Rutting (mm) Distribution by Road Segment, 2016

Section	Road Name	Length	Rut Depth (mm)	Problem Category
Modjo	Ererti kesem wonze	25.26	2.34	Isolated Problems
	Metehara Awash	39.80	2.56	Isolated Problems
	Mojo Addis	49.94	8.38	Moderate Problems
	Mojo Ejere Ererti	61.38	2.13	Isolated Problems
	Mojo Nazrete	19.83	4.89	Isolated Problems
	Nazrete Metehara	98.00	3.54	Isolated Problems
	Zeway Mojo	92.92	7.61	Moderate Problems
	Total	387.13	4.81	Isolated Problems
Debrebrehan	Addis Aleltu	38.91	2.05	Isolated Problems
	Aleltu Sembo	34.96	2.00	Sound
	Debrebrehan-Gudo beret	33.49	2.00	Sound
	Sembo Debrebrehan	41.71	2.00	Sound

	Total	149.07	2.01	Isolated Problems
Robit	Debresina Robit	31.97	5.91	Moderate Problems
	Gundobret Debresina	29.28	2.22	Isolated Problems
	Robit Ataye	47.90	3.89	Isolated Problems
	Total	109.15	4.03	Isolated Problems
Muketuri	Abay Wenze Dejen	22.07	34.90	Severe
	Addis Chancho	29.72	8.79	Moderate Problems
	Chagel Debrelibanos	5.14	8.61	Moderate Problems
	Chancho Commando	76.83	8.42	Moderate Problems
	Commando-Fitche	5.03	5.00	Moderate Problems
	Commando-G.Gurach	46.87	11.17	Moderate Problems
	G.Gurach Abay Wenze	52.77	20.12	Warning
	Total	238.43	13.98	Moderate Problems
Ambo	Addis Holota	27.30	3.96	Isolated Problems
	Addis Tatek	13.94	4.56	Isolated Problems
	Ambo Gedo	69.38	5.25	Moderate Problems
	Ginchi Ambo	37.45	3.93	Isolated Problems
	Holeta Muger	57.60	2.00	Sound
	Holota Ginchi	44.57	3.63	Isolated Problems
	Total	250.24	3.84	Isolated Problems
Woliso	Addis Tulubollo	66.80	5.15	Moderate Problems
	Tullu Bollo Weliso	35.68	5.01	Moderate Problems
	Weliso Welkite	42.48	4.75	Isolated Problems
	Welkite Gibe Wonze	31.16	3.68	Isolated Problems
	Total	176.12	4.76	Isolated Problems
Huruta	Eteya Asela	28.78	2.89	Isolated Problems
	Melkasa Eteya	34.20	2.61	Isolated Problems
	Melkasa Sodere	7.43	6.52	Moderate Problems
	Nazrete Melkasa	17.85	2.78	Isolated Problems
	Total	88.26	3.06	Isolated Problems
Butajira	Alemgena Lemen	43.75	5.42	Moderate Problems
	Butajera Wolbareg	55.20	3.53	Isolated Problems
	Butajera Zeway	54.79	3.18	Isolated Problems
	Hosina Areka	71.04	4.47	Isolated Problems
	Hosina Wolbareg	44.50	5.04	Moderate Problems
	Lemen Butajera	76.47	6.13	Moderate Problems
	Total	345.75	4.68	Isolated Problems
Endeber	Bojeber Gubre	54.18	2.00	Sound
	Butajira Bojeber	29.05	2.00	Sound
	Kose - Gilgel Gibe II	36.14	7.22	Moderate Problems
	Welkite - Mazoria	56.19	2.26	Isolated Problems
	Total	175.56	3.16	Isolated Problems
Alemgena Total		1,919.71	5.30	Moderate Problems

The Detailed Road Condition Assessment findings reveals that the overall paved road rutting value for Alemgena RNMD is 5.3 mm, this places the RNMD's paved road overall category for rutting in the Moderate Problems Category. The assessment also indicates that the Rutting Distress on paved road network under eight of the nine sections of Alemgena RNMD (Mojo, Robit, Ambo, Woliso, Huruta, Endibir, Woliso and Butajira) is in Isolated Problem category while that of Muketuri section is in Moderate Problem category. Rearranging the data shown above the length of road in each Problem category is as shown in the following table.

Table 3.8:- Rutting (mm) severity level (ERA maintenance manual)

Rut Depth	Road Length (Km)	Rut Depth(mm)	% Proportion
Sound: <2mm	250.99	2.19	13
Isolated Problems: 2-5 mm	875.31	3.31	46
Moderate Problems: 5-15 mm	718.57	6.88	37
Warning: 15-25 mm	52.77	20.12	3
Severe: >25 mm	22.07	34.90	1
Alemgena Total	1,919.71	5.30	100.00

Out of the total length of 1,919.7 km long paved road surveyed directorate wide about 13%, 46%, 37%, 3% and 1% are found to be in Sound, Isolated Problem, Moderate Problem, Warning and Severe Problem Category with mean rut depth of 2.19 mm, 3.31 mm, 6.88 mm, 20.12 mm and 34.90 mm respectively. The critical parts that need closer attention are the road length in Warning and Severe Problem category with length of nearly 75 km, which is just about 4 % of the network.

Condition Index (CI)

The collected distress data is used to determine a single Condition Index (CI) describing the overall condition of a road segment in the RNMD for the year 2016. This CI, calculated for each surveyed road segment, is a percentage index ranging between 0 and 100; 0 representing a road segment in very poor condition and 100 representing a road segment in very good condition. Table below shows the pavement CI for 2016 for each road segment in Alemgena RNMD.

