JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Assessment on Pavement Performance and Remaining Life cycle Analysis Using Integrated HDM-4 Software: Case Study within Kombolcha-Harbu Road section

By

Mohammed Yimam

This thesis is submitted to the School of Postgraduate Graduate Studies of Jimma University in a Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

(Highway Engineering)

May, 2017

Jimma, Ethiopia

JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Assessment on Pavement Performance and Remaining Life cycle Analysis Using Integrated HDM-4 Software: Case Study within Kombolcha-Harbu Road section

By:

Mohammed Yimam

Advisor:

Prof. Dr. Ing Esayas Alemayehu

Co-Advisor:

Eng.Tarekegn Kumela (M.Sc)

May, 2017
Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

As members of the Examining Board of the Final M.Sc. Open Defence, we certify that we have read and evaluated the thesis prepared by: Mr. Mohammed Yimam Entitled: Assessment on Pavement Performance and Remaining Life cycle Analysis Using Integrated HDM-4 Software: Case Study within Kombolcha-Harbu Road section: And we recommended that it is accepted as fulfilling the thesis requirement for the degree of Master of Science in Civil Engineering under highway engineering stream.

Eng.Anteneh Geremew	________________	________________
Chairman	Signature	Date
Prof. Dr.-Ing Esayas Alemayehu (PhD)	________________	________________
Main Advisor	Signature	Date
Eng. Tarekegn Kumela	________________	________________
Co Advisor	Signature	Date
Eng. Abel Tesfaye	________________	________________
Internal Examiner	Signature	Date
Dr.- Bilkila Teklu (PhD)	bikila teklu	22/05/2017
External Examiner	Signature	Date

DECLARATION

I hereby declare that this research study that means *Assessment on Pavement Performance and Remaining Life Cycle analysis Using Integrated HDM-4 Software onto Kombolcha-Harbu road alignment* is my original topic and work which has not been presented for a degree as well as Msc fulfillment at any other University.

Submitted By:

Mohammed Yimam ____________________ ________/_______/______

Name Signature Date

ACKNOWLEDGMENT

First and extremely , I would like to thanks almighty the God for the blessings and being with me work and activity during this study.

I would like to express my deepest gratitude to my advisor Prof.Dr.-Ing Esayas Alemayehu and too my Co-Advisor Mr. Tarekegn Kumela for their valuable guidance and encouragement starting from proposal writing to the completion of this thesis was vital for the success of the thesis work. Without their guidance and valuable comments and suggestions, it would not been simple to shape this study at this current format

And also I would like to thanks to Mr. Bogale Shiferaw for his guidance and great effort on the selection of Research topic and other information about available input data for the study of this research.

And also, I would like, to express my deepest gratitude to the following organizations who have contributed directly or indirectly in order to finish this work successfully. This are: the Ethiopian Roads Construction Cooperation kombolcha district, Ethiopian Road authority Road asset Management and professionals and Ethiopian Road Authority, alemgena districts and kombolcha district.

Last but not the least; my deepest gratitude goes to those who assisted me for this study, and particularly my beloved family and friends for their unreserved support and encouragement throughout my work.

Abstract

Transportation facilities constitute one of the most valuable public assets that account for a major share of public sector investment in the world. In order to facilitate this public sector investments, road was one of the basic assets that constructed and maintained regularly along different national and international boundaries. To constitute those investment actives the performance and life cycle condition of the road should be studied regularly. But the main problem to execute that road treatment activates the current and the future condition of the pavement should be properly studied.

Therefore; the main objective of this study was concerned on the assessment of pavement performance and life cycle analysis using HDM-4 software for a case study of Kombolcha-Harbu road section. Under this main topic of the study, the following specific objectives were studied; evaluate the existing pavement performance and deterioration conditions in terms of International roughness index, average rutting, texture depth and edge cracking area, quantify Pavement performance indicators like Pavement Condition Ratting and Present Serviceability Index, quantify the future pavement condition of selected road project using HDM-4 software, examine the effective type of pavement treatment in term of performance condition within the service life of road.

To meet those objectives of this study, both descriptive and explanatory type of survey has been applied and also historical data and current condition were the basic input parameters along this section of the road. The methodologies used for sampling for study this road section and data collection were purposive and quantitative techniques were used respectively.

The result of this study shows that the condition of the existing pavement for kombolcha-Harbu road section in terms of the international roughness index was evaluated as fair. The average rutting value for kombolcha-Harbu was about 4.196cm. *This value had shown that the deterioration condition in terms of rutting have evaluated as fair. The pavement performance evaluation indexes like present serviceability index and pavement serviceability rating was calculated as* 4.052 and 2.182 respectively.

Finally, *those results shows that the performance of the pavement was evaluated as very good and fair. In terms the condition of pavement evaluated on the existing and future condition the alternatives for maintenance of this road section should be used were rehabilitation-thin-overlay and periodic maintenance (patching and crack sealing).*

Key words: *IRI, PSI, PSR, maintenance & rehabilitation, life cycle analysis and pavement performance*

TABLE OF CONTENTS

DECLARATION……………………………………………………………………………i
ACKNOWLEDGMENT………………………………………………………………………ii
ABSTRACT…………………………………………………………………………………iii
TABLE OF CONTENTS……………………………………………………………………iv
TABLE OF LIST……………………………………………………………………………vii
TABLE OF FIGURES………………………………………………………………,,……viii
ACRONYMS……………………………………………………………………………… xi
CHAPTER ONE 1
INTRODUCTION 1
1.1 General Background..1
1.2 Statement of the problem 4
1.3 Research questions 5
1.4 Research objectives 5
1.4.1 General objective of study 5
1.4.2 Specific objective 6
1.5 Significance of the Study 6
1.6 Scope and limitation of the study..6
CHAPTER TWO 7
LITERATURE REVIEW 7
2.1 Pavement management system 7
2.2 Pavement Performance Studies and Evaluation..8
2.2.1 International Roughness index (IRI) 8
2.2.2 Pavement Performance Studies 11
2.2.3 Present Serviceability Index 11
2.2.4 Pavement Condition Rating (PCR)...13
2.2.5 Pavement Serviceability Rating (PSR)..28
2.3 Over view of HDM-4 modeling...29
2.3.1 Project analysis...30
2.3.2 Program Analysis 30

2.3.3 Strategic analysis 30
2.4 Deterioration Models in HDM-4 31
2.4.1 Cracking Model 31
2.4.2 Potholing Model 31
2.4.3 Rut Depth Model 32
2.4.4 Roughness Model 32
2.5 Cost effective pavement treatment alternative selection 32
2.6 Pavement remaining life cycle analysis 33
2.7 Geometric condition of the road 33
CHAPTER THREE 35
METHODOLGY 35
3.1 Introduction 35
3.2 Study area 35
3.3 Study design 36
3.4 Study population 38
3.5 Sample size and sampling techniques 38
3.5.1 Sample size 38
3.5.2 Sampling technique 38
3.6 Study Variables 38
3.6.1 Dependent variable: 38
3.6.2 Independent variables 38
3.7 Software and instruments 39
3.8 Data collection process 39
3.9 Data processing and analysis 39
3.9.1 Pavement condition survey 39
3.9.2 Data collection from Ethiopia Road Authority(ERA) 43
3.9.3 ERA Data Collection Equipment 45
3.9.4 Pavement performance evaluation 46
CHAPTER FOUR 47
RESULT AND DISCUSSION 47
4.1 Pavement performance evaluation of Kombolcha-Harbu road interms of IRI 47

4.2 Pavement performance eavalueation interms of Present serviceability index (PSI).....48
4.3 Pavement performance evaluation using Pavement Serviceability Rating (PSR)........50
4.4 Performance evaluation using condition of pavement defects.....................................51
4.4.1 Rutting measurement...51
4.4.2 Pavement Texture depth measurement and evaluation 52
4.4.3. Potholes measurement, counting and evaluation..54
4.4.4 Edge cracking measurement and evaluation 54
4.5 Prediction of the future pavement condtion...55
4.5.1 Prediction of international rouphness index 56
4.5.2 Prediction of texture depth 59
4.5.3 Prediction of rutting...61
4.5.4 Prediction of potholes…………………………………………………………….63
4.5.5 Prediction of edge cracking area 63
CHAPTER FIVE 64
Conculusion and recommendation...64
5.1 General 64
5.2 conculusion..64
5.3 Recommendations 65
Reference 66
Appendix…………………………………………………………………………….69

TABLE OF LIST

Table 3.1: Vehicles composition calculation for Kombolcha-Harbu road section.................45

Table 4.1: Ratting scale parameters for rut depth...53

Table 4.2: Average texture depth specification 53

Table 4.3: average texture depth calculation for kombolcha-Harbu road section..................54

Table 4.4: predicted IRI and recommended treatment...59

Table 4.5: Predicted texture depth and its condition..59

Table A: international roughness index for kombolcha-Harbu road section..........................69

Table B: PSI calculation for kombolcha-Harbu road section 77

Table C: Pavement serviceability ratting calculation fo kombolcha-Harbu road...................81

Table D: Measured rutting depth 83

Table E: Texture depth of kombolcha-Harbu road section..84

Table F: measured number, depth and width of potholes along kombolcha-Harbu road.....89

Table-G: measured edge cracking for kombolcha-Harbu road section 90

TABLE OF FIGURES

Fig1.1Life cycle analysis using HDM-4 3

Fig1.2: Location of the problem of kombolcha-Harbu road 5

Fig.2.1:ARRB Automated Survey Vehicle...10

Fig.2.2:High severity rutting 15

Fig.2.3:High severity alligator cracking 16

Fig.2.4:High severity Longitudinal Cracking 18

Fig.2.5: High severity Transverse Cracking 19

Fig.2.6: High severty bleeding..21

Fig.2.7: High severity Corrugation 22

Fig.2.9 Pavement condition Ratting Scale 27

Fig.2.10: Pavement Serviceability Ratting (PSR) scale..28

Fig.2.11: Rise+fall measurement representation 34

Fig 2.12 Horizontal Curvatures...34

Fig 3.1Diagrammatical representation of vehicles composition..35

Fig. 3.2 Study Procedure……………………………………………………………..….....37

Fig. 3.3 Edge measurement...…...40

Fig. 3.4 Potholes counting and measurement………………………………...……...41

Fig. 3.5: Rutting depth measurement……………..……………………….…………..………….41

Fig. 3.6: Cracking area measurement………………………..……………………………42

Fig. 3.7: Road Width and thickness measurement………………..………………………….42

Fig 4.3: PSI and IRI scaling specification 50

Fig 4.4: Graphical relation of IRI and PSR for kombolcha- Harbu road section 51

Fig.4.5: Location of measuered rutting point along Kombolcha-Harbu road section 52

Fig.4.7: No of potholes along kombolcha-Harbu road section..56
Fig.4.8: Location of dominnat edge cracking area along kombolcha- Harbu road section....57
Fig. 4.9: HDM-4 lifecycle analysis window..58
Fig.4.11 Predicted representation of average texture depth..61
Fig.4.13:The predicted numbers of potholes for kombolcha-Harbu road section.................63
Fig. 4.14 Predicted edge cracking along the age of the pavement…………………………..6 4

ACRONYMS

AACRA	Addis Ababa City Roads Authority
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway & Transport Officials
ARAN	Automatic Road ANalyzer
BPR	Bureau of Public Roads
CE	Cost effective
ERA's	Ethiopian Road Authority
FHWA	Federal Highway Authority
FPR	Flexible Pavement Restoration
GIS.	Geographical Information System
HDM-4	Highway Development and Management Model-4
HPMA	Highway Pavement Management Application
IRI	International Roughness Index
K/cha	Kombolcha
LISA	Lightweight Inertial Surface Analyzer
MIRR	Minimum Internal Rate of Return
M&R	Maintenance and Rehabilitation
PCA	Portland cement Association
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PMS	Pavement Management System
PQI	pavement Quality Indicator
PSI	Present Serviceability Index
RQI	Ride Quality Index
RTRRMS	Response Type Road Roughness Measuring Systems
Sv	Slope variance

CHAPTER ONE

INTRODUCTION

1.1 General Background

Transportation facilities constitute one of the most valuable public assets that accounts for a major share of public sector investment in the world. These investments are used to build, operate and preserve infrastructure that supports movement of people and goods by various modes. Efficient, economical and safe transportation is critical to a society in meeting its goals toward economic progress, social welfare and emergency preparedness. Defined as a systematic process of maintaining, upgrading and operating physical assets cost-effectively. Highway asset management combines engineering principles with sound business practices and economic theory, and provides a tool to facilitate an organized, logical and integrated approach to highway investment decision-making and pavement condtion evaluation for appropriate decision making of the road treatment.

Over the past two decades, state transportation agencies have developed management systems as analytical tools to support highway investment decision-making. These mainly include pavement, bridge, and maintenance management systems dealing with physical highway assets; and congestion and safety management systems handling highway system operations. [7]

The main focus of roadway activity in the mid of 20th Century was on the construction of new pavements. In the latter part of the 20th Century continuing into the 21st Century, this focus has shifted to the maintenance and rehabilitation of pavement infrastructures. Maintenance includes actions that increase the life cycle of road infrastructure and facilities. These actions include crack sealing, patching as well as resurfacing [1].

Pavements must be selected for maintenance when they are still effective. In most cases, the proper time to apply maintenance is before the need is apparent to the casual observer. This is because once pavements start to deteriorate; they deteriorate rapidly beyond the point where maintenance is effective. With the increasing use and awareness of pavement management systems and the growing emphasis on asset management of pavement infrastructure, it is important to strengthen the maintenance components of these systems and particularly the preventive maintenance component. [2]

The most recent definition of preventive maintenance by AASHTO Standing Committee on Highway states that preventive maintenance is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional conditions of the system (without increasing structural capacity." [3]

Agencies have found that applying a series of low-cost preventive treatments can effectively extend the service life of their pavements. Preventive maintenance techniques should be scheduled to maximize safety, maintainability, and the cost-effectiveness of pavement preservation efforts. However, it is difficult for most users to establish the level of distress at which a particular maintenance treatment should be applied. Selection of the most appropriate maintenance treatment for a given distress type should consider several factors including type and extent of distress, climate, existing pavement type, cost of treatment, traffic type and volume, expected life, availability of qualified contractors, availability of quality materials, time of year, pavement noise, facility downtime (user delays), surface friction, anticipated level of service, and other project-specific condition.

The Highway Development and Management Model-4 (HDM-4), has become widely used as a planning and programming tool for highway expenditures and maintenance standards. And also HDM-4 is a computer model that simulates physical and economic conditions over the periodic analysis like a life cycle for a series different treatment alternatives. HDM-4 is designed to make comparative cost estimates and economic evaluations for different construction and maintenance options, including different time-staging alternatives, either for a given road project on a specific alignment or for groups of links on an entire network. It estimates the total costs for a large number of alternative project designs and maintenance alternatives year by year. It's results discounting the future costs, based on the minimum internal rate of return (MIRR).

Three interacting sets of costs (related to construction, maintenance and road use) are added together over time in discounted present values, where the costs are determined by first predicting physical quantities of resource consumption and then multiplying these by unit costs or prices.

As illustrated in figure 1.1, HDM-4 consists of a series of sub-models that address different aspects of the analysis. In order to apply the model correctly, one needs to ensure that HDM-4 is given the appropriate input data and has been suitably calibrated. [14]

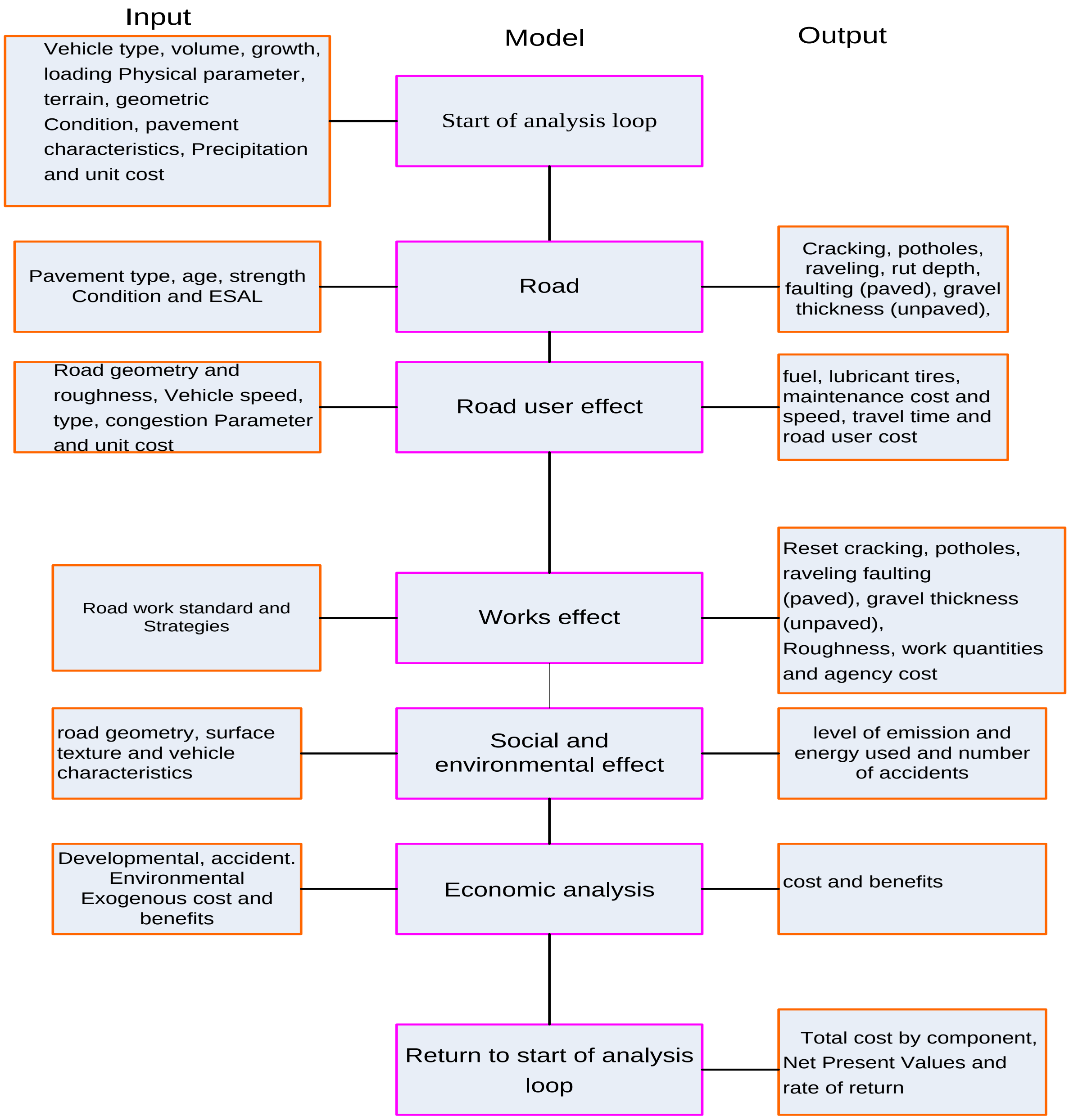

Fig 1.1 life cycle analysis using HDM-4

In Ethiopia road construction is one of the vital ongoing activities for the development of social need of the county. But many roads became deteriorated before they reach on the design life due to different cases. In order to increase their service life pavements, treatment is one the alternative to upgrade its functionality. To apply this treatment pavement life cycle management or analysis should be consider for applying cost-effective pavement treatment. This can be analyzed using different types of pavement management softwares like Highway Development and Management model-4(HDM-4) and Arc GIS. In case of this study the analysis was performed using HDM-4 software.

1.2 Statement of the problem

Pavement undergoes a process of deterioration directly after opening to traffic. This process under the effects of traffic, environmental and poor material conditions. Over time, the pavement deterioration has different mechanisms and faster rate of deterioration. Timing of maintenance action is important since it must be carried out at the time of maximum return period. Otherwise, the maintenance options needs should be higher if the pavement is allowed to further deterioration level. The pavement starts to deteriorate after opening to traffic. The deterioration starts at a low rate and with time this rate increases. Some studies showed that the highway network deteriorates to an extent that 60% of roads were reach the stage of functional failure in 20 year unless maintenance management systems were implemented. This situation was result in enormous increase in maintenance and reconstruction budget.[23]

Many studies in most Africa country showed that the reconstruction cost for a very poor pavement condition is four to five times the cost maintainace. Therefore, the implementation of an effective maintenance system should reduced the reconstruction costs. Preventive maintenance actions taken earlier have a very important role in keeping the pavement in a good condition for longer time, and in reducing the overall costs significantly. [24]
Ethiopia is a country where expansion of road infrastructure is growing at a very fast rate. But there are a numbers of road constructed in the past which have no conducted any types of treatments. This is basic problem for Ethiopia, due to improper none periodic treatment programing, lack of periodic life cycle analysis, un predicted condition of the future pavement deterioration and agencies were used traditional way of determining maintenance options wich was visual inspection of road condition. In many cases, maintenance activities are performed as a result of user complaints. This type of maintenance practice leads to inefficient and random ways of spending the maintenance budget.