Table 3.9: Summary of the Detailed Road Condition Assessment Finding, 2016

Section	Road Name	Length	Roughness	Condition Category
Modjo	Arerti kesem wonze	25.26	61	Fair
	Metehara Awash	39.80	70	Fair
	Mojo Addis	49.94	36	Poor
	Mojo Ejere Arerti	61.38	63	Fair
	Mojo Nazrete	19.83	62	Fair
	Nazrete Metehara	98.00	66	Fair
	Zeway Mojo	92.92	36	Poor
	Total	387.13	54.33	Fair
Debrebrehan	Addis Aleltu	38.91	74	Good
	Aleltu Sembo	34.96	74	Good
	Debrebrehan-Gudo beret	33.49	75	Good

	Sembo Debrebrehan	41.71	74	Good
	Total	149.07	74.22	Good
Robit	Debresina Robit	31.97	62	Fair
	Gundobret Debresina	29.28	71	Good
	Robit Ataye	47.90	64	Fair
	Total	109.15	65.29	Fair
Muketuri	Abay Wenze Dejen	22.07	17	Very Poor
	Addis Chancho	29.72	53	Fair
	Chagel Debrelibanos	5.14	41	Poor
	Chancho Commando	76.83	54	Fair
	Commando-Fitche	5.03	64	Fair
	Commando-G.Gurach	46.87	28	Very Poor
	G.Gurach Abay Wenze	52.77	13	Very Poor
	Total	238.43	36.20	Poor
Ambo	Addis Holota	27.30	71	Good
	Addis Tatek	13.94	41	Poor
	Ambo Gedo	69.38	46	Poor
	Ginchi Ambo	37.45	67	Fair
	Holeta Muger	57.60	80	Good
	Holota Ginchi	44.57	69	Fair
	Total	250.24	63.51	Fair
Woliso	Addis Tulubollo	66.80	51	Fair
	Tullu Bollo Weliso	35.68	58	Fair
	Weliso Welkite	42.48	62	Fair
	Welkite Gibe Wonze	31.16	50	Poor
	Total	176.12	54.89	Fair
Huruta	Eteya Asela	28.78	68	Fair
	Melkasa Eteya	34.20	77	Good
	Melkasa Sodere	7.43	31	Very Poor
	Nazrete Melkasa	17.85	68	Fair
	Total	88.26	68.37	Fair
Butajira	Alemgena Lemen	43.75	45	Poor
	Butajera Wolbareg	55.20	58	Fair
	Butajera Zeway	54.79	56	Fair
	Hosina Areka	71.04	45	Poor
	Hosina Wolbareg	44.50	49	Poor
	Lemen Butajera	76.47	49	Poor
	Total	345.75	50.22	Fair
Endeber	Bojeber Gubre	54.18	61	Fair
	Butajira Bojeber	29.05	62	Fair
	Kose - Gilgel Gibe II	36.14	30	Very Poor
	Welkite - Mazoria	56.19	74	Good
	Total	175.56	58.94	Fair
Alemgena Total		1,919.71	55.82	Fair

The Detailed Road Condition Assessment findings reveal that the overall paved road condition index of Alemgena Road Network Management Directorate is about 55.82 % which is lower side of the fair category. The assessment also indicate that condition index of paved road network under seven of the nine sections (Mojo, Robit, Ambo, Woliso, Huruta, Endibir and Butajira) is in Fair condition category while that of Debreberehan and Muketuri sections is in Good and Poor condition category respectively.

Summary of Distress information for Alemgena road district

The district Paved road network can also be categorised in terms of the different distresses that were rated, e.g. narrow cracks, wide cracks, drain condition, etc.

Table 3.10 the different types of distresses measured in this survey

Alemgena RNMD	IRI	NC (%)	WC(%)	DC (0-5)	EB(m^2/Km)	Texture	Pothole (No/km)	Raveling (%)	Rut Depth (mm)
Severe	74.84	-	142.86	-	-	-	7.43	71.04	22.07
Warning	581.13	46.87	67.30	13.94	-	-	-	252.65	52.77
Moderate	723.97	57.91	195.22	-	105.49	352.01	154.36	376.98	718.57
Isolated	539.77	795.47	873.30	190.13	848.88	1,156.90	1,094.24	886.86	875.31
Sound	-	1,019.46	641.03	1,715.64	965.34	410.80	663.68	332.18	250.99
	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71	1,919.71

The observation shows that the dominant distresses affecting roads in Severe and Warning problem categories are Roughness (IRI), Ravelling, Wide Crack and Rutting impacting 34 %, 17 %, 11 % and 4% of the RNMD's paved road network, respectively.

3.2 Pavement performance prediction model (ppp model) a Case study of Alemgena road disrrict (Fiche to Gohatsion road)

The project road is part of the road segment from Addis Ababa – Metema, particularly being part of the Addis Ababa – Debere Markos trunk road which has high traffic volume and load as it is the main corridor of Port Sudan, and additional traffic load arising from traffic generated as a result of industrial developments along the road corridor.

Pavement performance prediction model (ppp model) done for case one (102km - 104km), case two (119-121km) and case three from (139km – 141km)

I. Case study one from (102km-104km)

A. preliminary PPP regression model for Rutting

year	rutting
2016	2928.1
2017	3201.8
2018	3664.2
2019	3961.3
2020	4896.9
2021	5324.8
2022	5675.5
2023	6091
2024	6604.92
2025	7078.75
2026	7552.58
2027	8026.41
2028	8500.24

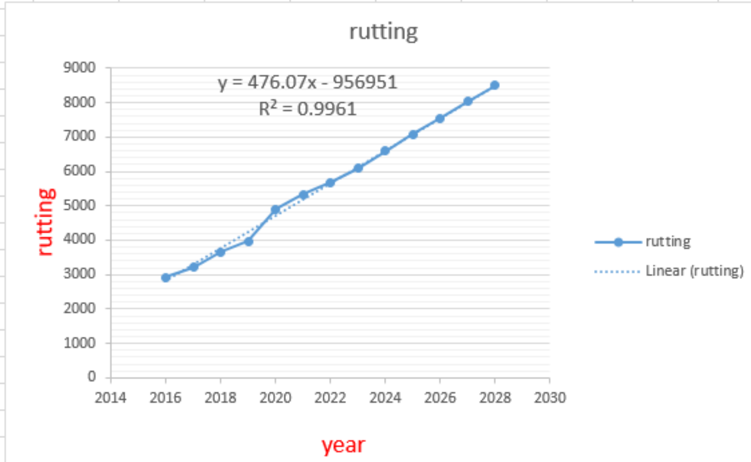

Figure 3.1 preliminary ppp regression model for rutting

Ppp regression model done for rutting by correlating pavement age with pavement rutting having R^2 value of 0.9961 that means rutting and pavement age is highly correlated. The correlation of age and rutting is based on the past eight years rut data and predict the future five years rut information.

The past eight years rut data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of rut depth on 2024 GC will be 6604.92 m^2 and the actual rut data on 2024 is 6545.1m^2.

The difference is 6604.92- 6545.1 = 59.82m^2

The average value is (6604.92 + 6545.1)/2 = 6575m^2

The percentage deference is = (59.89/6575) * 100% = 0.9%

The study shows the actual rut depth is 59.82m^2 less than the predicted value which is expressed in percentage of 0.9%

B. Preliminary PPP regression model for cracking

year	cracking
2016	438.7
2017	511.1
2018	551.4
2019	576.5
2020	609.9
2021	651.8
2022	691.3
2023	718.2
2024	764.464
2025	802.4
2026	840.336
2027	878.272
2028	916.208

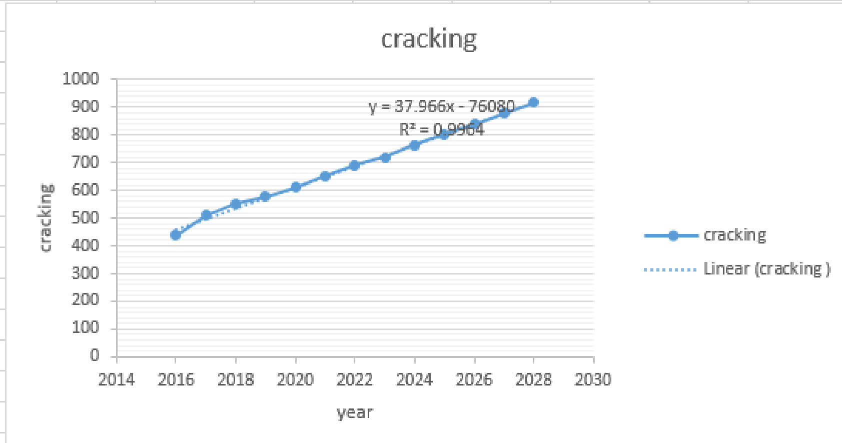

Figure 3.2 preliminary PPP regression model for cracking

The past eight years crack data are from 2016-2023 years, then the prediction made from 2024-2028 years. According to the prediction model, the value of crack on 2024 GC will be 764.5m^2 and the actual crack data on 2024 is 769.4m^2.

The percentage deference is = (5/766.95) * 100% = 0.65%

The study shows the actual crack is 5m^2 greater than the predicted value which is expressed in percentage difference of 0.65%

C. Preliminary PPP model for patching

year	paching
2016	477.73
2017	540.45
2018	563.4
2019	603.1
2020	648.1
2021	697.7
2022	743.3
2023	790.3
2024	829.808
2025	873.3
2026	916.792
2027	960.284
2028	1003.776

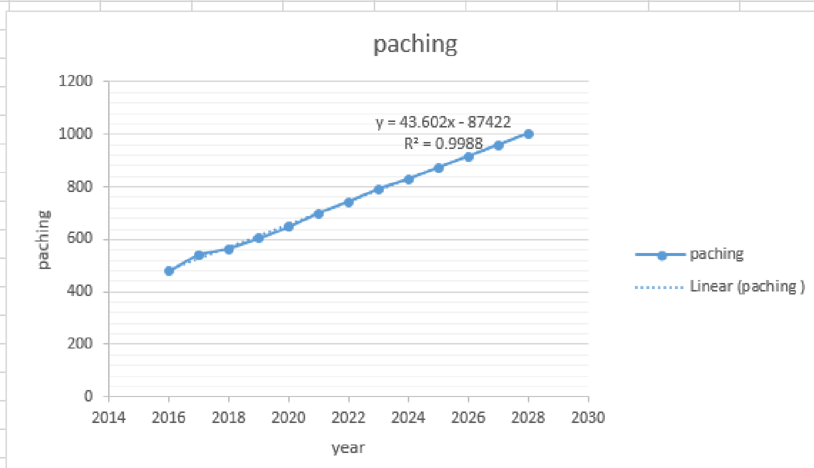

Figure 3.3 preliminary PPP regression model for patching

According to the prediction model, the value of patch on 2024 GC will be 829.8m^2 and the actual patch data on 2024 is 843.1m^2.