In this study, kombolcha-Harbu road was one of the road section constructed in the past that deteriroted before finish its design life. Therefore; for cost effective and pavement performance based treatment pavement perfornace evaluating index and HDM-4 model were used for pavement performance prediction.

Fig.1.2 Location of the problem of kombolcha-Harbu road

1.3 Research questions

In order to work on the above research objectives, research questions have been formulated and specific answers were obtained.

1. How to examine the condition of existing pavement?
2. What are the pavement performance indicators that show pavement condition?
3. How to forecasting the future performance of the pavement using HDM-4 calibrated software?
4. What are the maintenance options under each performance condtion of pavement?

1.4 Research objectives

1.4.1 General objective of study

The main objective of this study is to assess the performance of pavement and life cycle analysis using HDM-4 calbrated software along Kombolcha-Harbu road section

1.4.2 Specific objective

1. To evaluate the existing pavement performance and deterioration conditions interms of Interational roughness index
2. To quantify and evaluate Pavement performance indicators; Pavement serviceasiblity Ratting (PSR)and Present Serviceability Index (PSI).
3. To quantify the the future pavement condition of selected road project using HDM-4 calibrated software.
4. To examine the effective type of pavement treatment within the service life of road interms of value of pavement performnace.

1.5 Significance of the Study

The final output of this study was used to added academic knowledge on pavement management system and appropriate life cycle analysis with the help of HDM-4 model calibrated software. Under the analysis of the performance and life cycle analysis of this study section had the following significance; the current condtion of existing road was determinted and the appropriate maintenance option were suggested, the future condtion of the pavement along this section of study were predicted and its deterioration through out the remaining design life was evaluated, the dominat deterioration were locted along the length of the road section and used to more focus for condition assessment of this study section.

1.6 Scope and limitation of the study

Pavement management is a wide and vast study for effective analysis of new construction, upgrading and maintenance of road. And also the input data should be reliable in order perform cost effect project analysis. But to give overall recommedation about the best treatment option; cost and benefit analysis should be determined, and shortage of time, money material were affected. Therefore; to conduct this analysis it is so broad and and difficult to determined user cost of the asset.

Therefore; this study were only conducted based on the available data which is tested and organized by the Ethiopian Road Authority (ERA). But some data which easy to measure were determinted during condtion survery of the study section of this reaserch.

CHAPTER TWO

LITERATURE REVIEW

2.1 Pavement management system

Pavement Management System is a set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating, and maintaining pavements inaserviceable condition. It consists of two basic components:

A comprehensive database, which contains current and historical information on pavement condition, pavement structure, and traffic, and a set of tools that allows us to determine existing and future pavement conditions, predict financial needs, and identify and prioritize pavement preservation projects.

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 cyclek cost."[1]

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. [3]

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." [2]

2.2 Pavement Performance Studies and Evaluation

The concepts of pavement performance include some consideration of functional performance, structural performance, and safety. But in this study will consider the only functional and structural performance. The structural performance of a pavement relates to its physical condition; i.e., occurrence of cracking, faulting, raveling, or other conditions which would adversely affect the load-carrying capability of the pavement structure or would require maintenance. [15]

The functional performance of a pavement concerns how well the pavement serves the user. In this context, riding comfort or ride quality is the dominant characteristic. In order to quantify riding comfort, the "serviceability-performance" concept was developed. The serviceability of a pavement is expressed in terms of the present serviceability index (PSI). The PSI is obtained from measurements of roughness and distress, e.g., cracking, patching and rut depth of flexible pavement at a particular time during the service life of the pavement. Roughness is the dominant factor in estimating the PSI of a pavement. Thus, a reliable method for measuring roughness is important in monitoring the performance history of pavements .[4]

Evaluating pavement condition is important because deterioration of pavement can lead to costly maintenance and may cause crashes that can lead to serious risk, such as injuries to road users. Performing minor repairs at regular intervals can extend pavement life and decrease total life-cycle costs. In order to measure the condition of a pavement, the Department of Transportation travels with a van equipped with cameras, laser sensors and nondestructive testing gear. These sensors help identify distresses, degree of cracking, as well as the smoothness of the ride to determine the Ride Quality Index (RQI) rating for each section of roadway. The pavement percentages in Good or Poor condition then determines its future pavement preservation needs. The major pavement evaluating parameter that used for this study is; International Roughness Index, Present Serviceability Index and Pavement Condition Index and pavement condition rating. [5]

2.2.1 International Roughness index (IRI)

In the 1970s the World Bank sponsored several large scale reasearch programs aimed at deriving cost effective maintenance alternative for roadway pavements. Pavement roughness emerged as a primary indicator of the user costs associated with pavement condition. User costs, such as damages to vehicles, were found to often increase the total costs of lesser capital-intensive pavements beyond those of higher capital-intensive ones. In1982, IRI was proposed in Brazil by the World Bank as a standard statistic to correlate and to calibrate roughness measurements. IRI, expressed in units of slope, measures the cumulative suspension motion in a moving vehicle over the traveled distance m/km, in /mi, etc. Thus IRI describes the vehicle vibrations caused by profile roughness and is linearly proportional to road- way roughness. The lower the IRI value the flatter the paved profile. For example, An IRI of 0.0 m/km relates to a perfectly flat profile. There exists no upper limit on IRI, but in practice IRI values above 8 m/km relate to pavements nearly impassable by vehicle except at reduced speed.

Road roughness, or smoothness, inspections are performed to monitor the pavement conditions in order to evaluate the ride quality of new and rehabilitated pavements. Roughness is closely related to vehicle operating costs, vehicle dynamics, and drainage.

The American Society for Testing and Materials (ASTM) E 867 define roughness as the deviations of a pavement surface from a true planer surface with characteristic dimensions. A pavement profile represents the vertical elevations of the pavement surface as a function of longitudinal distance along a prescribed path of travel.

Both manual and automatic multifunction profiling systems are continuously being developed and marketed for improved performance. pavement roughness is the deviation of a pavement surface from a true planar surface, with wavelength deviations ranging between 0.5 and 50 meter. Wavelengths in this range dissipate energy in the vehicle suspension including deforming the tire body and convert energy into heat that dissipates. Pavement roughness is usually measured in terms of the International Roughness Index (IRI), a parameter developed by the World Bank to provide a stable and portable measurement standard for worldwide use. IRI commonly ranges from about 1 to 5 m/km (63 to 315 inches/mile) on a paved highway, with lower values indicating a smoother surface. According the U.S. Federal Highway Administration (FHWA) defines high-speed highway pavements with an IRI greater than 2.7 m/km (170 inches/mile) as being in "poor" condition. .[17]

Pavement profiling systems started with straightedge devices in the early 1900s. Other simple profiling devices, profilographs, and response type road roughness measuring systems (RTRRMS) were developed in the late 1950s and 1960s. Between the late 1960s and 1980s, highway agencies primarily adopted the profilograph for measuring and controlling initial roughness of new construction pavement. The use of inertial profilometers in monitoring pavement condition increased in the 1980s and early 1990s.[17]

The aforementioned equipment can be divided into five categories.

Manual devices: rod and level surveys, straightedge, rolling straightedge (high-low detector), Dipstick, ARRB walking profilometer, etc.

Profilographs: Rain hart profilograph, California profilograph, etc.

RTRRMS: Bureau of Public Roads (BPR) roughometer, Mays Ride Meter (MRM), Portland Cement Association (PCA) ridemeter, etc.

High-speed inertial profilometers: Automatic Road ANalyzer (ARAN) by Roadware Group Inc., Model T6600 Inertial Profilometer by K. J. Law Engineers Inc., etc.

Lightweight profilometers: Model 6200 lightweight inertial surface analyzer (LISA) by Ames Engineering, Inc., CS8700 lightweight profiler by Surface Systems & Instruments, Dynatest/KJL 6400 lightweight profilometer by Dynatest Consulting, Inc., etc.

Fig.2.1: ARRB Automated Survey Vehicle (source: kassa;pavement performance evaluation)

2.2.2 Pavement Performance Studies

Pavement roughness prediction models are generally simplifications of the actual relationships because of the complexity associated with the interaction between the various factors that affect deterioration. Models for roughness progression for flexible pavements using simplified incremental algorithms with actual field data of primarily variables are presented. The field data used is obtained for flexible pavements with lateritic gravel bases and sub bases with surface treatment as wearing course in Ghana, West Africa. The data covered major primary and secondary highways carrying a wide spectrum of traffic loading. The results indicate that environmental factors and structural capacity have significant influence on roughness progression. The strength of the pavement has a greater influence than the traffic loading on roughness progression, other factors remaining the same. Restoring the structural capacity of flexible pavements through timely maintenance intervention may help arrest the rate of deterioration. Direct transferability of models between different environmental, physical and operating conditions has its limitations and is not advisable.[13]

2.2.3 Present Serviceability Index

Represents that the concept of "serviceability" of roads and its evolution through time is widely accepted by pavement engineers and professionals as a way to evaluate road quality and conditions. Both the Present ServiceabilityIndex (PSI) and International Roughness Index (IRI) can be used as indicators ofroad riding quality and serviceability. The objective of the study was to develop realistic models for estimating PSI for asphalt pavement sections located in theurban city of Noida, near Delhi, the capital of India. The PSI model was developed asa function of the pavement age. An attempt was made to calibrate the American Association of State Highway & Transportation Officials (AASHTO) equation for PSI and determine the suitability of this equation in Indian pavement conditions for selected urban roads. The developed models were also validated. Based on the developed PSI model, the maintenance alternatives have been suggested for the urban road sections in the study area. [12]

Pavement serviceability refers to the ability of a pavement to provide the desired level of service to the user. The ability of the pavement to perform at its desired level of service is effected by pavement condition. The Present Serviceability Index (PSI) is the subjective assessment of serviceability by a panel of raters and is related to objective measures of surface condition response-type road roughness measuring system (RTRRMS). PSI is produce on a scale of zero to five where scale five refers to an excellent ride condition and scale of zero refers to a very poor ride quality. The figure below shows the trend of loss of serviceability due to pavement condition affected by time or traffic loading. The serviceability of the pavement is obtained from the raters who drive on the section of the pavement and assign ratings based on their subjective judgment of the ride condition's was the first and most commonly used method to relate the objective measure of surface condition to the public's perception of serviceability.

The PSI value is interrelated to the surface distress of the pavement. The original PSI equations were shown in equation given below.

$$PSI = 5.03 - 1.91\log(1+Sv) - 0.01\sqrt{C1+Pa} - 1.38(Rd)^2 \qquad (2.1)$$

Where:

S_v = Slope variance [log (1+ S_v) = function of profile roughness]

C_1 = Crack length in inch (1 in = 25.4mm)

Pa = Patching area in ft^2

R_d = Rut depth in inch

Slope variance

Slope Variance as a measure for roughness statistic during the AASHO Road Test From 1958 to 1960. Slope Variance is profile - based roughness statistic obtained from the slope profilometer that was used in the ASSHO Test. It is calculated from the statistical variance of surface slope defined for a constant distance of 1ft.

Where:

Sv = Slope variance

Yi = Difference elevation between two successive points at a constant distance of 1 ft (305mm)

n = Number of interval

The present serviceability index (PSI) and the International Roughness Index (IRI) for asphalt pavements models were developed by first analyzing the correlation between slope variance (SV) and PSI values using the AASHO Road Test data and then analyzing the correlation between SV and IRI for profiles representing a broad spectrum of road roughness levels. The following equations were obtained. [17]

$$PSI = 5 - 0.2397X^4 - 1.7741X^3 - 1.404X^2 + 1.5803X \quad [2.2]$$

$X = \log(1 + Sv)$ and

Sv=0.22704(IRI)

2.2.4 Pavement Condition Rating (PCR)

One of the key components of an effective pavement management system is an accurate assessment of the condition of the existing pavement network. This assessment has historically been accomplished by an annual visual pavement condition survey. The surface cracking of a pavement is represented by a Surface Rating and Dominant Distress for each segment of the pavement network.

However, the complete condition and performance of a pavement is broader than just an assessment of the surface distress. Other factors, such as ride quality, structural capacity and friction are also important components. Ride quality has emerged at the national level as a primary element of pavement performance and customer satisfaction. New technologies are now available to measure other important pavement distresses at the network level. Given these advancements, it is essential for the effective management of the pavement network to develop a more comprehensive metric of pavement condition, particularly a measure that provides the ability to include ride quality in condition assessment and decision making.

Pavement condition Rating (PCR) is an indicator that rates the surface condition of the pavement and It is built based on visual inspection of road section. PCR is used to quantify the road condition. The inspection period for road might vary from segment to another depending on the type of road (i.e., main or branch. etc.) and the volume of traffic represented by Average Annual Daily Traffic (AADT). [18]

Inspection procedures

These inspection procedures offer a method of determining pavement condition through observing and recording the presence of specific types and severities of defects or distresses on the pavement surface. The elements of pavement condition rating are the type of defect, the severity of the defect and the extent to which the road surface is affected by the defect. There are several types of defects and several possible severities and extents for each defect. These are described and illustrated for flexible pavements in the following pages of this study.

Rutting

Rutting is a surface depression within the wheel path. Rutting is results from a permanent deformation in any of the pavement layers or subgrades, usually caused by consolidation or lateral movement of the materials due to traffic loads. When the upper pavement layers are severely rutted, the pavement along the edges of the rutted area may be raised. Usually, the rutting occurs gradually across the wheel path, reaching a maximum depth in the center of the wheel path.

Measurement for Rutting

Severity: The average rut depth in the wheel path for the segment or sample. Recommended ranges for estimated severity.

Low - 6.35 mm to 12.7mm
Medium - 12.7 mm to 19.05mm
High –over 19.05mm
Extent: The extent of rutting is assumed to be the full length of the segment in the wheel path.

Measure: Take measurements in as many locations as is practical and average them.

Fig.2.2: High severity rutting

Alligator cracking

Alligator fatigue cracking is associated with loads and is usually limited to areas of repeated traffic loading. The cracks surface initially as a series of parallel longitudinal cracks within the wheel path those progresses with time and loads to a more branched pattern that begins to interconnect. The stage, at which several discontinuous longitudinal cracks begin to interconnect, is defined as alligator cracking.

Severity:

Low — Branched, longitudinal, discontinuous thin cracks are beginning to interconnect and form the typical alligator pattern with no spelling.

Medium — cracking is completely interconnected and has fully developed an alligator pattern. Some spelling may appear at the edges of cracks. The cracks may be greater than 6.35mm wide, but the pavement pieces are still in place.

High —the pattern of cracking is well developed. Spalling is very apparent at the crack. Individual pieces may be loosened and may rock under traffic. Pieces may be missing. Pumping of fines up through the cracks may be evident. Pattern of cracking is well developed. Spalling is very apparent at the crack. Individual pieces may be loosened and may rock under traffic. Pieces may be missing. Pumping of fines up through the cracks may be evident. [18]

Extent: The extent of alligator cracking is related to the length of wheel paths. There are two wheel paths in every lane. Accurate measurement and recording as a percentage of wheel path length is preferable. Recommended ranges for estimated extent.

1 percent to 9 percent of both wheel paths
10 percent to 24 percent of both wheel paths
25 percent to 49 percent of both wheel paths
50 percent to 100 percent of both wheel paths

Measure: Accumulate the lengths along the surveyed lane of each severity of the alligator cracking as it occurs in both wheel paths. Divide the accumulated lengths by twice the length of the segment (two wheel paths per lane). Multiply by 100 to get percent, and round to a whole number.

Fig.2.3: High severity alligator cracking

Longitudinal Cracking

Longitudinal cracks run roughly parallel to the roadway center line. Longitudinal cracks associated with the beginning of alligator cracking are generally discontinuous, broken, and occur in the wheel path. However, any longitudinal crack that is clearly within the wheel path should be rated. [18]

Note: Do not include cracks which reside only within of a lane edge. These cracks are assumed to be caused by, or related to, a paving construction joint and should be rated as non-wheel path longitudinal cracking. If your survey includes an item for joint or crack seal condition, you should include the seal condition of these lane edge construction joints in that survey item.

Severity:

Low — The cracks have very little or no spalling along the edges and are less than 6.35mm in width. If the cracks are sealed and the width of the crack prior to sealing is invisible, they should be classified as Low Severity.

Medium — the cracks have little or no spalling but they are greater than 6.35mm in width. There may be a few randomly spaced low severity connecting cracks near the main crack or at the corners of intersecting cracks.

High — Cracks are spalled and there may be several randomly spaced cracks near the main crack or at the corners of intersecting cracks. Pieces are visibly missing along the crack. At some point, this longitudinal cracking becomes alligator cracking.

Extent: The extent of longitudinal cracking is recorded as a percent of the length of the surveyed segment.

1 percent to 99 percent of length of segment

100 percent to 199 percent of length of segment

200 percent or more of length of segment

Measure: Accumulate the lengths along the surveyed lane of each severity of the longitudinal cracking as it occurs. Divide the accumulated lengths by the length of the segment. Multiply by 100 to get percent, and round to a whole number. [18]

Fig. 2.4:High severity Longitudinal Cracking

Transverse Cracking

Transverse cracks run roughly perpendicular to the roadway center line. They may be caused by surface shrinkage due to low temperatures, hardening of the asphalt, or cracks in underlying pavement layers. They may extend partially or fully across the roadway. Consider only those transverse cracks that are a minimum of 0.6m in length.

Severity:

Low — the cracks have very little or no spalling along the edges and are less than 6.35mm in width. If the cracks are sealed and the width of the crack prior to sealing is invisible, they should be classified as Low Severity.

Medium — the cracks have little or no spalling but they are greater than 0.6m in width. There may be a few randomly spaced low severity connecting cracks near the main crack or at the corners of intersecting cracks.

High — Cracks are spalled and there may be several randomly spaced cracks near the main crack or at the corners of intersecting cracks. Pieces are visibly missing along the crack.

Extent: The extent of transverse cracking is quantified as a frequency of occurrence expressed as a count per 30m of lane length. Recommended ranges for estimated extent. [18]

1 to 4 cracks per 30m

5 to 9 cracks per 30m

10 or more cracks per 30m

Measure: Accumulate the count along the surveyed lane of each severity of transverse crack as it occurs. Divide the accumulated counts by the length of the segment. Multiply by 100 to get the frequency, and round to a whole number.

Fig. 2.5:High severity Transverse Cracking

Raveling

Raveling is pavement surface deterioration that occurs when aggregate particles are dislodged (raveling) or oxidation causes loss of the asphalt binder (aging). The severity is rated by the degree of aggregate and binder loss. Rate the overall severity within the segment as the most predominate observed level.

Severity:

Low — the aggregate and/or binder has started to wear away but has not progressed significantly. The pavement only appears slightly aged and slightly rough. [18]

Medium — the aggregate and/or binder have worn away and the surface texture is moderately rough and pitted. Loose particles may be present, and fine aggregate is partially missing from the surface.

High — the aggregate and/or binder have worn away significantly, and the surface texture is deeply pitted and very rough. Fine aggregate is essentially missing from the surface, and pitting extends to a depth approaching one half the coarse aggregate sizes.

Extent:

The extent of raveling is estimated and expressed relative to the surface area of the surveyed lane. Recommended ranges for estimated extent.

Localized — Patchy areas, usually in the wheel paths.

Wheel Path — Majority of wheel tracks are affected, but little or none elsewhere in the lane.

Entire Lane — Most of the lane is affected.