The percentage deference is = (13.3/836.45) * 100% = 1.60%

The study shows the actual patching is $13.3m^2$ greater than the predicted value which is expressed in percentage difference of 1.60%

D. Preliminary PPP model for edge damage

year	edge damage
2016	25.28
2017	31.82
2018	36.32
2019	43.56
2020	46.3
2021	53.36
2022	64.71
2023	72.79
2024	76.3
2025	82.8
2026	89.391
2027	95.95
2028	102.51

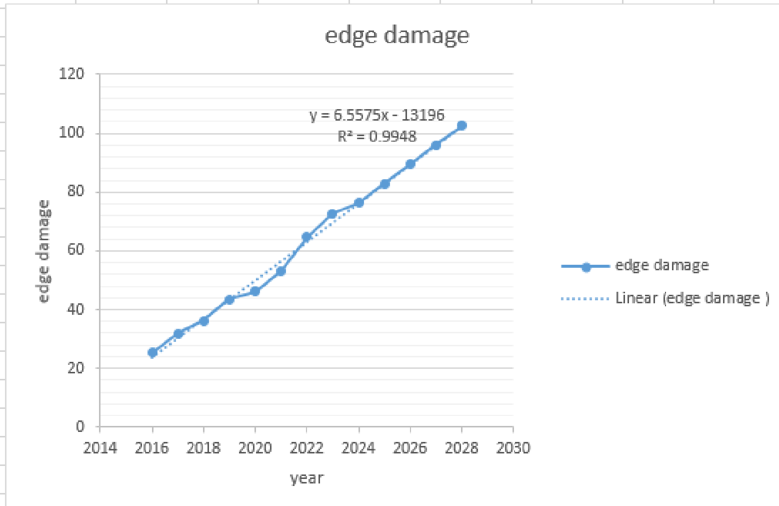

*Figure **3.**4 PPP regression model for edge damage*

According to the prediction model, the value of edge damage on 2024 GC will be $76.3m^2$ and the actual crack data on 2024 is $78.29m^2$.

The percentage deference is = (2/77.29) * 100% = 2.6%

The study shows the actual edge damage is $2m^2$ greater than the predicted value which is expressed in percentage difference of 2.6%

II. Case study two from (119km – 121km)

Pavement performance prediction model (ppp model) done for case two (119km - 121km),

A. Preliminary Ppp regression model for rutting

year	rutting
2016	1789.5
2017	1893.5
2018	1952.2
2019	2050.6
2020	2138.2
2021	2240.5
2022	2383
2023	2550.9
2024	2695.28
2025	2815.5
2026	2935.72
2027	3055.94
2028	3176.16

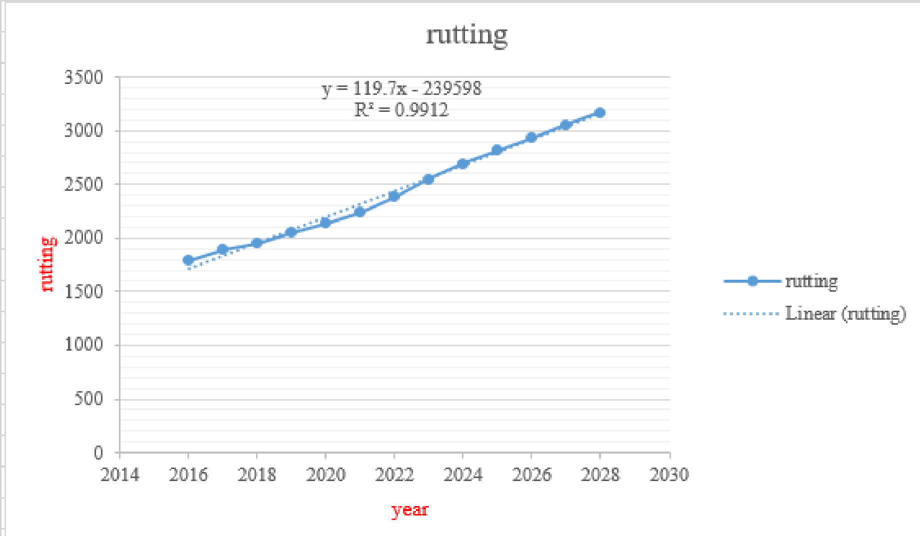

Figure 3.5 PPP regression model for rutting from 119km-121km

According to the prediction model, the value of rut depth on 2024 GC will be 2695.28m^2 and the actual rut data on 2024 is 2775m^2.

The percentage deference is = (80/2735) * 100% = 2.9%

The study shows the actual rut depth is 80m^2 greater than the predicted value which is expressed in percentage of 2.9%

B. Preliminary PPP regression model for cracking

year	cracking
2016	1562.2
2017	1649.8
2018	1746
2019	1883
2020	1970.24
2021	2027.72
2022	2132.55
2023	2207.7
2024	2319.048
2025	2412.675
2026	2506.302
2027	2599.929
2028	2693.556

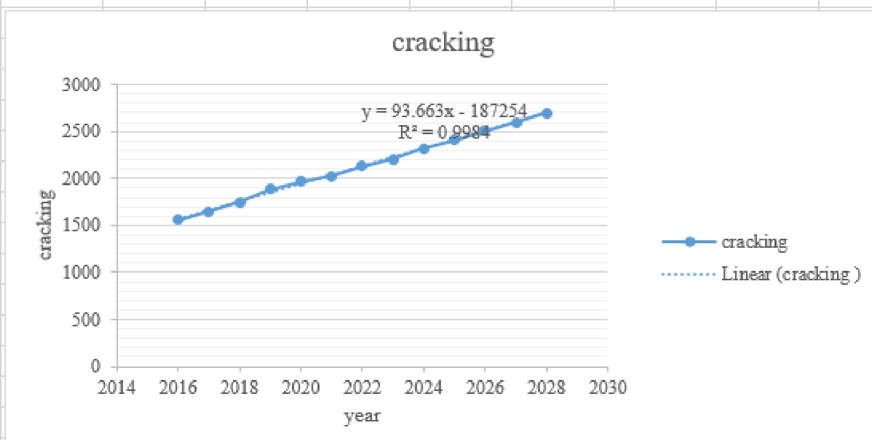

Figure 3.6 PPP regression model for cracking from 119km-121km

According to the prediction model, the value of crack on 2024 GC will be 2319m^2 and the actual crack data on 2024 is 2358.3m^2.

The percentage deference is = (39/2338.5) * 100% = 1.67%

The study shows the actual pavement crack is 39m^2 greater than the predicted value which is expressed in percentage difference of 1.67%

C. Preliminary PPP model for patching

year	paching
2016	427.52
2017	491.17
2018	520.38
2019	542.92
2020	601.55
2021	664.14
2022	781.86
2023	873.61
2024	883.416
2025	943.725
2026	1004.034
2027	1064.343
2028	1124.652

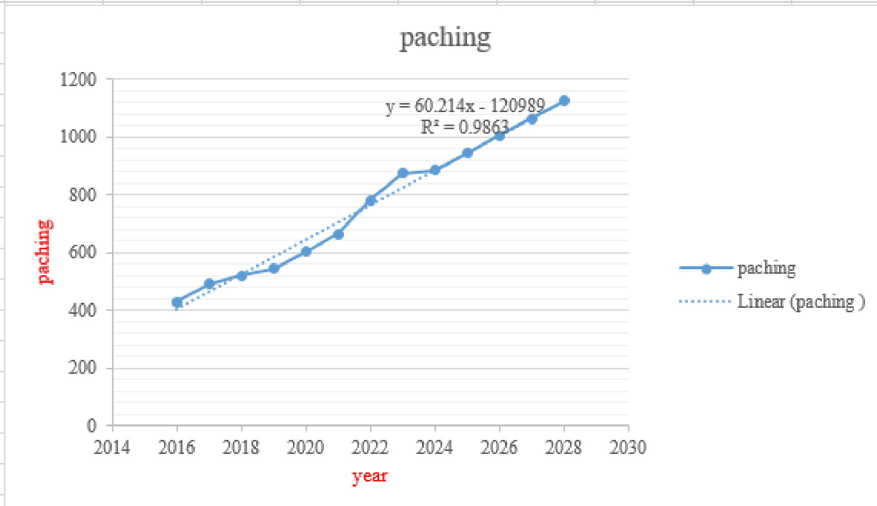

Figure 3.7 PPP regression model for patching

According to the prediction model, the value of pavement patch on 2024 GC will be 883.4m^2 and the actual patch data on 2024 is 911.8m^2.

The percentage deference is = (28.4/897.45) * 100% = 3.16%

The study shows the actual patching is 28.4m^2 greater than the predicted value, which is expressed in percentage difference of 3.16%

D. Preliminary PPP model for edge damage

year	edge damage
2016	26.7
2017	34.44
2018	45
2019	57
2020	68.64
2021	85.96
2022	103
2023	132
2024	132.968
2025	147.425
2026	161.882
2027	176.339
2028	190.796

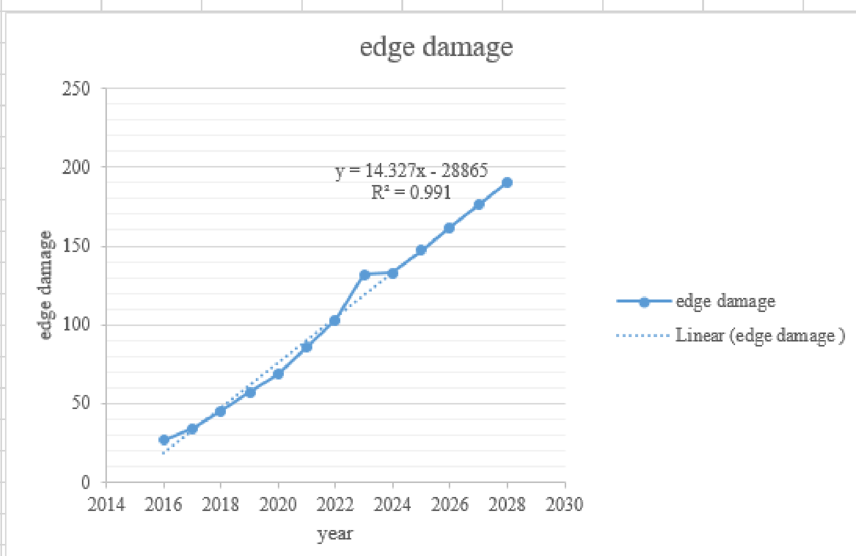

Figure 3.8 Preliminary PPP regression model for edge damage

According to the prediction model, the value of edge damage on 2024 GC will be 132.9m^2 and the actual crack data on 2024 is 136.6m^2.

The percentage deference is = (3.7/134.75) * 100% = 2.7%

The study shows the actual edge damage is 3.7m^2 greater than the predicted value which is expressed in percentage difference of 2.7%

E. Preliminary Ppp regression model for pothole

year	pothole
2016	70.29
2017	81.86
2018	97.11
2019	99
2020	137.98
2021	149.56
2022	179.56
2023	220.17
2024	222.432
2025	243.075
2026	263.718
2027	284.361
2028	305.004