Measure: Estimate the severity and extent

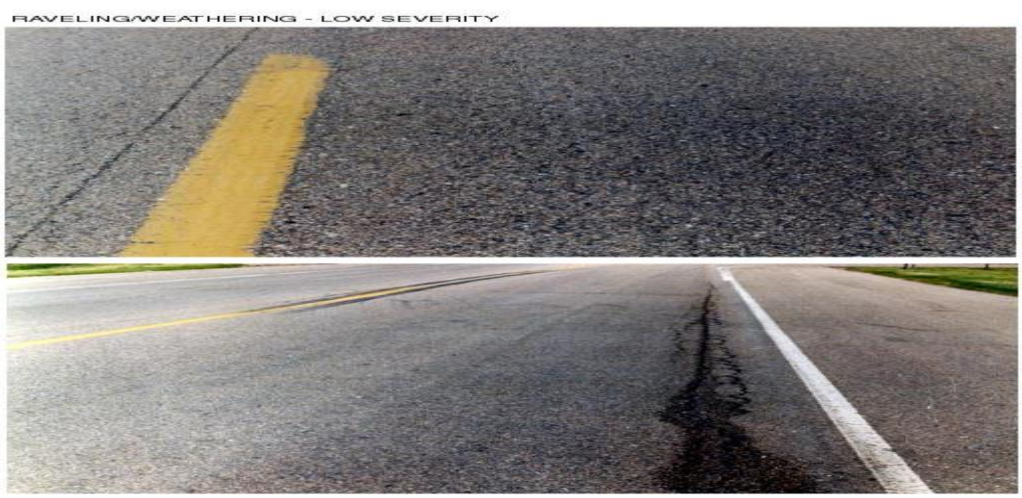

Fig.2.6: High severity Raveling

Bleeding

Bleeding is indicated by an excess of bituminous material on the pavement surface which presents a shiny, glass-like reflective surface that may become sticky in hot temperatures. At the lower severity levels, the extents "localized" and "wheel path" may be difficult to differentiate; however, as the severity increases, "wheel path" becomes better defined. Wheel path refers to tire tracking area and may be used to represent the condition of only one wheel track being heavily involved. [18]

Severity:

Low — Minor amounts of the aggregate have been covered by excess asphalt but the condition has not progressed significantly.

Medium — significant quantities of the surface aggregate have been covered with excessive asphalt. However, much of the coarse surface aggregate is exposed, even in those areas showing flushing.

High — Most of the aggregate is covered by excessive asphalt in the affected area. The area appears wet and is sticky in hot weather.

Extent:

The extent of bleeding is estimated and expressed relative to the surface area of the surveyed lane. Recommended ranges for estimated extent.

Localized — Patchy areas, usually in the wheel paths.

Wheel Path — Majority of wheel tracks are affected, but little or none elsewhere in the lane.

Entire Lane — Most of the lane is affected.

Measure: Estimate the severity and extent.

Fig. 2.7: High severty bleeding

Corrugation

This distress category covers a general form of surface distress which is not limited to the wheel path, although they may occur in the wheel path. The distress may occur in isolated areas, such as at intersections, or it may occur over a large part of the roadway surface.

Corrugations are regularly occurring transverse undulations in the pavement surface. Corrugations occur as closely spaced ripples; while waves are undulations whose distance from peak to valley is more than 0.95m.

Severity: The severity of corrugation is defined as the maximum vertical deviation from a 3.1m straightedge placed on the pavement parallel to the center line of the roadway.

Low — 3 mm to50.8mm per 3.1m.
Medium —50.8mm to101.6mm per 3.1m.
High — Over 101.6mm 3.1m per.
Extent: The extent of corrugations is expressed in percent of the lane area affected.

1 percent to 9 percent of the area of the segment
10 percent to 24 percent of the area of the segment
25 percent or more of the area of the segment
Measure: Determine severity by measuring the maximum difference in elevation that occurs within a 3.1m straightedge length centered over the area of displacement. Rate the overall distress by using the highest observed level. [18]

Fig.2.8: High severity Corrugation

Block Cracking

Block cracks divide the pavement surface into nearly rectangular pieces with cracks that intersect at about 90 degrees. This type of distress differs from alligator cracking in that alligator cracks form smaller, irregular shaped pieces with sharp angles. Also, alligator cracks are caused by repeated traffic loadings and are, therefore, generally located in traffic areas (i.e., the wheel paths).

Block cracking is caused principally by shrinkage of the asphalt concrete and daily temperature cycling. It is not load-associated, although load can increase the severity of individual cracks. The occurrence of block cracking usually indicates that the asphalt has hardened significantly through aging. Block cracking normally occurs over a large portion of the pavement area including no traffic areas. However, various fatigue related defects may occur in the same segment.

Severity: The severity of block cracking is defined by the average size of the blocks and the average width of the cracks that separate them.

Block Size

Low —2.7× 2.7 meter or greater.
Medium —1.5× 1.5 meter to 2.5 × 2.5 meter blocks.
High —1.2 meter blocks or less.
Crack Size

Low — Less than 6.1 meter.
Medium — Over 6.1 meter.
High — Spalled.
Extent: The extent of block cracking is assumed to be the full surveyed segment. If the block cracking does not extend throughout the segment, then rate the segment using longitudinal and transverse cracking.

Measure: Estimate the typical size of the blocks and select the appropriate standard block size and crack size. [18]

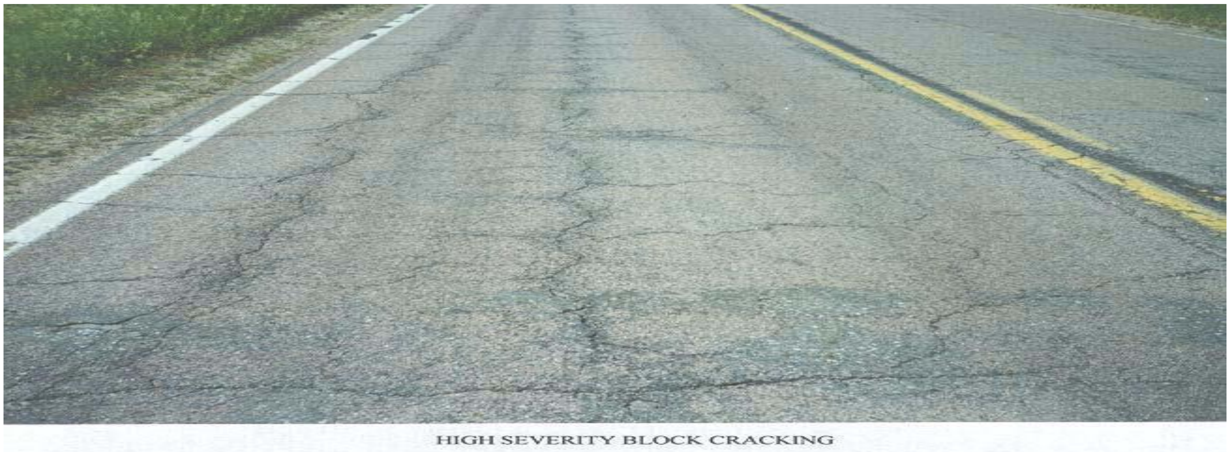

Fig. 2.9: High severity block cracking

Pavement Edge Condition

Edge raveling occurs when the pavement edge breaks away from roadways without curbs or paved shoulders. However, edge conditions can still occur with paved shoulders. Edge patching is the repair of this condition. The "lane less than 10 feet" distress indicates that the edge raveling has progressed to the point where the pavement width from the center line to the outer edge of roadway has been reduced to less than3.1 meter.

Severity: The severity of Pavement Edge Condition is defined as follows.

Low — Edge Raveling
Medium — Edge Patching
High — Edge lane less than3.1meter.
Measure: Accumulate the lengths along the surveyed lane of each type edge defect as it occurs. Divide the accumulated lengths by the length of the segment. Multiply by 100 to get percent, and round to a whole number.

Extent: The extent of pavement edge conditions is recorded as a percentage of the length of the surveyed segment. Recommended ranges for estimated extent.

1 percent to 9 percent of the length of the segment
10 percent to 24 percent of the length of the segment
25 percent or more of the length of the segment

The key component to a quality PMS is quality data collection during the pavement evaluation process. It is important that the data collected during each inspection can be compared with previous pavement inspections. Several methods for data collection are available. The methods selected should reflect the capabilities and goals of the pavement management system. All pavement management systems should include a visual inspection of some type. A properly executed visual evaluation is one of the most reliable and efficient forms of pavement evaluation available. It is simple, inexpensive, and provides a great deal of valuable information about pavement condition. Visual inspection techniques range from informal drive-over's to formal methods such as the PCR or Long Term Pavement Performance methods. Larger transportation networks, like Metro's, tend to use the more formal systems. These systems, particularly PCR, provide a comprehensive record of pavement distresses at the time of the evaluation and are highly repeatable. Larger systems also tend to use image-based survey methods, which use a vehicle to collect film, video, or digital images of the pavement system. These images are then analyzed for the required distress data. An image-based assessment has the advantages in safety and speed of a drive-over survey without sacrificing the quality of a walking survey. The survey vehicles may also be used to collect additional data, such as roughness or right-of-way images, concurrently with the images ASTM Standard D6433-99.

A visual inspection of the pavement surface can provide valuable information. Visual inspection data can be used to evaluate current pavement condition, predict future pavement performance, determine and prioritize pavement maintenance and rehabilitation needs, estimate repair quantities, and evaluate the performance of different maintenance and rehabilitation techniques and materials. Most roads rely on a visual inspection as the network level condition assessment used within their Pavement Management System.

Pavement inspection is conducted on inspection units. An inspection unit is a small segment of a pavement section or management unit selected of convenient size which is then inspected in details. The distress found in the inspection unit is used to calculate the PCR. [18]

An inspection unit can vary from 15 to 60 m long by one to four lanes wide. Generally, inspection unit should have a relatively uniform size within a uniform section. For instance, if a two lane road 7.8 m wide is being inspected, the inspection units could be approximately 30m long. For a four lane road 15.6 m wide, the inspection units can be 30 m long by 7.8 m wide and only go to the centerline. The units selected for inspection can be alternated between lanes.

When a small area of pavement is found to be much worse than the majority of the pavement, it can be inspected and identified as a "special" inspection unit. This is used to identify areas of localized deterioration such as an area damaged by utility cuts, crossing of construction traffic, or other localized problems. A weighted average is used to calculate the PCR when special inspection units are inspected.

The inspector checks the sample unit and recording the type, severity and amount must correspond to those defined in this Distress Identification Manual. The quantities and severities should normally be estimated using measuring techniques as accurate as possible.

The rating method is based upon visual inspection of pavement distress. Although the relationship between pavement distress and performance is not well defined, there is general agreement that the ability of a pavement to sustain traffic loads in a safe and smooth manner is adversely affected by the occurrence of observable distress. The rating method provides a procedure for uniformly identifying and describing, in terms of severity and extent, pavement distress. The mathematical expression for pavement condition rating (PCR) provides an index reflecting the composite effects of varying distress types, severity, and extent upon the overall condition of the pavement. The model for computing PCR is based upon the summation of deducts points for each type of observable distress. Deduct values are a function of distress type, severity, and extent. Deduction for each distress type is calculated by multiplying distress weight times the weights for severity and extent of the distress. Distress weight is the maximum number of deductible points for each different distress type. The mathematical expression for PCR is as follows as shown in Equation. [18]

PCR = 100 - ∑ Deduct……………………………………………[2.3]

Where:

n = number of observable distresses, and

Deduct = (Weight for distress) (Weight for severity) (Weight for Extent)

The values shown in Table present the various distresses for flexible pavement and current guidelines for establishing their severity and extent. Three levels of severity (Low, Medium and High) and three levels of extent (Occasional, Frequent, and Extensive) are defined. The definition for distress type, severity, and extent must be followed closely and be clearly understood by field personnel if the rating method is to provide meaningful data.

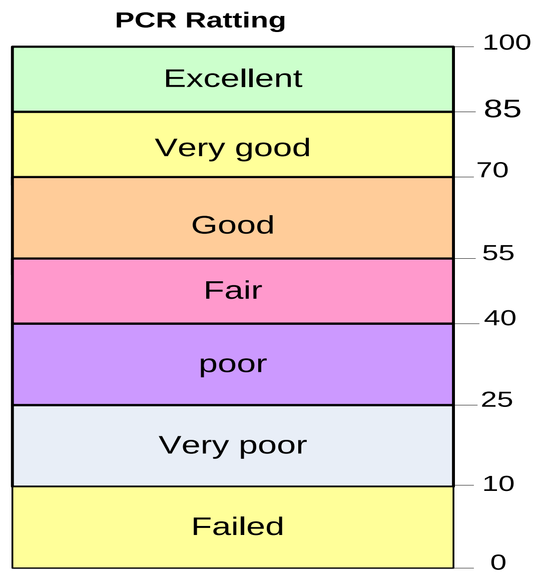

Fig.2.10 Pavement condition Ratting Scale

A Pavement Condition Rating (PCR) Scale was developed to describe the pavement condition using the PCR numbers calculated from previous Equation. This scale has a range from 0 to 100; a PCR of 100 represents a perfect pavement with no observable distress and a PCR of 0 represents a pavement with all distress present at their –High levels of severity and extent levels of extent. Figure illustrates the PCR Scale and the descriptive Condition of a pavement associated with the various ranges of the PCR values.[7]

2.2.5 Pavement Serviceability Rating (PSR)

The Present Serviceability Rating (PSR) is a subjective and ride-based observation interms of the roughness of the pavement inorder to estimate deterioration, deficiencies, and needed improvements based on early AASHO Road Tests. The higher the PSR value, the smoother the riding surface. The PSR is a grade numbe is shows rate of ability the sections to serve the designed traffic loads. Its rating scale is raging from 0-5; where 0 signifies very poor and the number 5 signifies "very good" as illustrated in below.

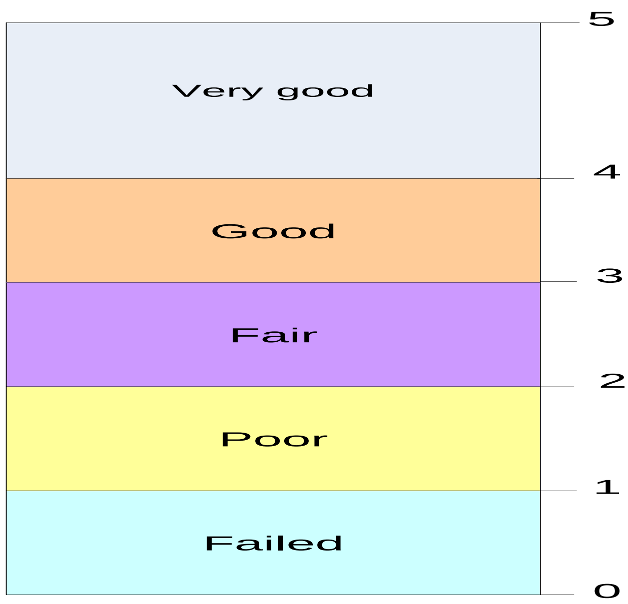

Fig.4.11: Pavement Serviceability Ratting (PSR) scale

Depending on The relation between PSR and IRI the condition of the pavement is evaluated using the equation.[9]

PSR = $5 * e^{(-0.26IRI)}$……………………………………….[2.4]

Where

PSR = present serviceability rating

IRI = international roughness index

2.3 Over view of HDM-4 modeling

Highway Development Management model-4(HDM-4) is the new successor version to the World Bank Highway Design and Maintenance Standards Model (HDM-III). The scope of the new HDM-4 tools has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. The HDM-4 incorporates three dedicated applications tools for project level analysis, road work programming under constrained budgets, and for strategic planning of long term network performance and expenditure needs.

It is designed to be used as a decision support tool within a road management system. Standard data import and export facilities are provided for linking HDM-4 to various database management systems. Local adaptation and calibration of HDM-4 models can be achieved by specifying default data sets that represent pavement performance and vehicle resource consumption in the country where the model is being used. The highway management process as a whole can, therefore, be considered as a cycle of activities that are undertaken within each of the management functions of planning, programming, preparation and operations. The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement, i.e. road deterioration, road work effects, road user effects and socio-economic and environmental effects. Once constructed, road pavements deteriorate as a consequence of several factors, i.e. Traffic loading, Environmental weathering, Effect of inadequate drainage systems.

Generally HDM-4 is capable of analyzing project, program, and strategic analysis in order to help determine the performance of a road [HDM].[19]

2.3.1 Project analysis

Project analysis allows assembling of several road works or more than one road section together under one agreement. Project title, road network, and vehicle fleet information are required to create a project. To begin a project analysis, work standards, general traffic composition and growth rate, extra benefits, and costs must be specified**.** Project analysis provides the physical, functional and economic feasibility of specified project alternatives by comparing the alternatives. The major issues that the project analysis estimates are pavement structural performance, life cycle prediction of deterioration, maintenance effects and costs, road user costs and benefits, and economic comparison of project alternatives.[19]

2.3.2 Program Analysis

The program analysis deals primarily with the prioritization of a long list of candidate road projects into a one-year or multi-year work program under budget constraints. Program analysis deals with individual sections that are distinctive physical units distinguishable from the road network throughout the analysis. The program analysis examines the yearly maintenance program. The multi-year program method performs one preservation treatment or one treatment after the previous treatment assigned to each road section. These treatments are prompted based on distress threshold. This study is used to identify the road sections required for maintenance under a particular budget because the program analysis provides an easy evaluation of the whole road network .[19]

2.3.3 Strategic analysis

Strategic analysis is performed on the entire road network for long term budget planning or for optimizing the maintenance strategies. In strategic analysis, the road system loses its individual section characteristics by grouping all road segments with similar characteristics into the road network matrix categories. In any case, the whole network is subdivided into several networks according to the main qualities that control the pavement performance. A typical road network matrix can be categorized according to the following: Traffic volume or loading, Pavement type Pavement condition, environment or climatic zones, functional classification[19].

2.4 Deterioration Models in HDM-4

Pavement deterioration models relate the functions, which are the measure of distress due to the magnitude of loads, number of load repetitions, pavement composition and thickness, and subgrade moisture. They should be able to predict the change in pavement condition over a given period of time under a set of conditions. They are exponential in nature, and the rate varies depending upon its condition with the passage of time. Road deterioration is computed as the incremental change in pavement condition over a period of time due to the effects of pavement characteristics, traffic, environment, and maintenance inputs. A model represented in incremental form can take care ofpavements in any initial stage of condition and at any age and is the most preferred form for economic evaluation of road pavements and maintenance strategies. There are eight deterioration models in HDM-4 under three categories. Most of them are characterized by initiation and progression. The major deterioration models in HDM-4 are discussed below.

2.4.1 Cracking Model

Cracking is one of the most important measures of deterioration in bituminous pavements. Fatigue and ageing have been identified as the principal factors which contribute to cracking of a bituminous pavement layer. The propagation of cracking is accelerated through the embrittlement resulting from ageing and the ingress of water, which can significantly weaken the underlying pavement layers. There are two types of cracking considered in HDM-4: structural and transverse thermal cracking. The first one is effectively load and age or environment-associated cracking. It is modeled based on the relationships derived by. Initiation of all structural cracking is said to occur when 0.5% of the carriageway surface area is cracked. The second one is generally caused by large diurnal temperature changes or in freeze or thaw conditions, and, therefore, usually occurs only in certain climates. For each type of cracking, separate relationships are given for predicting the time to initiation and then the rate of progression.[14]

2.4.2 Potholing Model

Potholing usually develops in a surface that is either cracked, ravelled, or both. The presence of water accelerates pothole formation both through a general weakening of the pavement structure and lowering the resistance of the surface and base materials to disintegration. Potholing models use the construction defects indicator for the base as a variable. Initiation of potholes arises once the total area of wide structural cracking exceeds 20%. Ravelling-initiated potholes arise when the ravelled area exceeds 30%. Progression of potholes arises from potholes due to cracking, raveling, and the enlargement of existing potholes. It is affected by the time lapse between the occurrence and patching of potholes.

2.4.3 Rut Depth Model

Rut depth is defined as the permanent traffic-associated deformation within pavement layers which, if channelised into wheel paths, accumulates over time and becomes manifested as a rut. Rut depth modeling is performed after the values of all the surface deterioration of cracking, raveling, potholing, and edge-break at the end of the year have been calculated.[22]

2.4.4 Roughness Model

Roughness consists of several components of roughness such as cracking, structural, rutting, potholing, and environment. The total incremental roughness is the sum of these components. The surface deterioration values used in predicting roughness are those that have been adjusted so that the total damaged surface area plus the undamaged area equals 100%.

The remaining three models are edge-break, texture depth, and skid resistance. They are only characterized by progression models. These models are not common compared to the other deterioration models.[14]

2.5 Cost effective pavement treatment alternative selection

The effectiveness is defined in terms of performance improvement of the overall index (called Pavement Quality Indicator (PQI), Pavement Condition Index (PCI), Pavement Condition Rating (PCR) etc. The effectiveness can be defined in terms of either the life extension resulting from the treatment or the PQI area.

A cost-effectiveness (CE) analysis is performed in order to select rehabilitation strategies thereby providing an optimal solution. The selection procedure chooses sections/strategies for implementation based on highest cost-effectiveness. The selection process stops when the specified constraints are met or if the constraints cannot be met. When performance constraints are included, the selection has to affect the performance constraints in the implementation year. The number of performance constraints affected influences the selection as well as the cost-effectiveness.

2.6 Pavement remaining life cycle analysis

The operation of HDM-4 is similar for each of project, program or strategy analysis. In each case, HDM-4 simulates total life cycle conditions and costs for an analysis period under a specified scenario of circumstances. The model stimulates, for each pavement section, year-by-year, the pavement condition and resources used for maintenance under each strategy, as well as the vehicle speeds and physical resources consumed by vehicle operation. Interacting sets of costs related to those incurred by the road administration and those incurred by the road user, are added together over time in discounted present values. Economic benefits are then determined by comparing the total cost streams for various maintenance alternatives with a base case, usually representing minimal routine maintenance.[20]

Environmental effects such as vehicle emissions and energy consumption calculation they are not included in the cost streams. Life-cycle analysis, unlike multi-year program analysis, requires at least two principles for each section in order to compare the defined works alternatives with the base alternative for the specific analysis period. Optimal alternatives for each section are selected to maximize the economic benefits for the whole network while restricting the financial costs to less than the available budget.[21]

2.7 Geometric condition of the road

Rise and fall

The analysis of pavement management and life cycle analysis are defined based on length, carriageway width, traffic flow, Shoulder width, and surface class. Carriageway width is the width of the road including shoulders and auxiliary lanes devoted to the use of vehicles.

A shoulder is the part of the highway that is next to the regularly traveled highway segment and is on the same level as the highway. The surface class is entered as bituminous asphalt pavement.

Rise plus fall is defined as "the sum of the absolute values of total vertical rise and total vertical fall of the original ground along the road alignments over the road section in either direction divided by the total section length. This is shown in Figure given below and can be ca lculated using the equation.

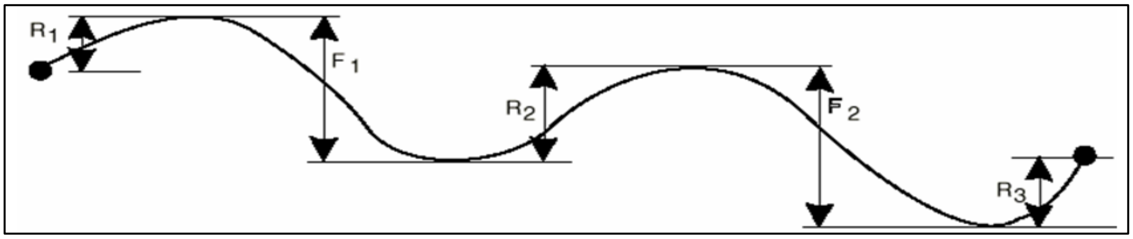

Fig.4.12: Rise+fall measurement representation

Figure Rise + fall [17]

$Rise + fall = \frac{R1+R1+R3+F1+F2}{Length}$......................................[2.5]

Another geometric characteristic that is used to describe the road section is super elevation. Super elevation of a curve section is "the vertical distance between the heights of the inner and outer edges of the road divided by the road width." [17] The horizontal curvature is defined as the weighted average of the curvatures of the curve sections of the road. This is shown in Figure and the Equation below is used to calculate the curvature.

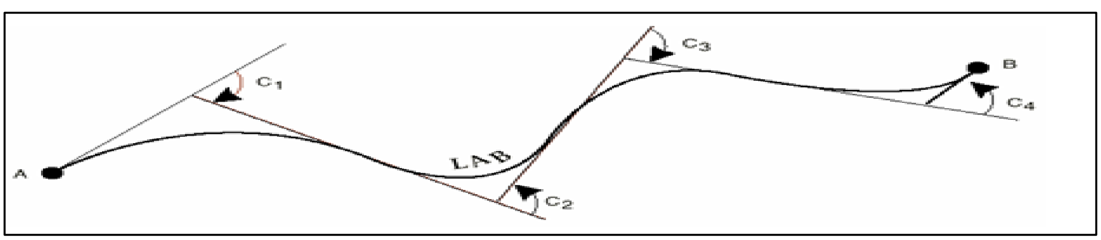

Fig. 4.13 Horizontal Curvatures [17]

$$Horizontal\ Curvature\ \left(\frac{deg}{km}\right) = \frac{C1 + C2 + C3 + C4}{Length} \dots\dots\dots\dots\dots\dots\dots\dots\dots. [2.6]$$

CHAPTER THREE

METHODOLGY

3.1 Introduction

This thesis presents a pavement performance evaluation and life cycle management study performed for Kombollcha-Robit road alignment using HDM-4 software packages to analyze the current pavement condition and predict future pavement conditions, then allocate available maintenance option depending on the condition and performance of each pavement section analyzed. Several software packages exist such as PAVER and Street Saver, but because of the primarily use in Ethiopia HDM-4 which is developed by the World Bank is selected for analysis of this case study.

The purpose of this study is to assess the performance of existing road section and examine the future condition of the remaining service life of the pavement using statically formulated models and HDM-4 calibrated software respectively. To analysis the performance of pavement, the following parameters were used in the case of this study. These are International Roughness Index (IRI), Present Serviceability Index and Pavement serviceability rating (PSR). To quantify those parameters, the primary data recorded during condition survey and the secondary data studied by Ethiopia Road Authority (ERA) were used.

3.2 Study area

The study area undertaken was komobolcha-Harbu road section located in Amhara region at the northern central part of Ethiopia. It was located approximately 400km from Addis Ababa and approximately 17km length from Road section. The Road was connect kombolcha and Harbu town.The altitude and latitude of the road is vary in between 10o00'N 39∘54'E-11.500∘N 39.440o/10.000oN 39.900oE-11.083oN 39.733oE respectively and also the elevation of the road is vary within 1280m – 1915m above sea level.

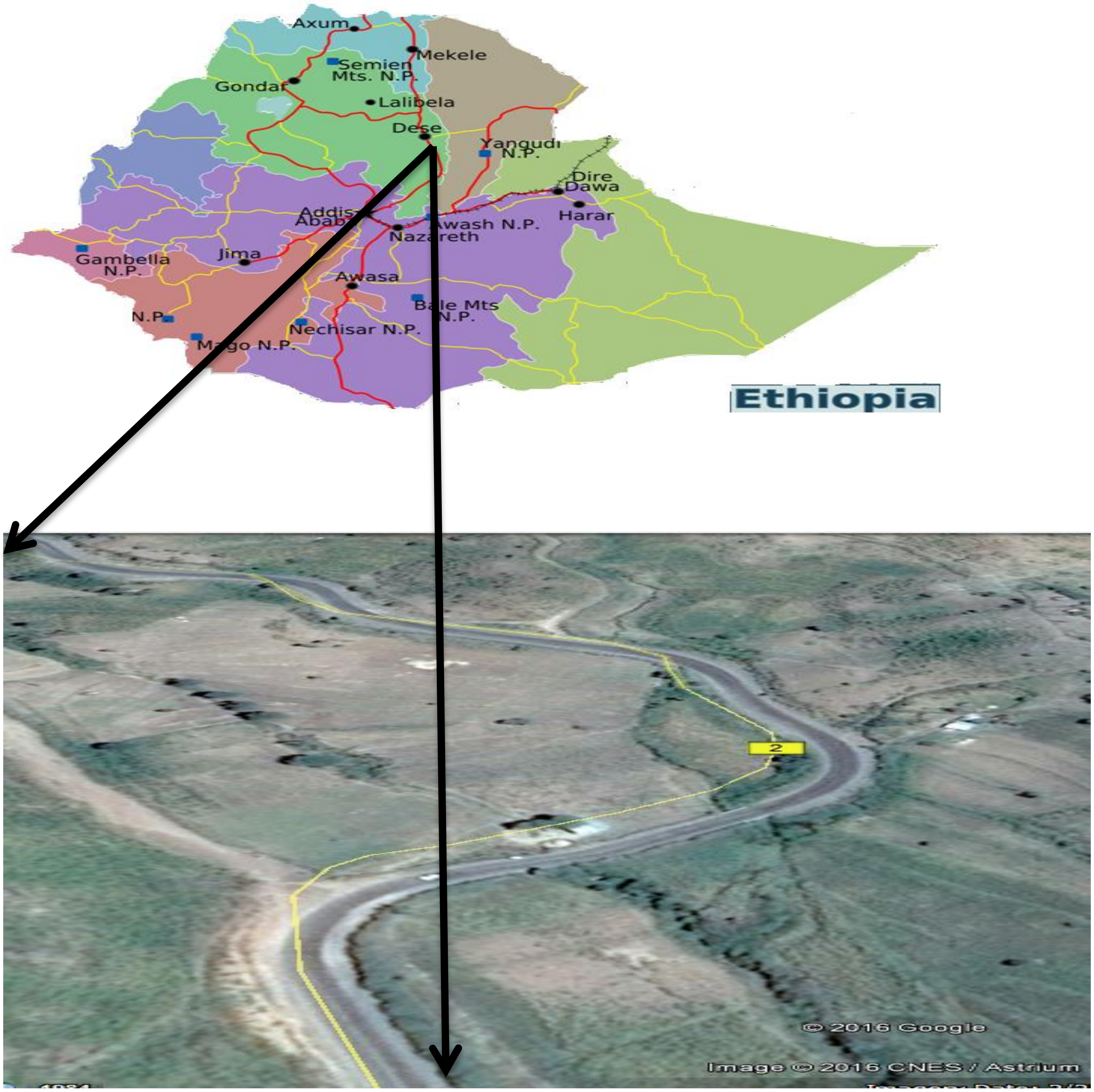

Fig.3.1 The three section of Google earth representation of the study area

3.3 Study Design

In order to answer those specific objectives this study, both descriptive and explanatory type of survey has been applied. Descriptive was used to describe the existing condition of the pavement. Explanatory was used to explore the parameters of performance evaluation indexes and used to quantify the future condition of the pavement.

This research were analyzed depending on two types of research strategies like surveying and also more focus on quantitative analysis of the pavement performace evaluation indexes and future condition prediction . Under this study the following task shown on the chart were conducted.

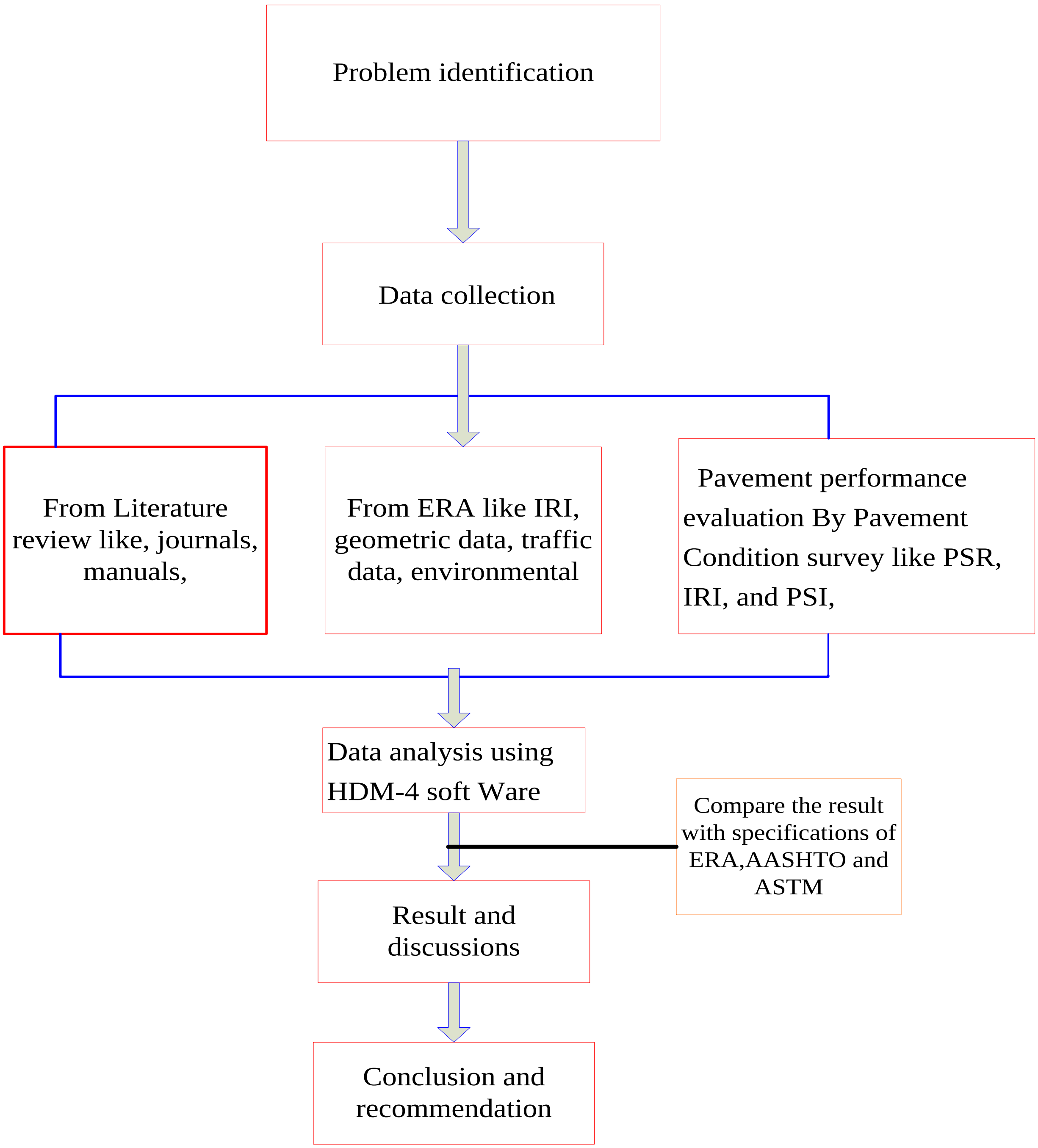

Fig. 3.2 Study Procedure

3.4 Study population

The population under this study was 17Km of the road section which was studied interms of pavement deterioration, traffic volume, vehicle type and category, and pavement performance indicators like; international roughness index, present serviceability index, and pavement serviceability rating.

3.5 Sample size and sampling techniques

3.5.1 Sample size

In this study the sample area was selected depending on the pavement condition that needs treatment on the current time and the average international roughness index along kombolcha Harbu road section. The size of selected sample was cover about 100% of the road section specified for this study. The sample size of pavement performance and life cycle analysis was limited about 17km section of road.

3.5.2 Sampling technique

The technique used on this study was non-probability sampling technique which especially concerned on purposive sampling technique. Because; this road project was selected depending on the Intenational Roughness Index along Kombollcha-Harbu road section.

3.6 Study Variables

3.6.1 Dependent variable:

The dependent variable in this study was the main topics that excuate every actions. Therefore pavement performance and life cycle analysis is the dependent variable in this final study of kombolcha –Harbu road section.

3.6.2 Independent variables

The independent variables determined in the studies of Pavement performance and life cycle analysis were; International Roughness Index (IRI), Pavement Condition Rating (PCR), Pavement Serviceability Index (PSI), raveling , edge crack, rutting depth ,texture depth and other type of cracking.

3.7 `Software and instruments

The following instruments and software were used for this study: HDM-4 - to analysis future life cycle condition, Ms-excel- data storage purpose, Microsoft office Visio 2003- for drawing chart, MatLab R2010-for graphical analysis of data**,** google earth: for location of the study area tape SPSS software for regression analysis and ruler- for measurement of extent and severity of the damge road section.

3.8 Data collection process

In order to attain the main objective of this study both secondery and primery datas were used for the analysis of quantitative and qualitative values of the study. Before starting any data collection, formal letter was obtained from JIT and also official permission was obtained from ERA Kombolcha district and Alem Gena district. Those quantitative and qualitative data were analysed based on the necessary input parameters of collected datas. Data collection process included field visual inspection, selecting representative samples along study area, and fieldmeasurements of geometric and deterioration condition were conducted. The most secondery datas were collect at the intervals of 100m length of road section. After collected all datas which were necessary for HDM-4 calbrated software, the future condition of the pavement throuth the remaining design life of the pavement should be determined.

3.9 Data processing and analysis

Preliminary datas were collected by visual survey along Kombolcha-Harbu road section. Those datas which surveyed during condition assessment were area block crack, alligator crack, longitudinal crack, rutting depth, the numbers of pothole, reveling, area of edge crack,current geometric condition all are measured. Then calibrated to the HDM-4 software for the analysis of the future condition the pavement along the age. But the inputs for this clabrated software like some geometric condition, pavement roughness data, environmental condition and traffic volume data i.e AADT was count on that road section has taken from ERA kombolcha district.

3.9.1 Pavement condition survey

In order determine the extent or rate of damage Kombolcha-Harbu road section using visual inspection,first identify location of the type of failures and then measured the state of the existing pavement by assessing the physical conditions of the existing pavement along a road. After assessment, the only used method was ERA measuring specification i.e at the interval of 100m length the following pavement damages geometric condition were measured.

Edge cracking measurement

During pavement condition survery the measurement was undertaken at the interval of 100m which started from 0+000 station to 17+000. But this station was classified to three sections for the purpose of simplifying the measurement. The stations that coved for measurement of first, second and third sections were 0+000 to 4+000, 6+000 to 10+000 and 11+000 respectively. The edge cracks area were measured for the three sections of this study area given on the apendex part of this study.

Fig. 3.3 Edge cracking measurement

Potholes counting and measurement

The potholes along this road section were counted throuth out the length of the road at the time of condition survey.

Fig. 3.4 Potholes counting and measurement

Rutting depth measurement

The rutting along this road section was measured form wheels path of the pavement. This road failures was measured at some part the stations occurred along road length. Becasuse rutting was not the major problem for the damge of this road section.

Fig. 3.5: Rutting depth measurement

Cracking area measurement

The cracks that measured along Kombolcha-Harbu road section were similarly classified for three road sections. During the condition survey the following type of cracks were measured. These are longitudinal cracking, transversal crack, and block cracking. But HDM-4 calibrated software was used total cracking area as an put interms percentage with relating to the none defected area of the road section. The measurement of those cracks and their total values has given at the appendix part of this study.

Fig. 3.6: Cracking area measurement

Road Width and thickness measurement

The width and thickness of the road at each 100m interval of stations was measured. After measured the width and thickness at the stations, the average width were determined for the alnalysis purpose of life cycle of the pavement using HDM-4 calibrated software. The masurment was occure at the appendix.

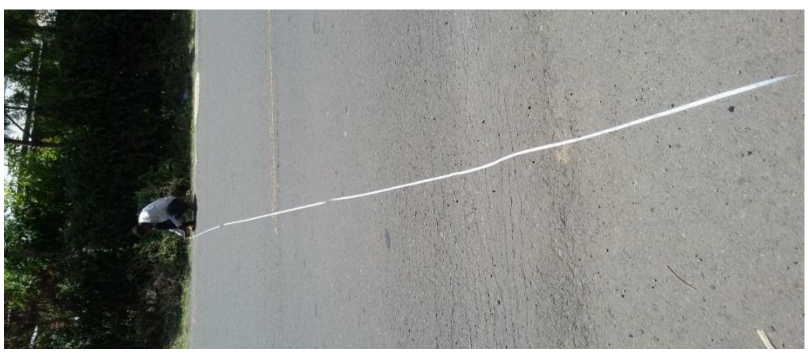

fig. 3.7: Road Width and thickness measurement

3.9.2 Secondery Data collection from Ethiopia Road Authority(ERA

Traffic volue and loading

The traffic volume of this study area was taken from Ethiopian Road Authority Kombolcha district. This data was the 2016 data collected from kombolcha to Kemissie road section. The data was presented at the appendix-A.

Determination of cumulative traffic volumes

In order to determine the cumulative number of vehicles over the remaining design period of the road, the following procedure should be followed.

1. Determine the initial traffic volume ($AADT_0$) using the results of the traffic survey and any other recent traffic count information that is available. For paved roads, detail the AADT in terms of car, bus, truck, and truck-trailer.
2. Estimate the annual growth rate "i" expressed as a decimal fraction, and the anticipated number of years "X" between the traffic survey and the opening of the road.
3. Determine AADT1 the traffic volume in both directions on the year of the road opening by:

$$AADT1 = AADT0\,(1+i)^{x} \quad \ldots\ldots\ldots\ldots [3.1]$$

For paved roads, also determine the corresponding daily one-directional traffic volume for each type of vehicle.

4. The cumulative number of vehicles, T over the chosen design period X (in years) is obtained by:

$$T = 365\ AADT\ [\ (1+i)^{x} - 1]\ /\ (\ i\ ) \ \ldots\ldots\ldots\ldots [3.2]$$

For paved roads, conduct a similar calculation to determine the cumulative volume in each direction for each type of vehicle.