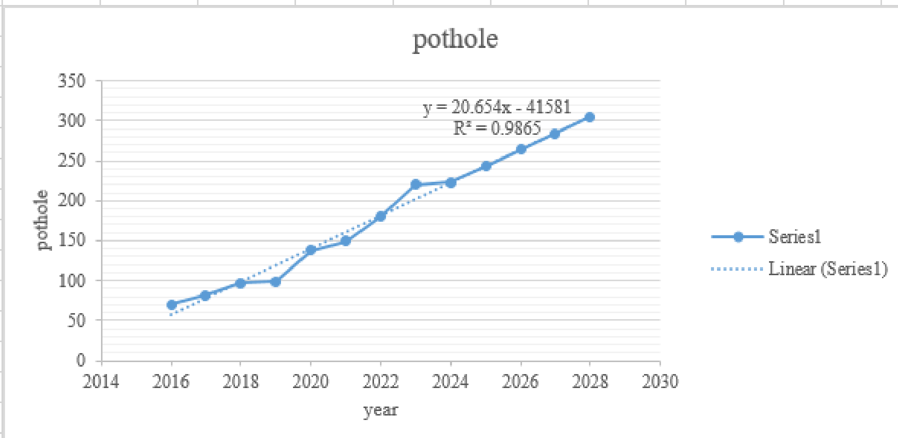

Figure 3.9 PPP regression model for pothole

According to the prediction model, the value of pothole on 2024 GC will be 222.4m^2 and the actual pothole data on 2024 is 232m^2.

The percentage deference is = (9.6/227.2) * 100% = 4.2%

The study shows the actual edge damage is 9.6m^2 greater than the predicted value which is expressed in percentage difference of 4.2%

F. Preliminary Ppp model for pavement shoving

year	shoving
2016	184.1
2017	196.2
2018	228.32
2019	258.62
2020	296.58
2021	313.94
2022	346
2023	376
2024	403.032
2025	431.45
2026	459.868
2027	488.286
2028	516.704

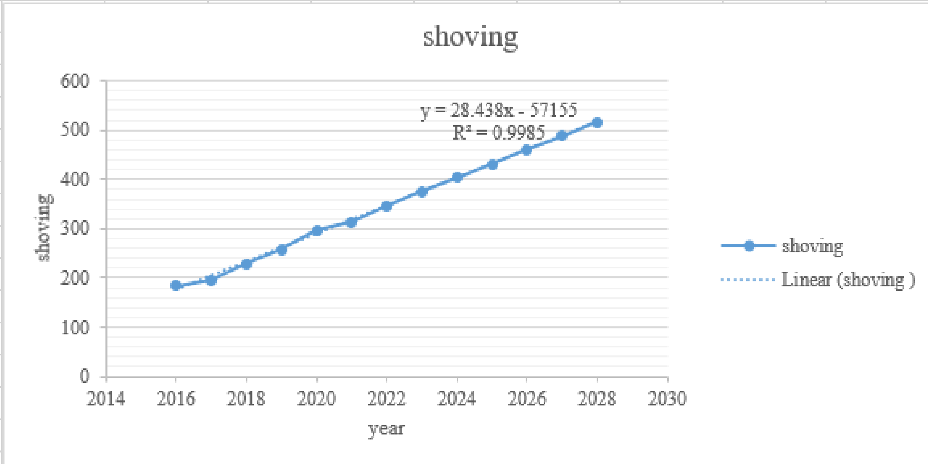

Figure 3.10 preliminary PPP regression model for shoving

According to the prediction model, the value of shoving on 2024 GC will be 403m^2 and the actual shoving data on 2024 is 397.5m^2.

The percentage deference is = (5.5/400.25) * 100% = 1.37%

The study shows the actual shoving is 5.5m^2 less than the predicted value which is expressed in percentage difference of 1.37%

III case study three from (139km – 141km)

Pavement performance prediction model (ppp model) done for case three (139km - 141km),

A. Preliminary Ppp regression model for rutting

year	rutting
2016	1236.2
2017	1384.6
2018	1405.5
2019	1470.9
2020	1674
2021	1997.9
2022	2190
2023	2341.5
2024	2440.88
2025	2604.5
2026	2768.12
2027	2931.74
2028	3095.36

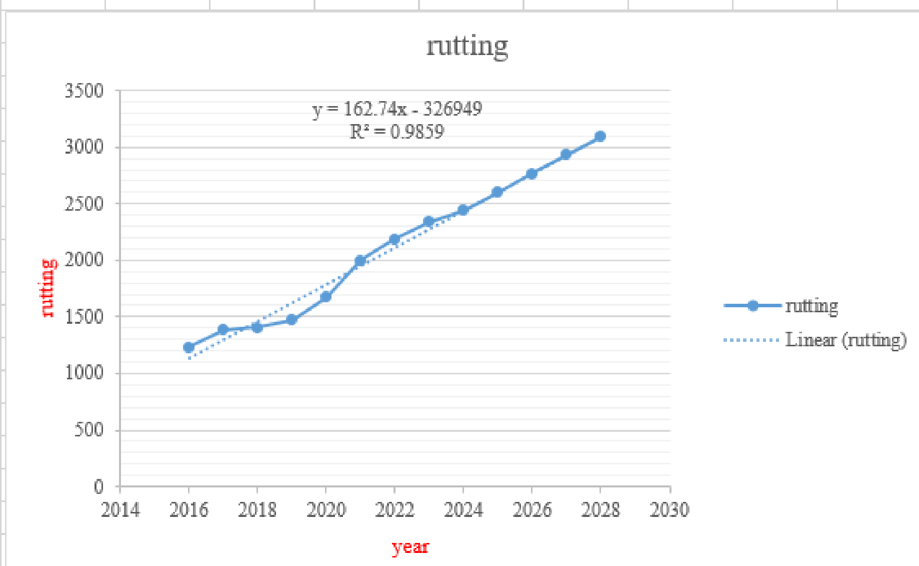

Figure 3.11 PPP regression model for rutting from 139km-141km

According to the prediction model, the value of rut depth on 2024 GC will be 2440.8m^2 and the actual rut data on 2024 is 2431m^2.