Axle Load

The damage road was highly dependent on the axle loads of the vehicles. For pavement design purposes the damaging power of axles is related to a "standard" axle of 8.16 metric tons using empirical equivalency factors. In order to determine the cumulative axle load damage that a pavement will sustain during its design life, it is necessary to express the total number of heavy vehicles that will use the road over this period in terms of the cumulative number of equivalent standard axles load (ESAL). Axle loads can be converted and compared using standard factors to determine the damaging power of different vehicle types. A vehicle's damaging power, or Equivalency Factor (EF), can be expressed as the number of equivalent standard axles (ESAs), in units of 80 kN. The design lives of pavements are expressed in terms of the ESAs they are designed to carry.

Finally, the cumulative ESAs over the design period (N) are calculated as the products of the cumulative one-directional traffic volume (T) for each class of vehicle by the mean equivalency factor for that class and added together for each direction. The higher of the two directional values should be used for design. The relationship between a vehicle's EF and its axle loading isnormally considered in terms of the axle mass measured in kilograms.[25]

Equivalency factor = $(\frac{alxleload(i)}{8160})^{n}$……………………………………………….[3.3]

Where; axle i = mass of axle i

n = a power factor that varies depending on the pavement construction type subgrade but which can be assumed to have a value of 4.5 and the standard axl load is taken as 8160kg.

Vehicles composition determination and classifcation

Vehicle composition

The composition of vehicles along each section of road can be calculated from the current AADT of the traffic volume. Therefore to calculate composition first the traffic volume of the current AADT should . for the factored traffic volume of the road, the composition of vehicle classes was calculated below.

Table 3.1: Vehicles composition calculation for Kombolcha-Harbu road section

Vehicle classification	2016 AADT from kombolcha-Harbu				Growth Rate(i) %	Factored AADT of 2016 $=AADT_O[1+i]^1$	Composition (%)
	Cycle-I	Cycle-II	Cycle-III	Average $AADT_O$			
Car	18	16	16	17	2.6	18	1.83
Land Rover	123	71	141	112	3.6	117	11.9
Small Buses	367	324	385	359	1.8	366	37.2
Large Buses	142	145	146	145	1.6	148	15
Small Truck	17	20	9	16	2.1	17	1.73
Medium truck	122	95	117	112	3.4	116	11.8
Heavy Truck	98	62	124	95	3	98	9.95
Truck & Trailer	112	82	108	101	3.1	105	10.7
Total	999	815	1046	957	2.65	985	100

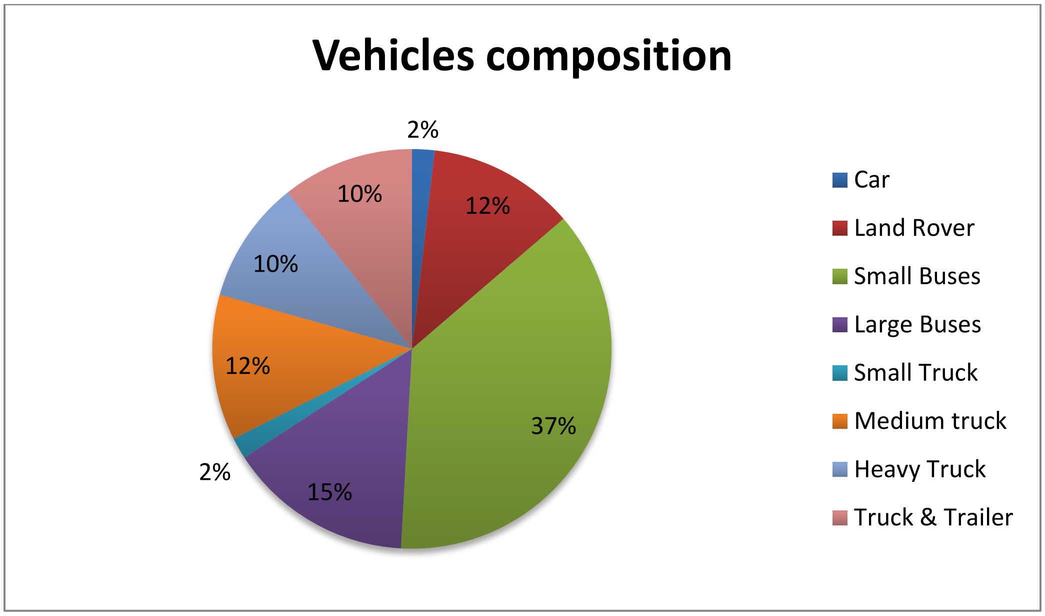

Fig. 3.8: Diagrammatical representation of vehicles composition

3.9.3 ERA Data Collection Equipment

Data collection for the PMS is done through the Hawkeye 2000 (on paved roads) Hawkeye 1000 (on unpaved roads) systems. The Hawkeye 2000 system is installed in the Mercedes Benz Vito vehicle and provide roughness from laser measured longitudinal profiles processed through the Hawkeye Toolkit software, rutting from laser measured transverse profiles processed through the Hawkeye Toolkit software, texture from laser measured texture in right wheel path and processed through the Hawkeye Toolkit software, Pavement video files from two pavement view cameras, from which defects such as cracking, raveling, potholes and structural failures are extracted through the Hawkeye Toolkit software rating form approach and asset view video files from one asset view camera facing forward for measuring of defects such as edge break, measurement of pavement dimensions, recording of side drainage facilities, evaluating side drainage condition through the Hawkeye Toolkit software rating form approach. The input data for analysis of this study can be determined from the current condition of the road. [10]

International Roughness Index (IRI)

The roughness data was collected by ERA Hawkeye 2000 system installed on the Mercedes Benz Vito vehicle and provide roughness from laser measured along longitudinal profiles and then processed through the Hawkeye Toolkit software. From this data only the study section of the road was considered to evaluate the performance of the road. The IRI value selected were depending on deterioration condition of pavement starting from excellent to failed road condition inorder to represent the whole section of the road. Therefore; the analysis purpose of the IRI value were taken as the total average value for each road section.

3.9.4 Pavement performance evaluation

The collected data was analzed by using the regression modeling approached and HDM-4 calibratewd software. This leads to evaluate the present condition of pavement and estimate the future remaining life cycle of the existing road condition. As explained at the previous chapter of this study the pavement evaluation parameter like international roughness index, present serviceability index, pavement and pavement condition rating are analyzed using both regression modeling equation and HDM-4 calibrated software package. According to this study international roughness index was the basic input parameter for both regression model and HDM-4 model to evaluate life cycle of the pavement. The IRI value was measured by using the a calibrated response type by Ethiopian Road Authority (ERA) for conducting appropriate pavement preservation along Kombolcha to Harbu road section. But the PSI and PSR are determined form IRI value and pavement age and pavement condition rating was analyzed using manually condition survey of existing road section within the study area.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Pavement performance evaluation of Kombolcha-Harbu road intermes of IRI

This road section was occurred between Kombolcha-Habru towns. The analysis was conducted on 17 km of the road section. The measured IRI value was surveyed by ERA automotive vehicle at the two lane of road section for the maintenance purpose. To analysis the future condition of the pavement, its current condition should be determined depending on the average IRI value along the length of the road section. The performance of the pavement was evaluated depending on the specification given on the ERA manual 2011.

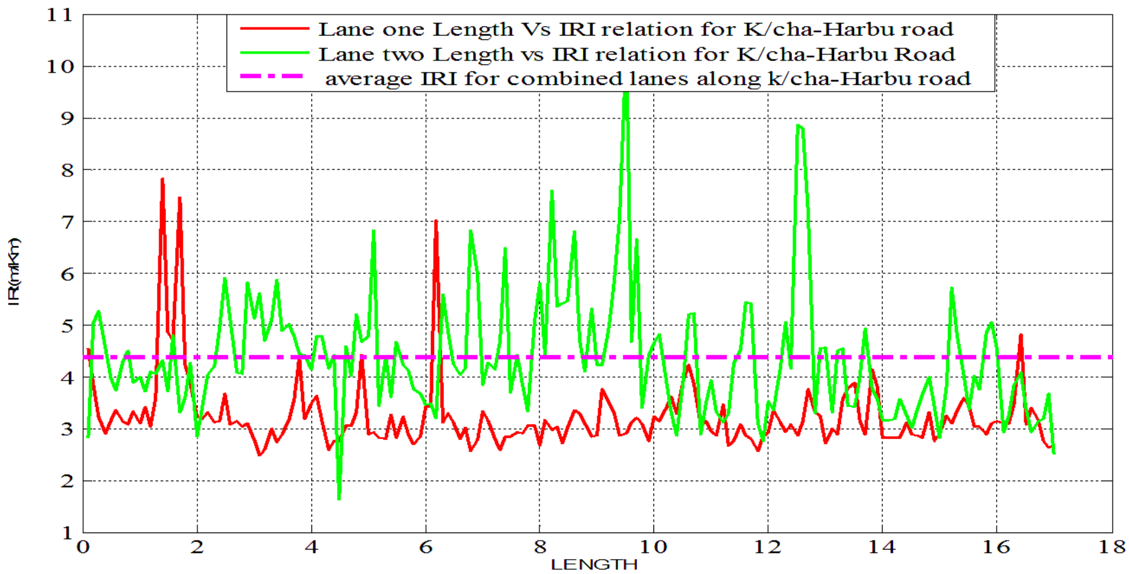

Fig.4.1 Lane one IRI values along Kombolcha- Habru road section

From the graphical representation of the road length and international roughness index of Kombolcha-Habru road section, the mean value of IRI value was determined as 4.24 m/Km. from the graphical relation of this road section, the road was more deteriorated approximately at length of 0.8-12.6Km. Then depending on the average values of IRI the condition of the pavement along this section was evaluated as fair condition. Because the IRI value 4.24 m/Km was occurred between 2.87 and 5.95.

4.2 Pavement performance evaluation intermes of Present serviceability index (PSI)

Pavement serviceability measurement is referred to the process to obtain the Present Serviceability Index (PSI) value at each selected section of road. For this study, it was interested to conduct on flexible pavement which the value of PSI can be determine by using the equation given below. However, the slope variance cannot be measure manually by the observer. Slope variance can be obtained from IRI as suggested by the ASSHTO Road Test. Therefor; the PSI value under this section of the study area was calculated form IRI value of kombolcha-Harbu road section. As explained on the literature review of this research, the statically model was used to calculate PSI value. The model that used for this analysis of PSI was given below

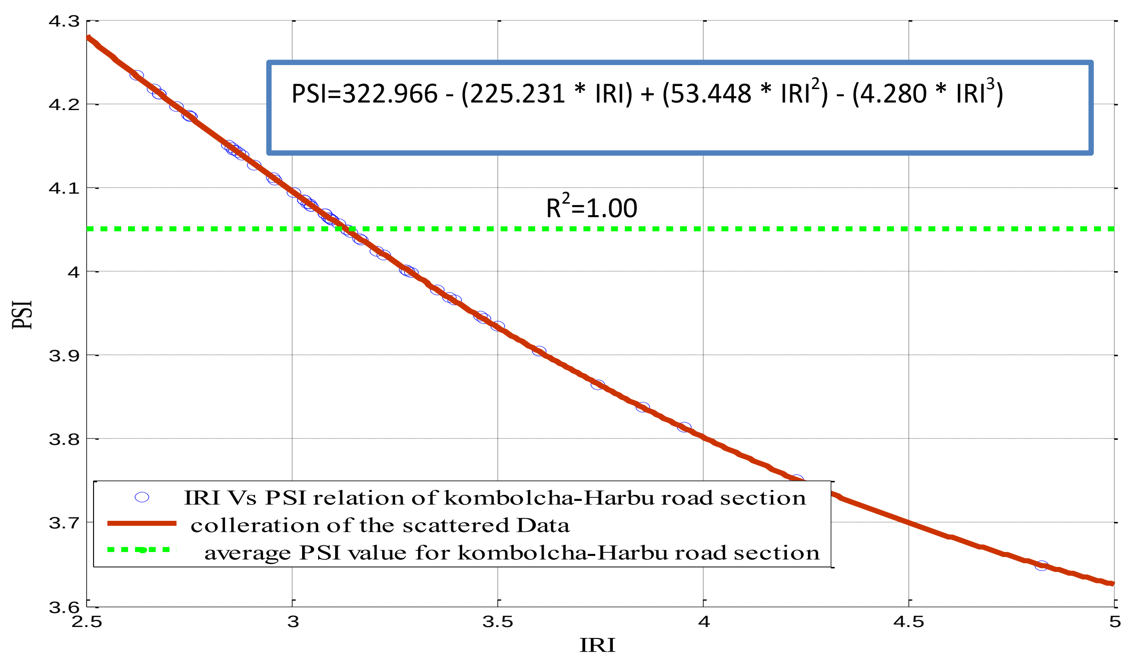

Fig.4.2 The relation between PSI and IRI for kombolcha to Habru road section.

The relation between IRI and PSI of the scattered plotting can be related by fourth degree polynomial function shown on the graph. From this linear relation as the value of present serviceability index increase, the international roughness index becomes decrease. And also from the scattered data the concentration of high pavement roughness were occurs below 4 of the PSI. The regression relation between the two parameter was determined by MatLab software is gives:

The resulting regression analysis after correlating IRI with PSI is expressed by the following single polynomial equation with its corresponding correlation coefficients:

PSI=322.966 - (225.231 * IRI) + (53.448 * IRI^2) - (4.280 * IRI^3)……………………….[4.1]

Where R^2=1.00

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant (P<0.05 with moderate value of R^2.

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R^2 values and level of confidence is greater than 95%.

The scaling of the present serviceability index is ranging from 0 to 5.

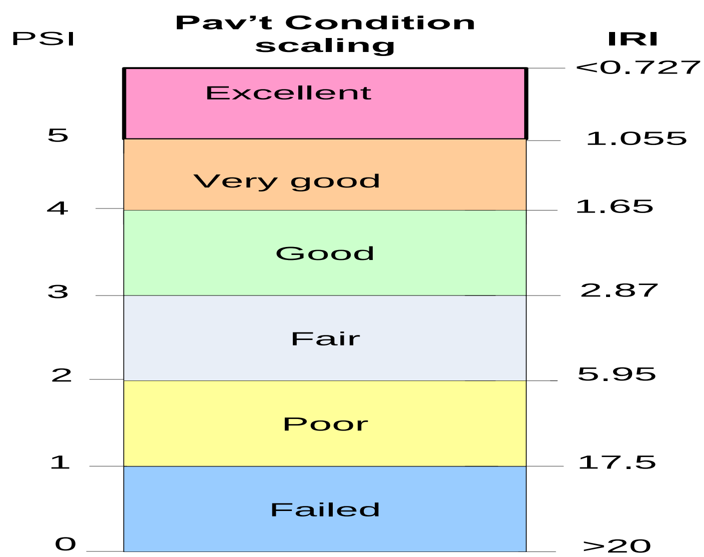

Fig.4.4: PSI and IRI scaling specification

From the above values of pavement serviceability index the condition of pavement is evaluated using the scale of 0 to 5. Therefore; to know the performance of the pavement at section of this study was determined from the average values of pavement serviceability index. The average value of PSI for Kombolcha-Habru was 4.052. Therefor from the above pavement condition scaling values the condition of the road at section of the study are evaluated as very good.

4.3 Pavement performance evaluation using Pavement Serviceability Rating (PSR)

Using the equation illustrated at literature review of this study the performance of the road along kombolcha-Harbu road section of this study can be analyzed in terms of PSR. The equation used for the analysis of the PSR was given below and the whole analysis was present the appendix of this study. But using the graphical relation of the two pavement evaluating parameters i.e. PSR and IRI, and also from the average value of PSR the performance of the pavement was evaluated.

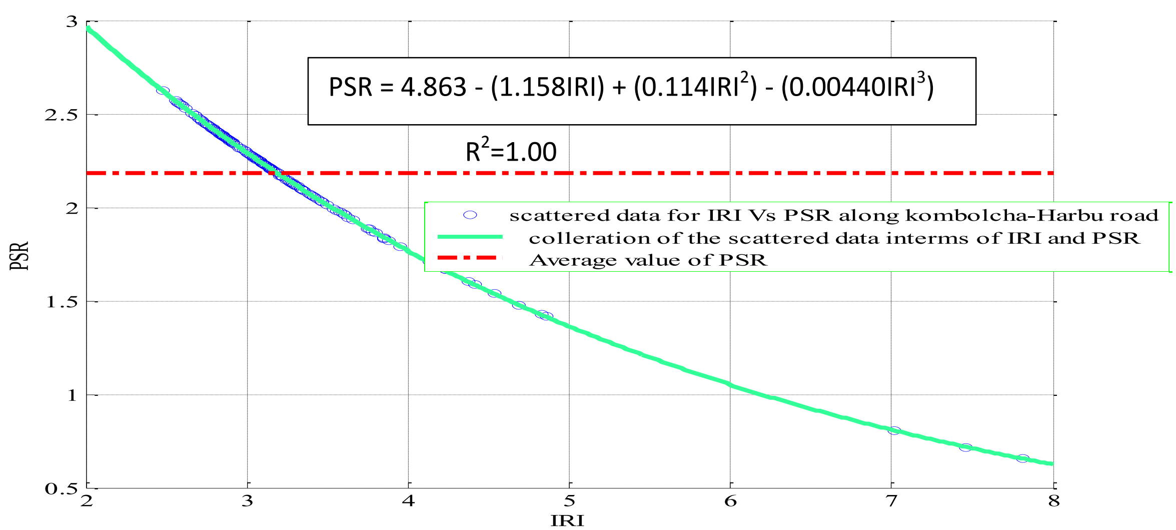

Fig.4.5 Graphical relation of IRI and PSR

From the above graphical representation of PSR and IRI all this road section have a linear relationship which was given by the mathematical equations. This mathematical equation is generated by MatLab software from curve fitting of the scattered data plot of PSR and IRI.

The resulting regression analysis after correlating IRI with PSR is expressed by the following single polynomial equation with its corresponding correlation coefficients:

PSR = 4.863 - (1.158IRI) + (0.114IRI2) - (0.00440IRI3)…………………………………4.2

Where R^2=1.00

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant ($P<0.05$ with moderate value of R2.

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R2 values and level of confidence is greater than 95%.

The pavement serviceability ratting can be evaluated using the average values of PSR for kombolcha–Harbu road section evaluated by the average values of PSR was calculated as 2.182. Therefore the serviceability ratting of the pavement was evaluated as fair.

4.4 Performance evaluation using condition of pavement defects

4.4.1 Rutting measurement

Rutting is Permanent traffic-associated deformation within pavement layers along the wheel paths. This can be measured using condition assessment or survey at the field. The rut depth measured on the study of road section was occurred at five stations of the road length. This road defect was located around 2.5-2.7 km, 5.6-5.7 km, 12.5-12.75 km, 14.2-14.25 and 16.6-16.63 road length. From this stations of rutting length, the rutting depth was measured at the interval of 20m for each area of rutting length.

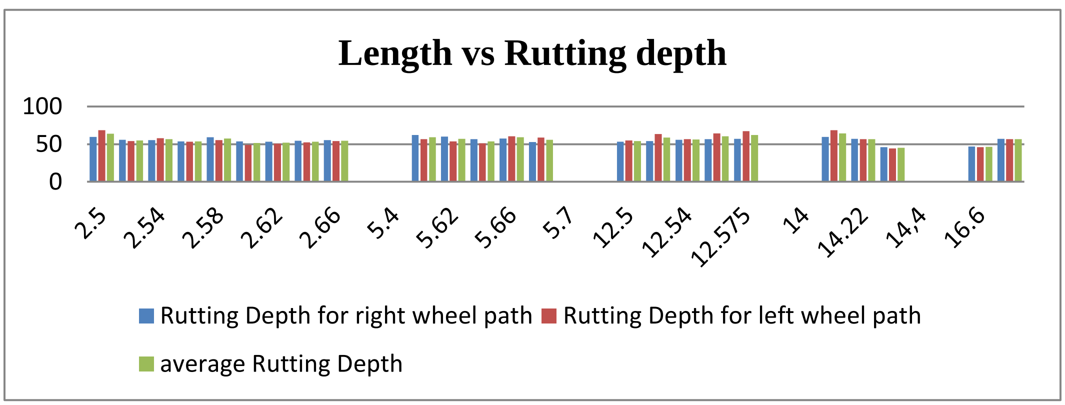

Fig.4.6: Location of measured rutting point along Kombolcha-Harbu road section

The above chart show that the rutting depth along kombolcha-Harbu road section was more damaged over 2.5km to 2.66 km of the road section. But to know the overall condition of the road intermes of rutting depth, the average value of the rutting depth was calculated from the left and right wheel path of rutting depth. For the analysis of the future condition of the pavement using HDM-4 software, the calibrated rutting value was 4.196cm. This mean rutting value show that the road was more affected rutting along those lengths of the road. Because its value was above the specification.

Table 4.1: Ratting scale parameters for rut depth (Source: Shahin and Walther, 1990)

Rutting scale	Mean rutting depth (cm)
new	O
good	<2
fair	2-5
poor	5-10
bad	>10

Therefore from the above values of rut depth the condition of pavement can be evaluated as fair condition. Because the mean rutting depth was occurred in between 2-5cm of the specification.

4.4.2 Pavement Texture depth measurement and evaluation

The texture depth was measured by laser texture measurement device that calibrated on automotive international roughness index measuring device. This device was work by measuring the distance between the sensor and the road surface. This sensor moves along the road were recorded at 100m of intervals. The scaling of texture depth was ranging from 0.1mm to 4mm which indicate 0.1mm texture depth means the road is slippery but 4mm indicate the road is not slippery means its condition is good.

Table 4.2: Average texture depth specification

Surface texture	Texture depth(mm)
Good	>0.7
Fair	0.5-0.7
poor	0.3-0.5
bad	<0.3

Therefore the average values of texture for each section of the road can be determined from the current texture condition of the road studied by ERA. This average value was calculated from the value given at the appendix-A of this study.

Table 4.3: Average texture depth calculation for kombolcha-Harbu road section

Average texture depth	Kombolcha-Habru texture depth(mm)
Texture of lane-I	0.948
Texture of lane-II	0.958
Total average depth	0.953

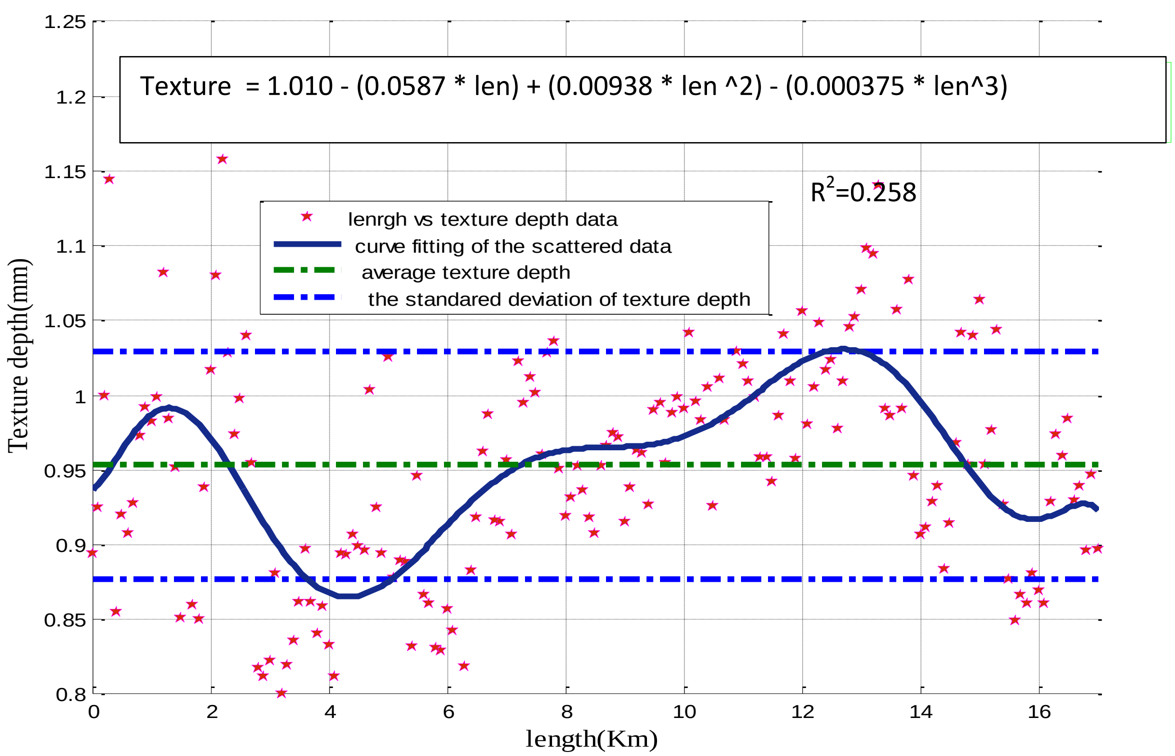

Fig.4.7: The plot of texture depth kombolcha-Harbu road section

Therefore they value of 0.953 is greater than 0.5 i.e. the road is not more slippery, because the surface roughness of the road high due to presence pavement deterioration. In general the condition of the pavement along kombolcha-Harbu road section was interpreted interims of collated equations formulated by Mathlab software. This equation was given a

4.4.3. Potholes measurement, counting and evaluation

The numbers of potholes can be counted using manual condition survey along this study area. Then the numbers of the potholes per kilometer of the road section was used as an input for HDM-4 calibrated software. Their numbers were counted from the video recorded during condition survey of the study section and also the representative potholes were measured for knowing their extent and severity. But only consider three representative potholes for measurement for 1 km of road length. Therefore; the road was classified for 17 sections which have about 1km length for each. The measured values and their numbers were given at the appendix of this study. From the measured values the total numbers potholes counted during condition survey ware about 273 No/km.

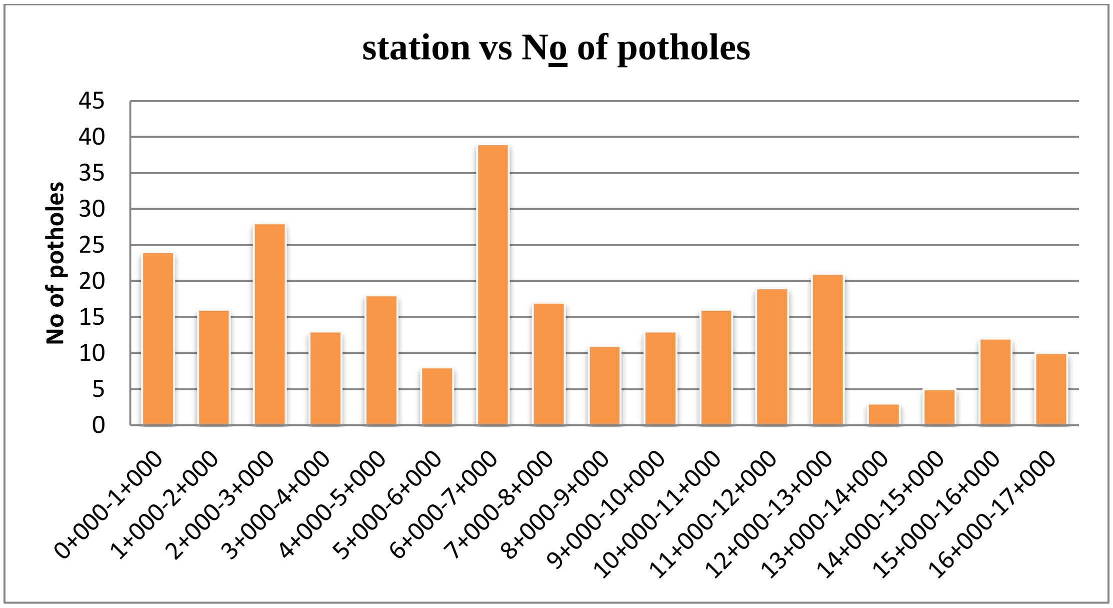

Fig.4.8: No of potholes along kombolcha-Harbu road section

From chart given on the above the road was more affected by potholes at the station of 6+000 to 7+000 and 2+000 to 3+000 road sections.

4.4.4 Edge cracking measurement and evaluation

The edge crack was measured from condtion survey of kombolcha- Harbu road section. During the assessment of this road section, the effect of edge crack on this road section was more dominant. But for the analysis of the future condition of the pavement intermes of edge cracking, measurements were taken at different section of the road. This measurement was conducted at the left and right sides of the pavement. During this measurement only consider high severity edge crack for the analysis of the future pavement condition. Therefor; the measured edge cracks were consider about around 21 points that located at different station and at both side of the road edges. The overall measured values of edge cracks were given at the appendix-A of this study.

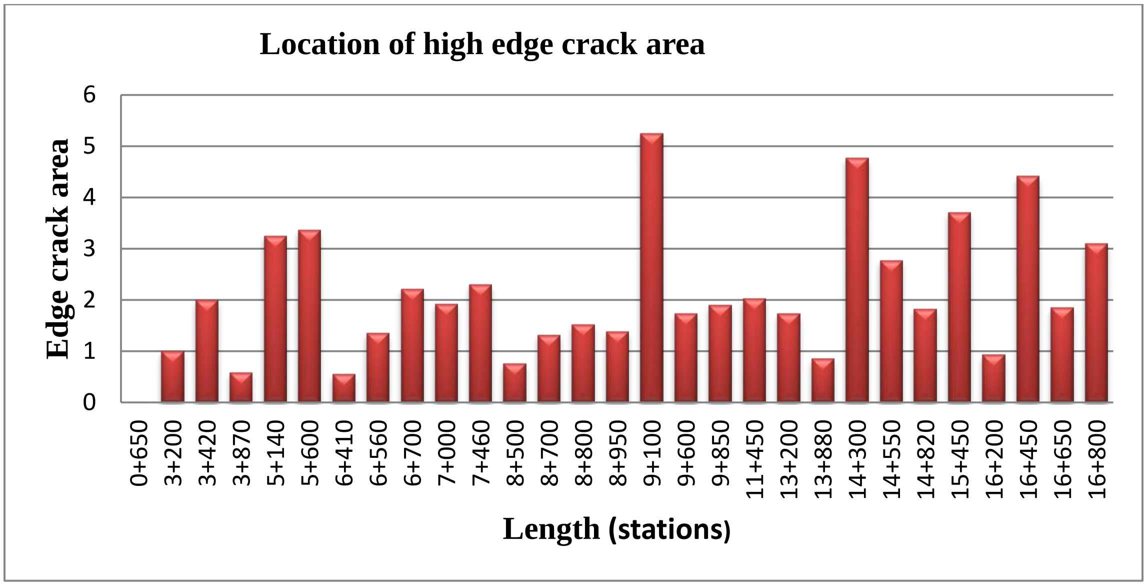

Fig.4.9: Location of dominant edge cracking area along kombolcha- Harbu road section

From the above graphical representation of measured edge crack, the dominant failures due to edge cracking were occurred at the stations of 5+140, 5+600, 9+100, 14+300, 14+550, 5+450, 16+450 and 16+800. Therefore ; for the analysis of the future condition of the pavement about the remaining service life of the pavement the only considered total edge cracking are was 60.45.

4.5 Prediction of the future pavement condition

Pavement life cycle analysis is performed depending on the current condition of road along kombolcha-Harbu road section. In this analysis only consider the pavement deterioration condition like edge crack, rutting depth, raveling, skid resistance, international roughness index within the future or remaining service life of the pavement. To analysis this parameters of pavement condition the key modeling or Software was used HDM-4 calibrated software especially at the life cycle analysis approach of the road. This life cycle analysis approach was included under program analysis of road project using application of HDM-4 calibrated software.

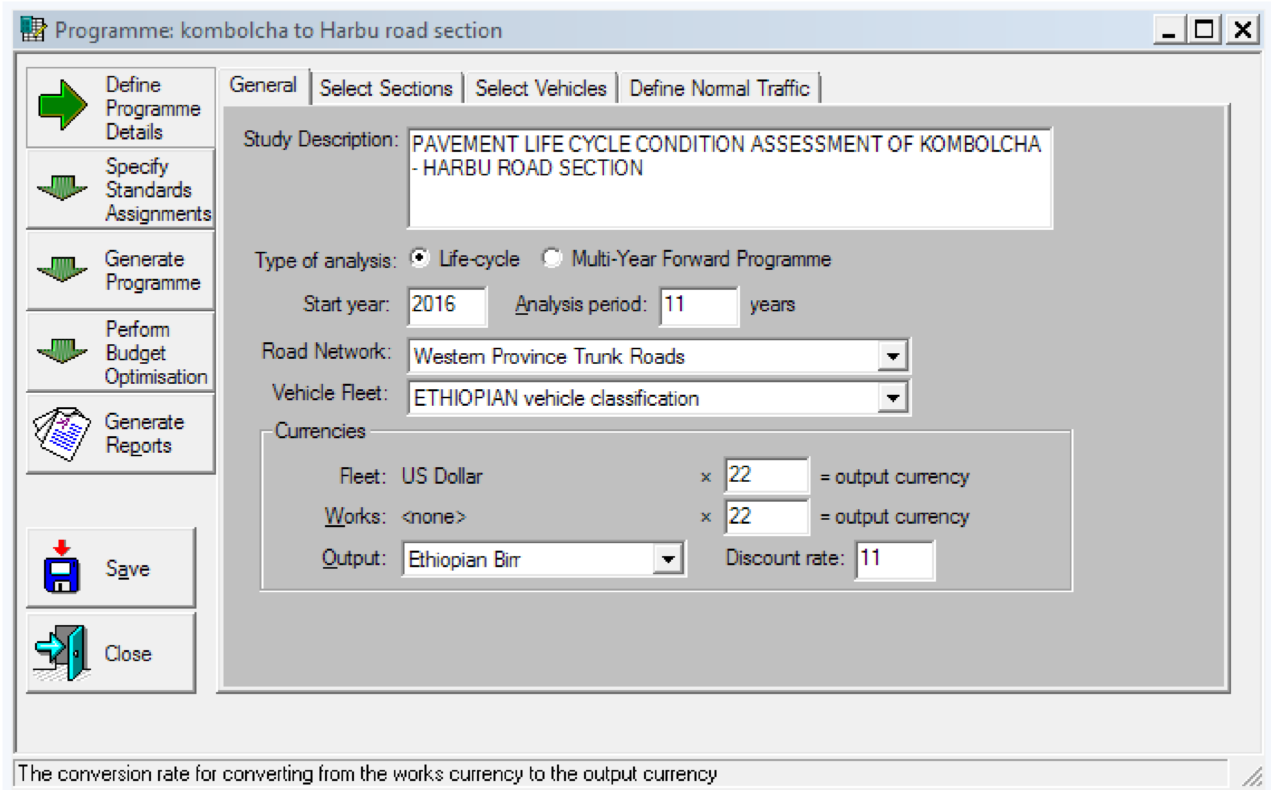

Fig. 4.10: HDM-4 lifecycle analysis window

The prediction of the remaining life condition of pavement was used to estimate the time and appropriate option of maintenance and rehabilitation. Generally this future condition of pavement was estimated depending on the current or at mid of 2016 pavement condition data. The expected output of this analysis was given at the appendix of this study. The condition for each sections of the road was discussed below.

4.5.1 Prediction of international roughness index

The future IRI condition of the pavement along this road section was represented by the sample of 17Km length of the road. From the output of HDM-4 analysis the estimated condition were international roughness index, axial loading, rutting condition, cracking area, structural numbers, edge break area, texture depth, skid resistance and also the future traffic volume also estimated by using HDM-4 software. But the focused for the first study was international roughness index which was the basic pavement performance indicator. The predicted value of the international roughness index was presented at the appendix-A of this study.

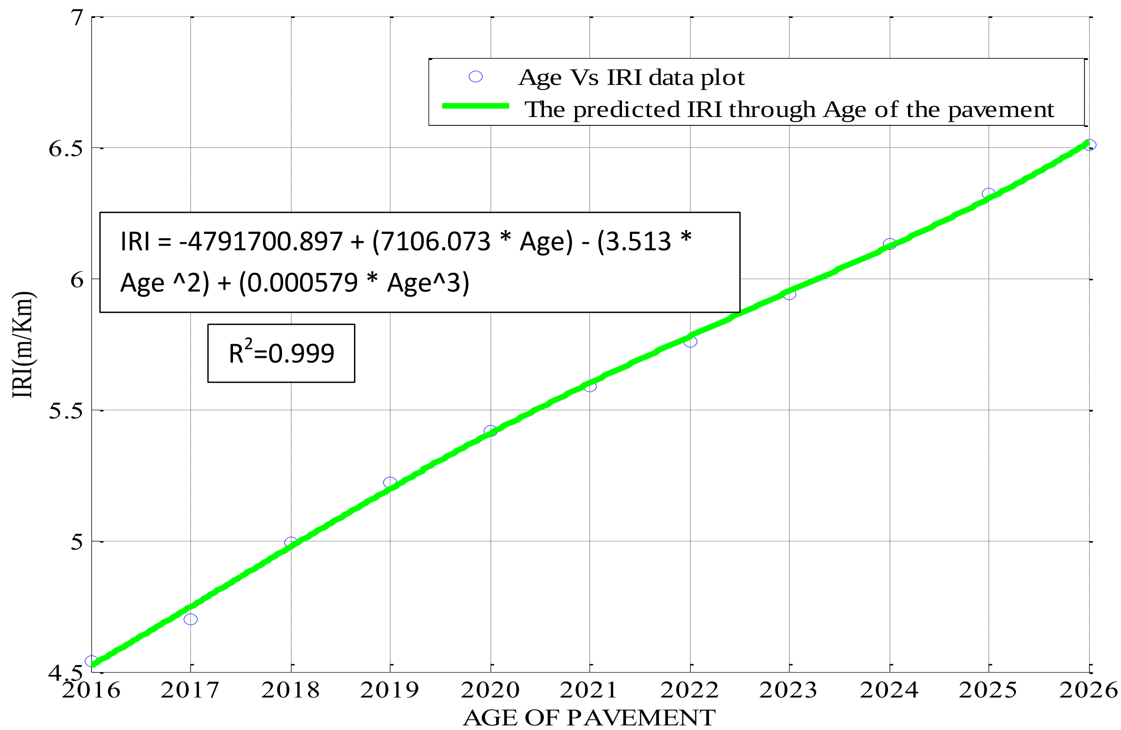

Fig.4.11: Graphical relations of the age of pavement and predicted IRI

From the above graphical representation of age of the pavement and international roughness index, the defect of the road was gradually increase throughout the age of the road.

The resulting regression analysis after correlating IRI with age is expressed by the following single polynomial equation with its corresponding correlation coefficients:

RI = -4791700.897 + (7106.073 * Age) - (3.513 * Age ^2) + (0.000579 * Age^3)…………..4.3

Where R^2=0.999

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant (P<0.05 with moderate value of R^2.

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R2 values and level of confidence is greater than 95%.

Therefore; from the predicted values of the international roughness index, at the end of the design life of the pavement, the IRI will be about 6.51m/Km i.e. the road is becomes more deteriorates throughout age. But the overall performance of the pavement at each year's design life was evaluated as:

Table 4.4: predicted IRI and recommended treatment

Years	IRI	Pavement condition	Recommended treatment/maintenance
2016	4.54	fair	patching+crack sealing
2017	4.70	fair	patching+crack sealing
2018	4.99	fair	patching+crack sealing
2019	5.22	fair	patching+crack sealing
2020	5.42	fair	patching+crack sealing
2021	5.59	fair	patching+crack sealing
2022	5.76	fair	patching+crack sealing
2023	5.94	fair	patching+crack sealing
2024	6.13	poor	thin overlay
2025	6.32	poor	thin overlay
2026	6.51	poor	thin overlay

The pavement condition was evaluated depending on the scaling given first page of the result of this study. This shows that; when IRI was in between 2.78 -5.95 and 5.95 -17.5 the condition of the pavement were fair and poor respectively. From result of this international index this road section was not failed at the end of the deign life. Because of this the service lives of road wills extend by applying thin overlay.

4.5.2 Prediction of texture depth

From the result of texture depth, the condition of pavement throughout the remaining design life was became decrease. This shows that the consistency the smoothness of the road surface is more affected by enemy the pavement and its performance is become decrease along the age.