The percentage deference is = (9.8/2435.9) * 100% = 0.4%. The study shows the actual rut depth is 9.8m^2 less than the predicted value which is expressed in percentage of 0.4%

B. Preliminary PPP regression model for cracking

year	cracking
2016	405.6
2017	443
2018	459.4
2019	472.3
2020	503
2021	552.7
2022	567
2023	571
2024	608.688
2025	633.55
2026	658.412
2027	683.274
2028	708.136

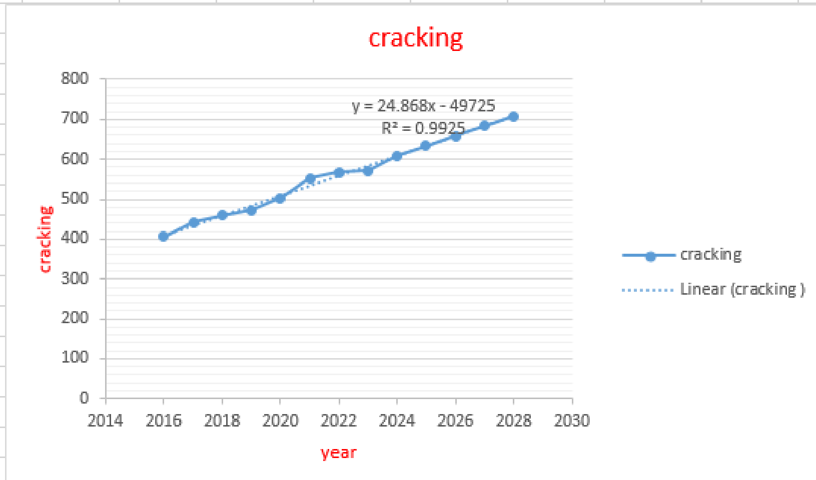

Figure 3.12 PPP regression model for cracking from 119km-121km

According to the prediction model, the value of crack on 2024 GC will be 608.6m^2 and the actual crack data on 2024 is 593m^2.

The percentage deference is = (15.6/600.8) * 100% = 2.59%. The study shows the actual pavement crack is 15.6m^2 less than the predicted value which is expressed in percentage difference of 2.59%

C. Preliminary PPP model for patching

year	paching
2016	798.14
2017	887.5
2018	911.56
2019	941.2
2020	977
2021	1025.44
2022	1088
2023	1106.5
2024	1157
2025	1199.125
2026	1241.25
2027	1283.375
2028	1325.5

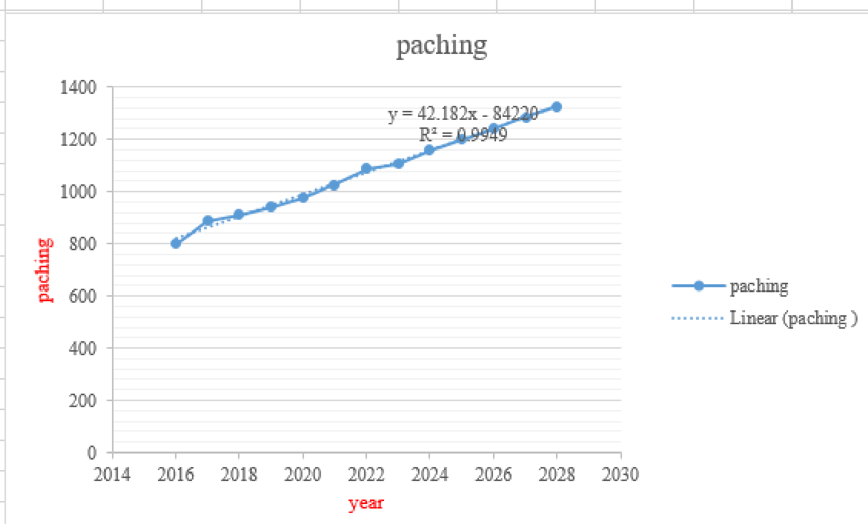

Figure 3.13 preliminary PPP regression model for patching

According to the prediction model, the value of pavement patch on 2024 GC will be 1157m^2 and the actual patch data on 2024 is 1165.6m^2.

The percentage deference is = (8.7/1161.3) * 100% = 0.75%. The study shows the actual patching is 8.7m^2 greater than the predicted value which is expressed in percentage difference of 0.75%

D. Preliminary PPP model for edge damage

year	edge damage
2016	4.2
2017	11.2
2018	13.2
2019	15.6
2020	23
2021	23.8
2022	28.2
2023	30
2024	33.772
2025	37.4
2026	41.028
2027	44.656
2028	48.284

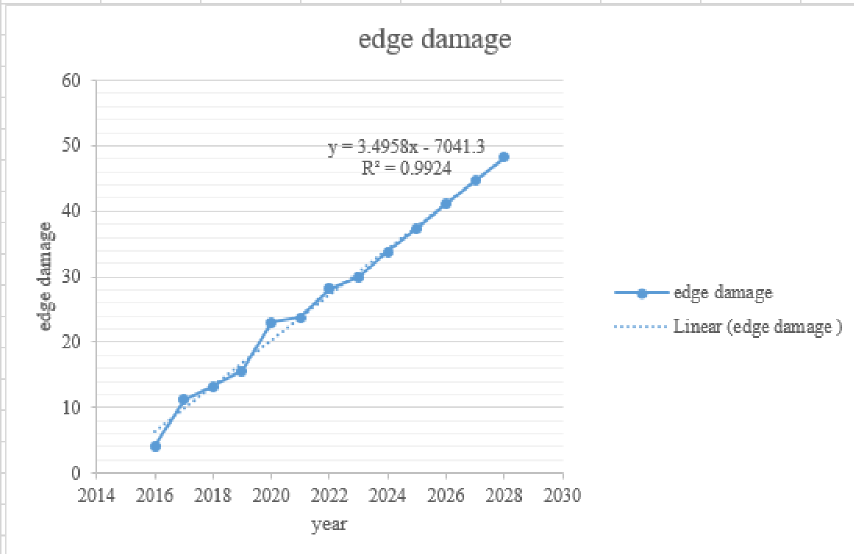

Figure 3.14 Preliminary PPP regression model for edge damage

According to the prediction model, the value of edge damage on 2024 GC will be 33.7m^2 and the actual crack data on 2024 is 35m^2.

The percentage deference is = (1.3/34.35) * 100% = 3.78%. The study shows the actual edge damage is 1.7m^2 greater than the predicted value which is expressed in percentage difference of 3.78%

E. Preliminary Ppp regression model for pothole

year	pothole
2016	190.71
2017	201.35
2018	212.76
2019	214
2020	217.4
2021	230.5
2022	231
2023	236.8
2024	245.3152
2025	251.595
2026	257.8748
2027	264.1546
2028	270.4344

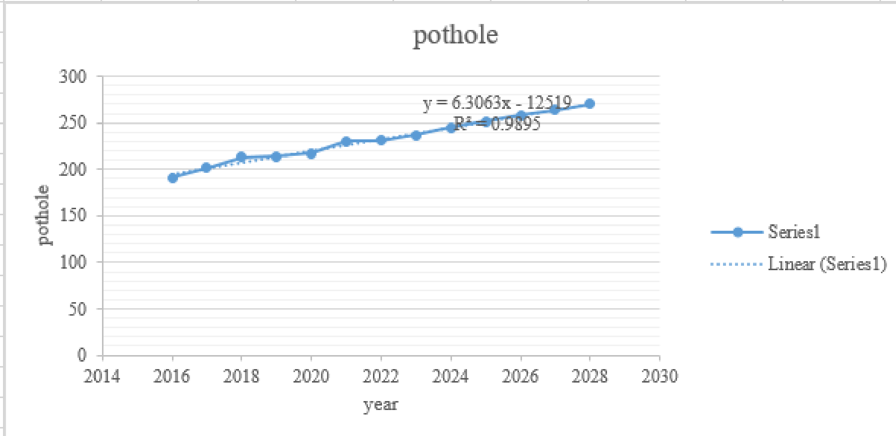

Figure 3.15 PPP regression model for pothole

4. Conclusion

This thesis used the Ethiopian Road Administration as a case study to evaluate the current state of pavement management techniques and develop a pavement performance prediction model. Inadequate upkeep of damaged roads is the biggest issue facing the development of the road sector. In actuality, repair is carried out after the road condition deteriorates, despite the road sector pavement management directorate's plans and arrangements for prompt rehabilitation of damaged roads. It resulted in significant maintenance costs when less expensive preventive maintenance may have prevented this loss. Therefore, it is crucial to assess road pavement management techniques and create a PPP model in order to minimize maintenance costs.

4.2 Recommendation

Subgrade with high swell should be avoided in future road design and construction, or it should be properly treated by excavating and replacing expansive inset subgrade to a depth where moisture variation is minimal and sufficient cover is provided to overcome the swell pressure caused by moisture increase under subgrade. To reduce unnecessary expenses, the pavement management team should do routine maintenance before the road sustains significant damage. HDM-4 software is used by the Ethiopian road administration pavement management section to aid with maintenance tasks. However, the department has yet to implement the PPP model.

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Bibliography

Cain, C. (2003), *Building Down Barriers: A Guide to Construction Best Practice*, Spoon Press, London.

Dawson, T.A. (2012) *Evaluation of Pavement Management Data and Analysis of Treatment Effectiveness Using Multi-Level Treatment Transition Matrices*. Doctoral Dissertation. Michigan State University, East Lansing, MI.

Ethiopian Roads Authority Drainage Design Manual, (2002).

Ethiopia Transportation System Improvement Project (TRANSIP) (February 2016).

ERA (2013), *Road Sector Development Program: 16 Years Performance Assessment*, Ethiopian Roads Authority, Addis Ababa.

Khatta, M.J., G.Y. Baladi, Z. Zhang, and S. Ismail. 2008. *Review of Louisiana's Pavement Management System - Phase I.* Transportation Research Record, Volume 2084. Transportation Research Board, Washington, DC.

Khurshid, M.B.Irfan, M., and Labi, S. (2009) Service *Life of Thin HMA Overlay Using Different Performance Indicators*. Transportation Research Board Annual Meeting, Washington, DC.

Meraf Elias, assessment of drainage system in Adama, 2015.

Morton, R. (2002) *Construction UK: Introduction to the Industry*. Oxford: Blackwell Publishing.

MoWUD (2001) *Study for Capacity Building of the Construction Industry Ethiopia,* Ministry of Works and Urban Development, Addis Ababa.

NCHRP. Transportation Asset Management Guide. Project 20-24(11) for AASHTO. 2002.

Luo, Z. (2006) *Flexible Pavement Condition Model Using Cluster-wise Regression and Mechanistic-Empirical Procedure for Fatigue Cracking Modeling*. Doctoral Dissertation. The University of Toledo, Toledo, OH.

OECD (2001), Asset Management for the Roads Sector,‖ Program of Co-Operation in the Field of Research on Road Transport and Intermodal Linkages, Organization for Economic Cooperation and Development, Directorate.

Robert. K. yin, case study research and application, six edition, 2018. Statistic in plain English second edition

Fiche – Gohatsion Road Overlay Project, through Admeasurements and Performance Based Road Contract Draft Engineering Design Review Report

United Nations Economic Commission for Africa "Road safety performance review of Ethiopia (2020)"