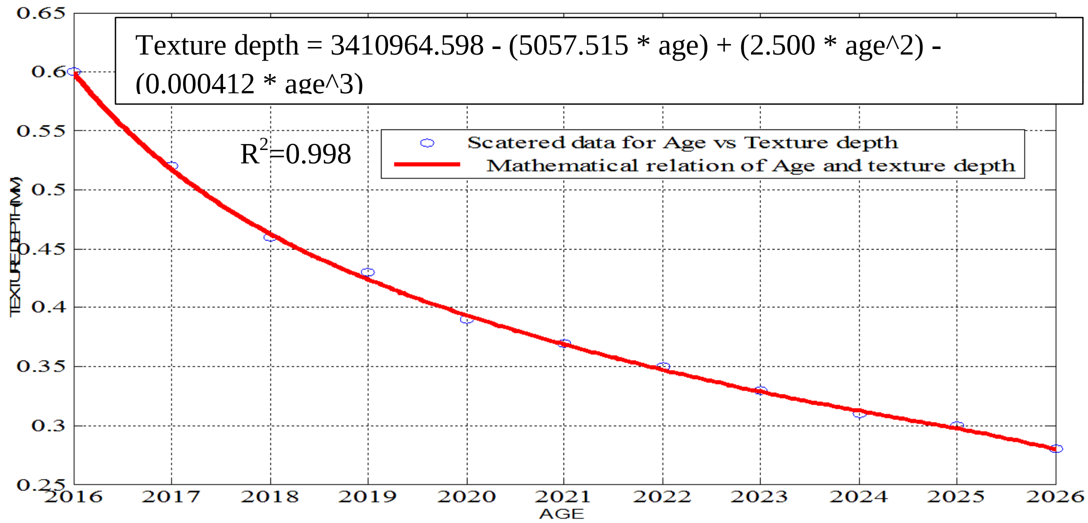

Fig.4.12: Predicted representation of average texture depth

Therefore; from texture depth specification the surface condition of the pavement throughout the remaining design life of the pavement was predicted. This predicted result was presented at the appendix of HDM-4 output.

The resulting regression analysis after correlating texture depth with age is expressed by the following single polynomial equation with its corresponding correlation coefficients:

Texture depth = 3410964.598 - (5057.515 * age) + (2.500 * age^2) - (0.000412 * age^3)

Where R^2=0.998

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant (P<0.05 with moderate value of R2.).

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R2 values and level of confidence is greater than 95%.

Table 4.5: Predicted texture depth and its condition

years	predicted texture depth(mm)	surface condition
2016	0.60	fair
2017	0.52	fair
2018	0.46	poor
2019	0.43	poor
2020	0.39	poor
2021	0.37	poor
2022	0.35	poor
2023	0.33	poor
2024	0.31	poor
2025	0.30	poor
2026	0.28	bad

4.5.3 Prediction of rutting

The rutting depth of kombolcha- Harbu road section that predicted over the remaining service life of was also became increase as the age of the pavement increase. But from this study, the rutting depth was predicted and then its condition throughout age was suggested depending on the specification.

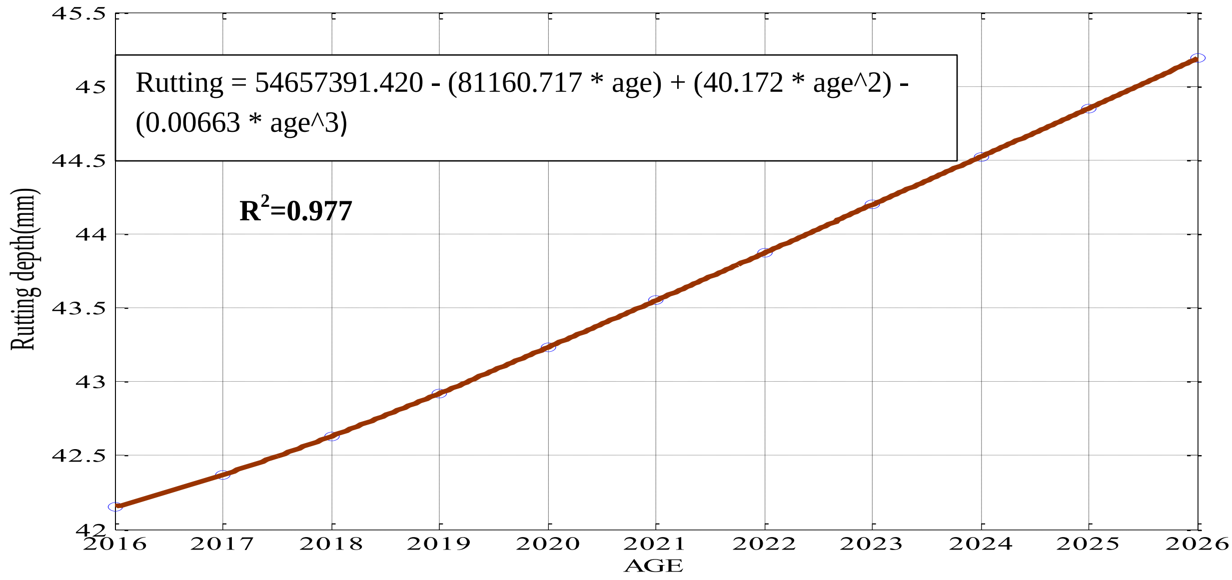

Fig.4.13: Predicted rutting depth of kombolcha-Harbu road section

The resulting regression analysis after correlating rutting depth with age is expressed by the following single polynomial equation with its corresponding correlation coefficients:

Rutting = 54657391.420 - (81160.717 * age) + (40.172 * age^2) - (0.00663 * age^3)

Where R^2=0.977

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant (P<0.05 with moderate value of R2.).

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R2 values and level of confidence is greater than 95%.

Finally the condition along the remaining service of life the pavement was evaluated using the specification. From the result of predicted rutting value given on the output of HDM-4 software, the condition of the pavement was still on the fair condition throughout the service life of the pavement.

4.5.4 Prediction of potholes

The numbers of potholes along this section of the road will gradually increase From the result of HDM-4 the numbers potholes were range from 291 to 505 at 2016 and 2026 respectively.

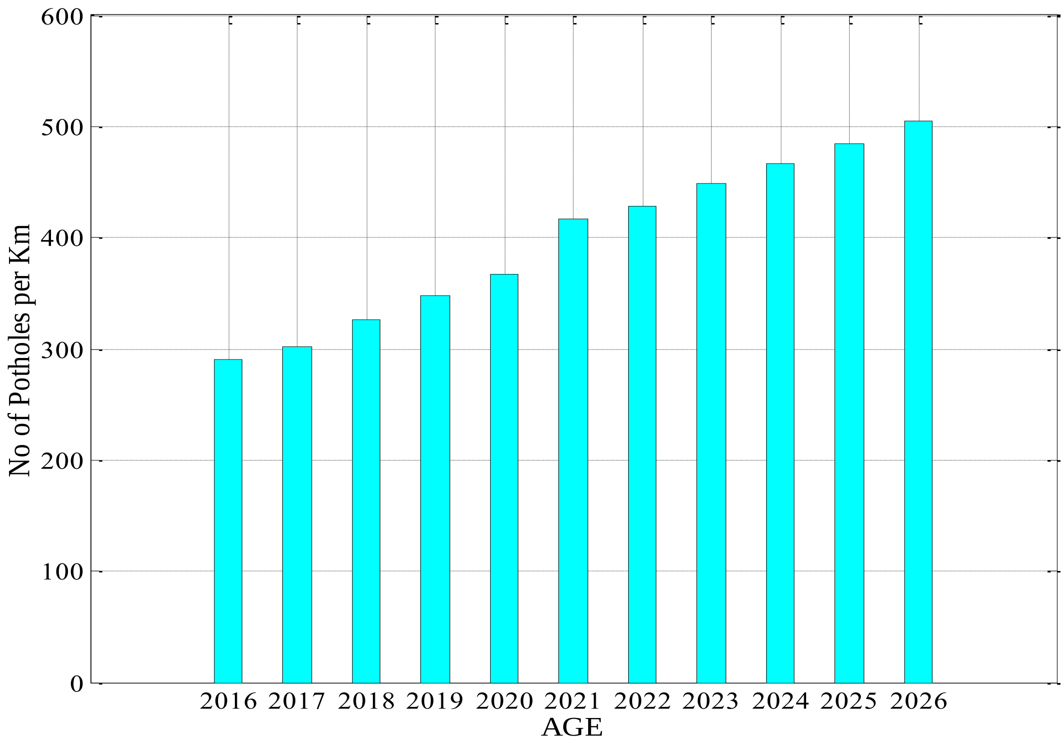

Fig.4.13: The predicted numbers of potholes for kombolcha-Harbu road section

4.5.5 Prediction of edge cracking area

The area of the predicted cracking area was also determined by HDM-4 calibrated software.

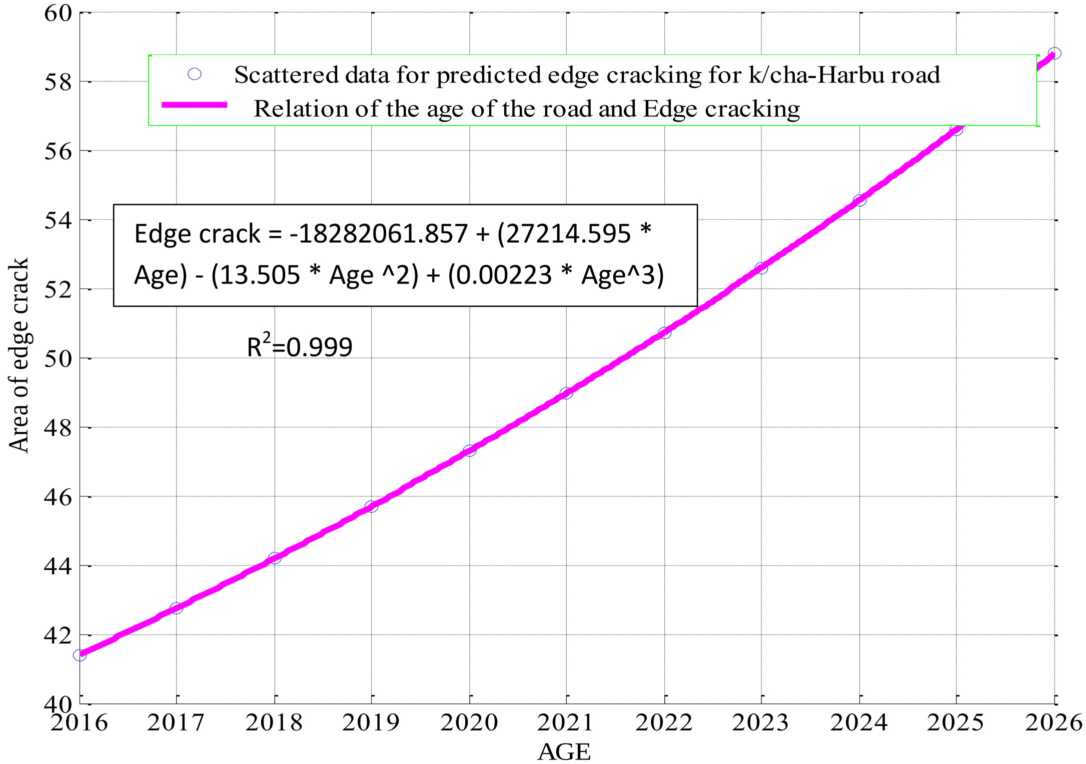

Fig.4.14: Area of edge crack along the age of the pavement

The resulting regression analysis after correlating cracking area with age is expressed by the following single polynomial equation with its corresponding correlation coefficients:

Edge crack = -18282061.857 + (27214.595 * Age) - (13.505 * Age ^2) + (0.00223 * Age^3)

Where R^2=0.999

The details of the above statistical out-put indicates that the relationship developed between IRI and PSI is significant (P<0.05 with moderate value of R2.).

From the resut of regression out put given at appendix-B of this study shows that the two variables were strogly related. Because their R2 values and level of confidence is greater than 95%.

CHAPTER FIVE

Conclusion and recommendation

5.1 General

To execute a Pavement Management System (PMS) of a road network and to predict future pavement performance using HDM-4 calibrated software under project life cycle analysis, it is necessary to have sufficient, accurate, reliable, consistent and timely information. Generally the conclusion and recommendation of this study was explained for Kombolcha –Harbu link road.

5.2 conclusions

The final result of this pavement performance evaluation and prediction under life cycle analysis listed as follow;

- The condition of the existing pavement interims of the international roughness index was evaluated as fair condition. Because the IRI value 4.24 m/Km was occurred between 2.87 and 5.95.
- The average rutting value for kombolcha-Habru road section was about 4.196cm. From this value, the condition of pavement can be evaluated as fair condition. Because the mean rutting depth was occurred in between 2-5cm of the specification.
- The average texture depth for kombolcha-Habru road section was 0.953mm, which indicates the condition of pavement was good and not more slippery; because the average value is greater than 0.7mm of the specification.
- The pavement performance evaluation index like present serviceability index was calculated as 4.052. From the result of present serviceability index the average values, the serviceability of this road section was very good.
- The alternatives that selected for maintenances of this road in terms of the future conditions of the pavements were periodic maintenance (patching and crack sealing) and at the end of the design life rehabilitation (thin-overlay) are appropriate.

5.3 Recommendations

From the analysis of the pavement performance and life cycle analysis, the following recommendations were given:

For ERA

- For proper maintenance and cost effective pavement treatment, the future annual pavement condition in terms of all performance evaluating indexes like; IRI PCI and PSI should be forecasted or measured.
- In order to properly use HDM-4 software for pavement management, all deterioration condition and factors should be calibrated in case of Ethiopian condition.
- The equations of pavement performance evaluating index should be formulated intermes all distresses type which were dominant in case of Ethiopia condition.
- The selection of maintenance option in terms of performance condition was better than that of engineering experienced; for appropriate fund allocation and educates pavement preservation along the remaining service life.
- By using the present and future conditions of the pavement, timely maintenance should be applied.

Reference

[1] AASHTO (1985). Guidelines on Pavement Management, American Association of State Highway and Transportation Officials. Washington, D.C.

[2] Pavement Management System Development. National Cooperative Highway Research Program Report 215: NCHRP, TRB, National Research Council. Washington, D.C.

[3] Pavement management systems. A report prepared by the OECD scientific expert group. OECD, Paris, 1987.

[4] AASHTO (1993). AASHTO Guide for Design of Pavement structures. American Association of State Highway and Transportation Officials, Washington D.C.

[5] Kyendo, M., (1991).Flexible Road Pavement Performance and Maintenance Studies. Thesis for fulfillment of Master of Science in Civil Engineering, University of Nairobi.

[6] Sayers, M. W., Gillespie, T. D., and Queiroz, C. A. V. 1986. "International experiment to establish correlations and standard calibration methods for road roughness measurements." . World Bank Technical Paper, No. 45. The World Bank, Washington, D.C

[7] FHWA. 1999. Asset Management Primer. Office of Asset Management, Federal Highway Administration, U.S. Department of transportation, Washington D.C.

[8] AASHTO (1993). AASHTO Guide for Design of Pavement structures. American Associationof State Highway and Transportation Officials, Washington D.C.

[9] Al-Omari, B. And M.I. Darter (1992): Relationships between IRI and PSR. Report NumberUILU-ENG-92-2013. Springfield, IL: Illinois Department of Transportation.

[10] Quality Management Plan for Data Collection. ERA, November 2011

[11] http://www.google.com/url?q=http://www.state.nj.us/transportation/eng/pavement/pdf/PMS Overviews0709.pdf&sa=U&ved=0ahUKEwj6i22qMvRAhUlAsAKHZzODosQFggpMA Wgx9M04UYghH2O2NCy6Piw&usg=AFQjCNFg4fJnPsUEfUHBn0pb-N0fPVzzHA

[12] Shah Y. U., Jain S.S., Jain M. K. and Tiwari Devesh entitled "Pavement Maintenance Management System for Urban Arterial Roads – A Case Study using HDM-4" published in the Proceedings of International Conference on Highway Engineering2012, held at CentaraL Grand Hotel Bangkok, Thailand, 18-20 April, 2012, pg. 339 –345

[13] Edward Fekpe and Nii O. Attoh-Okine (1995). "Deterioration modeling for lateritic base flexible pavements", Construction and Building Materials 1995 Volume 9 Numb 3, Great Britain

[14] Bennett, C.R., Paterson, W.D.O. 2000. A guide to the calibration and adaptation. HDM - 4. Volume 5. The Highway Development and Management Series. PIARC.

[15] Aggarwal, S. (2003). "Development of pavement Management system for Indian National Highway Network", PhD. Thesis, Indian institute of technology Roorkee,

[16] Wang, Z 2000, 'Formulation and Assessment of A Customizable Procedure for Pavement Distress Index', Doctor of Philosophy Degree, University of Tennessee, Knoxvill

[17] Skok, G., Labuz, J., Westover, T., Dai, S., Lukanen, E., Pavement Rehabilitation Selection, Local Road Research Board, INV-808, 2008.

[18] Sotil, A., & Kaloush, K. (2004). "Development of Pavement Performance Models for DelhiTownship, Ohio Pavement management System." Compendium of Papers CD-ROM, 73. Meeting of the Transportation Research Board, National Research Council, Washington, D

[19] Kerali, H. R., Robinson, R., & Paterson, W. D. O. (1998). Role of the New HDM-4 in Highway Management. 4th International Conference on Managing Pavements, 1-14. Retrieved August 23,2016, from http://pavementmanagement.org/ICMPfiles/1998047.PDF

[20] Odoki, J.B., Kerali H.G.R (2000). Highway Development and Management Series: Volume 4-Analytical Framework and Model Description. World Roads Association (PIARC), Paris and the World Bank, Washington DC.

[21] Labi, S., Sinha K. C. (2005). Life-Cycle Evaluation of Flexible Pavement Preventive Maintenance, American Society of Civil Engineers (ASCE), Journal of Transportation . Engineering. 131(10): 744-751

[22] Baladi G. Y., Novak E. C., and Kuo W. H. (1992).Pavement Condition Index - Technical Remaining Service Life, American Association for Testing and Materials (ASTM), Special Publication (STP), Atlantic City. 112(1): 63-90

[23] The world Bank 1988, 'Road Deterioration and Maintenance Effects, Models for Planningand Management', The World Bank, Paterson, Washington, DC.

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

[25] ERA. Ethiopian Roads Authority Standard Manuals. Pavement Design Manual: Flexible Pavements and Gravel Roads,Volume I. 2002.

Appendix-A

Table A: international roughness index for kombolcha-Harbu road section

Distance (km)	IRI Right	IRI Left	IRI Avg	Speed (km/h)	Easting (m)	Northing (m)	Zone	Hemisphere
0.1	4.18	4.89	4.535	41.2	597728	1104184	37	N
0.2	3.97	3.73	3.85	47.5	597781	1104268	37	N
0.3	3.16	3.28	3.22	50.9	597831	1104356	37	N
0.4	3.08	2.71	2.895	45.9	597857	1104452	37	N
0.5	3.19	3.1	3.145	41.9	597881	1104547	37	N
0.6	3.48	3.21	3.345	51.1	597902	1104644	37	N
0.7	3.16	3.13	3.145	57.7	597920	1104740	37	N
0.8	3	3.13	3.065	58.3	597945	1104838	37	N
0.9	3.29	3.39	3.34	46.9	597974	1104934	37	N
1	3.22	2.99	3.105	41.7	598055	1104990	37	N
1.1	3.79	3.02	3.405	34.3	598144	1105040	37	N
1.2	2.88	3.17	3.025	38.3	598230	1105088	37	N
1.3	3.51	3.68	3.595	34.8	598316	1105137	37	N
1.4	7.72	7.91	7.815	24.3	598404	1105188	37	N
1.5	3.68	6.03	4.855	23.8	598484	1105239	37	N
1.6	4.86	4.52	4.69	26.3	598467	1105332	37	N
1.7	6.89	8.04	7.465	21.9	598425	1105421	37	N
1.8	4.13	4.33	4.23	37.4	598396	1105516	37	N
1.9	4.18	3.53	3.855	36	598427	1105608	37	N
2	3.29	3.14	3.215	35.4	598500	1105675	37	N
2.1	3.22	3.16	3.19	32.3	598579	1105739	37	N
2.2	3.58	3.04	3.31	32.5	598652	1105804	37	N
2.3	3.07	3.16	3.115	40.9	598731	1105866	37	N
2.4	3.09	3.17	3.13	33.5	598807	1105929	37	N
2.5	3.49	3.83	3.66	26.7	598882	1105993	37	N
2.6	2.98	3.16	3.07	43.6	598959	1106054	37	N
2.7	2.92	3.36	3.14	51.2	599035	1106118	37	N
2.8	3.08	2.97	3.025	56.2	599111	1106183	37	N
2.9	3.04	3.15	3.095	55.8	599186	1106247	37	N
3	2.97	2.57	2.77	61.3	599263	1106310	37	N
3.1	2.65	2.3	2.475	63.5	599339	1106374	37	N
3.2	2.74	2.43	2.585	64.3	599413	1106438	37	N
3.3	3.17	2.81	2.99	64.9	599491	1106502	37	N
3.4	2.84	2.61	2.725	58.5	599568	1106567	37	N
3.5	3.05	2.72	2.885	54.4	599643	1106630	37	N

3.6	3.52	2.78	3.15	50	599719	1106695	37	N
3.7	3.94	3.13	3.535	49.1	599794	1106758	37	N
3.8	4.83	3.91	4.37	56.9	599870	1106822	37	N
3.9	3.27	3.11	3.19	62.5	599946	1106884	37	N
4	3.85	3.09	3.47	66	600029	1106935	37	N
4.1	3.92	3.34	3.63	48.3	600126	1106971	37	N
4.2	3.45	2.88	3.165	35.1	600217	1107003	37	N
4.3	2.6	2.59	2.595	53.5	600308	1107035	37	N
4.4	3	2.49	2.745	68.6	600401	1107066	37	N
4.5	3.02	2.5	2.76	73.9	600495	1107100	37	N
4.6	3.17	2.93	3.05	69.9	600589	1107135	37	N
4.7	3.09	3.03	3.06	66.6	600675	1107185	37	N
4.8	3.63	2.97	3.3	67.1	600753	1107247	37	N
4.9	4.69	4.14	4.415	58	600832	1107310	37	N
5	2.93	2.82	2.875	50.2	600907	1107371	37	N
5.1	2.86	2.97	2.915	62.2	600984	1107432	37	N
5.2	2.96	2.67	2.815	65.5	601062	1107493	37	N
5.3	2.82	2.76	2.79	67.8	601140	1107554	37	N
5.4	3.07	3.47	3.27	69.1	601219	1107616	37	N
5.5	2.8	2.84	2.82	71.6	601297	1107677	37	N
5.6	3.14	3.31	3.225	73.8	601375	1107739	37	N
5.7	2.92	2.86	2.89	73.4	601453	1107799	37	N
5.8	2.62	2.78	2.7	73.8	601529	1107860	37	N
5.9	2.68	3.02	2.85	73.7	601607	1107922	37	N
6	3.34	3.49	3.415	67	601682	1107987	37	N
6.1	3.28	3.55	3.415	51.8	601719	1108082	37	N
6.2	5.67	8.36	7.015	23.9	601742	1108173	37	N
6.3	3.22	3.03	3.125	48.9	601792	1108260	37	N
6.4	3.57	2.99	3.28	57.7	601849	1108338	37	N
6.5	3.35	2.88	3.115	66	601910	1108418	37	N
6.6	3.02	2.59	2.805	63.4	601967	1108500	37	N
6.7	3.21	2.81	3.01	71.9	602028	1108577	37	N
6.8	2.71	2.43	2.57	79.8	602087	1108657	37	N
6.9	3.17	2.4	2.785	77.7	602146	1108736	37	N
7	3.62	3.06	3.34	73.1	602206	1108817	37	N
7.1	3.43	2.9	3.165	68	602266	1108897	37	N
7.2	2.87	2.72	2.795	61.8	602305	1108988	37	N
7.3	2.62	2.54	2.58	62.1	602315	1109087	37	N
7.4	2.98	2.72	2.85	62.6	602327	1109184	37	N

7.5	3.05	2.63	2.84	60.6	602377	1109267	37	N
7.6	3.04	2.79	2.915	60.8	602438	1109347	37	N
7.7	3.07	2.73	2.9	61.2	602496	1109428	37	N
7.8	3.23	2.87	3.05	61.4	602533	1109519	37	N
7.9	3.44	2.65	3.045	65.8	602566	1109612	37	N
8	2.83	2.5	2.665	73	602599	1109705	37	N
8.1	3.32	3.02	3.17	74.3	602632	1109798	37	N
8.2	3.33	2.59	2.96	74.4	602671	1109887	37	N
8.3	3.29	2.77	3.03	74.5	602727	1109970	37	N
8.4	2.94	2.5	2.72	75.2	602785	1110051	37	N
8.5	3.15	2.86	3.005	74.5	602842	1110133	37	N
8.6	3.59	3.12	3.355	74.5	602899	1110213	37	N
8.7	3.47	3.1	3.285	74.5	602957	1110294	37	N
8.8	3.39	2.79	3.09	74.7	603015	1110376	37	N
8.9	3.14	2.55	2.845	75	603073	1110458	37	N
9	3.11	2.61	2.86	75	603130	1110539	37	N
9.1	3.96	3.53	3.745	74.9	603187	1110620	37	N
9.2	3.77	3.23	3.5	74.6	603245	1110700	37	N
9.3	3.44	3.12	3.28	74.4	603302	1110781	37	N
9.4	3.07	2.67	2.87	74.3	603359	1110863	37	N
9.5	3.17	2.65	2.91	73.9	603416	1110943	37	N
9.6	3.36	2.87	3.115	73.5	603473	1111024	37	N
9.7	3.69	2.73	3.21	73.4	603530	1111105	37	N
9.8	3.33	2.86	3.095	73.3	603588	1111187	37	N
9.9	3.07	2.44	2.755	73.2	603645	1111268	37	N
10	3.61	2.84	3.225	72.6	603701	1111348	37	N
10.1	3.29	2.98	3.135	72.5	603759	1111429	37	N
10.2	3.78	3.01	3.395	72.4	603815	1111510	37	N
10.3	3.59	3.62	3.605	69.6	603871	1111592	37	N
10.4	3.68	2.9	3.29	62	603930	1111672	37	N
10.5	4.33	3.58	3.955	63.8	603987	1111755	37	N
10.6	4.56	3.9	4.23	63.5	604055	1111824	37	N
10.7	4.16	3.55	3.855	65.7	604143	1111868	37	N
10.8	3.41	2.69	3.05	65.2	604241	1111890	37	N
10.9	3.32	2.97	3.145	67	604326	1111939	37	N
11	3.16	2.75	2.955	69.5	604384	1112021	37	N
11.1	2.99	2.74	2.865	65.8	604437	1112104	37	N
11.2	3.75	3.17	3.46	67.3	604519	1112154	37	N
11.3	2.95	2.41	2.68	73.4	604609	1112195	37	N

11.4	2.97	2.53	2.75	72.5	604699	1112238	37	N
11.5	3.33	2.83	3.08	69.9	604789	1112282	37	N
11.6	2.98	2.73	2.855	66.6	604879	1112326	37	N
11.7	2.91	2.67	2.79	66.7	604950	1112394	37	N
11.8	2.74	2.38	2.56	72.8	605015	1112468	37	N
11.9	3	2.67	2.835	76.6	605081	1112543	37	N
12	3.19	2.67	2.93	75.1	605147	1112616	37	N
12.1	3.79	2.9	3.345	71.9	605214	1112692	37	N
12.2	3.34	2.88	3.11	56.6	605278	1112766	37	N
12.3	3.05	2.78	2.915	65.4	605344	1112838	37	N
12.4	3.23	2.93	3.08	74.3	605410	1112912	37	N
12.5	2.87	2.85	2.86	76.1	605477	1112985	37	N
12.6	3.41	2.88	3.145	75.1	605543	1113060	37	N
12.7	3.76	3.75	3.755	75.7	605609	1113134	37	N
12.8	3.3	3.33	3.315	75.5	605677	1113209	37	N
12.9	3.35	3.15	3.25	74.9	605741	1113283	37	N
13	2.6	2.82	2.71	74.9	605807	1113356	37	N
13.1	3.3	2.66	2.98	74.9	605873	1113430	37	N
13.2	3.08	2.7	2.89	74.6	605939	1113504	37	N
13.3	3.59	3.52	3.555	74.5	605989	1113589	37	N
13.4	4.19	3.37	3.78	74.6	606029	1113680	37	N
13.5	4.29	3.48	3.885	74.4	606067	1113771	37	N
13.6	3.3	2.98	3.14	75	606106	1113863	37	N
13.7	3.05	2.72	2.885	74.8	606148	1113954	37	N
13.8	4.07	4.19	4.13	75	606187	1114044	37	N
13.9	3.89	3.71	3.8	74.7	606229	1114135	37	N
14	2.84	2.78	2.81	74.4	606268	1114225	37	N
14.1	2.73	2.92	2.825	74.6	606307	1114316	37	N
14.2	2.85	2.8	2.825	74.7	606347	1114407	37	N
14.3	2.96	2.68	2.82	74.5	606387	1114497	37	N
14.4	3.23	2.99	3.11	73.4	606427	1114589	37	N
14.5	2.98	2.77	2.875	73.8	606466	1114679	37	N
14.6	2.81	2.9	2.855	74.6	606504	1114771	37	N
14.7	2.74	2.88	2.81	75	606532	1114866	37	N
14.8	3.43	3.17	3.3	74.6	606558	1114961	37	N
14.9	2.8	2.71	2.755	74.4	606585	1115057	37	N
15	3.03	2.79	2.91	74.6	606620	1115149	37	N
15.1	3.35	3.16	3.255	73.5	606664	1115239	37	N
15.2	3.11	3.09	3.1	72.5	606724	1115316	37	N

15.3	3.42	3.25	3.335	64.1	606770	1115404	37	N
15.4	3.58	3.57	3.575	60.4	606768	1115502	37	N
15.5	3.54	3.34	3.44	62.3	606778	1115600	37	N
15.6	2.84	3.22	3.03	66.3	606792	1115699	37	N
15.7	2.88	3.2	3.04	66.4	606808	1115797	37	N
15.8	2.64	3.12	2.88	68.1	606831	1115893	37	N
15.9	3.12	3.08	3.1	67.2	606869	1115984	37	N
16	3.25	3.02	3.135	63.9	606926	1116065	37	N
16.1	3.06	3.13	3.095	60.1	606975	1116152	37	N
16.2	3.11	3.09	3.1	58.4	607017	1116241	37	N
16.3	3.64	3.3	3.47	45.5	607090	1116306	37	N
16.4	4.08	5.57	4.825	43.7	607087	1116402	37	N
16.5	2.88	3.28	3.08	51	607003	1116450	37	N
16.6	3.64	3.13	3.385	58.9	606909	1116487	37	N
16.7	3.25	3.08	3.165	60.4	606847	1116564	37	N
16.8	2.75	2.76	2.755	59.8	606796	1116649	37	N
16.9	2.63	2.62	2.625	54.5	606746	1116734	37	N
17	2.68		2.68	51.1	606700	1116822	37	N

Lane two

Distance (km)	IRI Right	IRI Left	IRI Avg	Speed (km/h)	Easting (m)	Northing (m)	Zone	Hemisphere
0.1	1.6	2.9	1.5	28.2	580755	1225470	37	N
0.2	1.7	3	1.6	37.5	580769	1225370	37	N
0.3	1.8	3.1	1.7	38	580774	1225271	37	N
0.4	1.9	3.2	1.8	42.4	580779	1225171	37	N
0.5	2	3.3	1.9	40.7	580780	1225071	37	N
0.6	2.1	3.4	2	44.1	580782	1224972	37	N
0.7	2.2	3.5	2.1	43.3	580784	1224872	37	N
0.8	2.3	3.6	2.2	41.9	580786	1224771	37	N
0.9	2.4	3.7	2.3	42.6	580788	1224673	37	N
1	2.5	3.8	2.4	44.4	580775	1224574	37	N
1.1	2.6	3.9	2.5	45.6	580744	1224480	37	N
1.2	2.7	4	2.6	47.8	580697	1224391	37	N
1.3	2.8	4.1	2.7	46.9	580662	1224299	37	N
1.4	2.9	4.2	2.8	48.7	580647	1224199	37	N
1.5	3	4.3	2.9	50.7	580647	1224099	37	N
1.6	3.1	4.4	3	47.3	580651	1223999	37	N
1.7	3.2	4.5	3.1	42.3	580654	1223898	37	N
1.8	3.3	4.6	3.2	38.6	580657	1223799	37	N

1.9	3.4	4.7	3.3	36.5	580659	1223700	37	N
2	3.5	4.8	3.4	38.1	580662	1223601	37	N
2.1	3.6	4.9	3.5	47	580665	1223501	37	N
2.2	3.7	5	3.6	47.1	580668	1223401	37	N
2.3	3.8	5.1	3.7	49.3	580671	1223302	37	N
2.4	3.9	5.2	3.8	48	580673	1223202	37	N
2.5	4	5.3	3.9	43.6	580658	1223102	37	N
2.6	4.1	5.4	4	51.1	580659	1223005	37	N
2.7	4.2	5.5	4.1	57	580657	1222904	37	N
2.8	4.3	5.6	4.2	54.3	580708	1222819	37	N
2.9	4.4	5.7	4.3	56.7	580758	1222733	37	N
3	4.5	5.8	4.4	50.9	580841	1222682	37	N
3.1	4.6	5.9	4.5	51.3	580941	1222682	37	N
3.2	4.7	6	4.6	54.2	581042	1222687	37	N
3.3	4.8	6.1	4.7	46	581144	1222688	37	N
3.4	4.9	6.2	4.8	31.4	581206	1222631	37	N
3.5	5	6.3	4.9	44.4	581222	1222532	37	N
3.6	5.1	6.4	5	50	581236	1222432	37	N
3.7	5.2	6.5	5.1	50.8	581257	1222334	37	N
3.8	5.3	6.6	5.2	53.3	581297	1222243	37	N
3.9	5.4	6.7	5.3	53.6	581335	1222150	37	N
4	5.5	6.8	5.4	51.3	581372	1222056	37	N
4.1	5.6	6.9	5.5	50.5	581410	1221965	37	N
4.2	5.7	7	5.6	51.7	581448	1221872	37	N
4.3	5.8	7.1	5.7	48.7	581487	1221780	37	N
4.4	5.9	7.2	5.8	40.4	581527	1221688	37	N
4.5	6	7.3	5.9	3.3	581562	1221600	37	N
4.6	6.1	7.4	6	40.9	581601	1221506	37	N
4.7	6.2	7.5	6.1	37.6	581639	1221413	37	N
4.8	6.3	7.6	6.2	45.7	581677	1221322	37	N
4.9	6.4	7.7	6.3	47.2	581721	1221230	37	N
5	6.5	7.8	6.4	51	581791	1221160	37	N
5.1	6.6	7.9	6.5	56.7	581876	1221105	37	N
5.2	6.7	8	6.6	63.2	581938	1221030	37	N
5.3	6.8	8.1	6.7	74.2	581956	1220933	37	N
5.4	6.9	8.2	6.8	76	581978	1220835	37	N
5.5	7	8.3	6.9	74.5	582028	1220748	37	N
5.6	7.1	8.4	7	74.4	582091	1220669	37	N
5.7	7.2	8.5	7.1	73.5	582154	1220590	37	N

5.8	7.3	8.6	7.2	73.3	582197	1220502	37	N
5.9	7.4	8.7	7.3	73	582202	1220403	37	N
6	7.5	8.8	7.4	73.3	582198	1220303	37	N
6.1	7.6	8.9	7.5	74.6	582192	1220203	37	N
6.2	7.7	9	7.6	75.1	582189	1220104	37	N
6.3	7.8	9.1	7.7	74.9	582185	1220004	37	N
6.4	7.9	9.2	7.8	74.7	582181	1219904	37	N
6.5	8	9.3	7.9	74.4	582178	1219806	37	N
6.6	8.1	9.4	8	69.1	582175	1219704	37	N
6.7	8.2	9.5	8.1	57.5	582170	1219605	37	N
6.8	8.3	9.6	8.2	60.7	582184	1219507	37	N
6.9	8.4	9.7	8.3	65.1	582217	1219413	37	N
7	8.5	9.8	8.4	66.5	582258	1219321	37	N
7.1	8.6	9.9	8.5	66.3	582297	1219230	37	N
7.2	8.7	10	8.6	67.3	582337	1219139	37	N
7.3	8.8	10.1	8.7	67.9	582376	1219047	37	N
7.4	8.9	10.2	8.8	66.5	582410	1218953	37	N
7.5	9	10.3	8.9	63.5	582424	1218854	37	N
7.6	9.1	10.4	9	62.4	582420	1218754	37	N
7.7	9.2	10.5	9.1	62.8	582413	1218655	37	N
7.8	9.3	10.6	9.2	63.1	582406	1218556	37	N
7.9	9.4	10.7	9.3	44.4	582400	1218452	37	N
8	9.5	10.8	9.4	30.2	582388	1218355	37	N
8.1	9.6	10.9	9.5	50.9	582343	1218269	37	N
8.2	9.7	11	9.6	57.2	582286	1218189	37	N
8.3	9.8	11.1	9.7	58.1	582246	1218097	37	N
8.4	9.9	11.2	9.8	61.6	582258	1217998	37	N
8.5	10	11.3	9.9	63.6	582296	1217905	37	N
8.6	10.1	11.4	10	62.1	582333	1217812	37	N
8.7	10.2	11.5	10.1	60.4	582371	1217719	37	N
8.8	10.3	11.6	10.2	63.2	582410	1217628	37	N
8.9	10.4	11.7	10.3	65.4	582449	1217536	37	N
9	10.5	11.8	10.4	65	582486	1217443	37	N
9.1	10.6	11.9	10.5	64.2	582522	1217350	37	N
9.2	10.7	12	10.6	62.1	582545	1217252	37	N
9.3	10.8	12.1	10.7	58.4	582553	1217153	37	N
9.4	10.9	12.2	10.8	35.5	582560	1217049	37	N
9.5	11	12.3	10.9	24.9	582565	1216956	37	N
9.6	11.1	12.4	11	51.2	582573	1216856	37	N

9.7	11.2	12.5	11.1	47.1	582582	1216756	37	N
9.8	11.3	12.6	11.2	53.2	582590	1216658	37	N
9.9	11.4	12.7	11.3	65.2	582599	1216560	37	N
10	11.5	12.8	11.4	69.8	582612	1216460	37	N
10.1	11.6	12.9	11.5	70.1	582643	1216365	37	N
10.2	11.7	13	11.6	71	582682	1216274	37	N
10.3	11.8	13.1	11.7	70.5	582720	1216181	37	N
10.4	11.9	13.2	11.8	67.2	582760	1216091	37	N
10.5	12	13.3	11.9	68.7	582799	1215999	37	N
10.6	12.1	13.4	12	67.4	582838	1215907	37	N
10.7	12.2	13.5	12.1	67.4	582877	1215815	37	N
10.8	12.3	13.6	12.2	68	582917	1215723	37	N
10.9	12.4	13.7	12.3	69	582955	1215631	37	N
11	12.5	13.8	12.4	67.1	582977	1215533	37	N
11.1	12.6	13.9	12.5	64.2	582951	1215437	37	N
11.2	12.7	14	12.6	63.7	582913	1215344	37	N
11.3	12.8	14.1	12.7	63.8	582887	1215248	37	N
11.4	12.9	14.2	12.8	64.8	582906	1215150	37	N
11.5	13	14.3	12.9	65.6	582938	1215056	37	N
11.6	13.1	14.4	13	61.6	582989	1214970	37	N
11.7	13.2	14.5	13.1	59.2	583077	1214927	37	N
11.8	13.3	14.6	13.2	60	583176	1214927	37	N
11.9	13.4	14.7	13.3	61.1	583277	1214929	37	N
12	13.5	14.8	13.4	60.1	583378	1214932	37	N
12.1	13.6	14.9	13.5	58.2	583476	1214922	37	N
12.2	13.7	15	13.6	58.7	583555	1214863	37	N
12.3	13.8	15.1	13.7	57.5	583624	1214791	37	N
12.4	13.9	15.2	13.8	57.5	583720	1214781	37	N
12.5	14	15.3	13.9	25.6	583823	1214787	37	N
12.6	14.1	15.4	14	33.4	583911	1214753	37	N
12.7	14.2	15.5	14.1	44.8	583954	1214667	37	N
12.8	14.3	15.6	14.2	55.1	583972	1214568	37	N
12.9	14.4	15.7	14.3	59	583990	1214470	37	N
13	14.5	15.8	14.4	63	584008	1214370	37	N
13.1	14.6	15.9	14.5	59.2	584028	1214272	37	N
13.2	14.7	16	14.6	64	584046	1214174	37	N
13.3	14.8	16.1	14.7	65.2	584065	1214075	37	N
13.4	14.9	16.2	14.8	62.8	584090	1213977	37	N
13.5	15	16.3	14.9	63.8	584159	1213908	37	N

13.6	15.1	16.4	15	61	584245	1213858	37	N
13.7	15.2	16.5	15.1	63.9	584285	1213768	37	N
13.8	15.3	16.6	15.2	64.1	584297	1213670	37	N
13.9	15.4	16.7	15.3	65.4	584259	1213578	37	N
14	15.5	16.8	15.4	70.4	584213	1213488	37	N
14.1	15.6	16.9	15.5	67.1	584155	1213409	37	N
14.2	15.7	17	15.6	64.3	584061	1213369	37	N
14.3	15.8	17.1	15.7	50.8	583993	1213300	37	N
14.4	15.9	17.2	15.8	54.8	584026	1213207	37	N
14.5	16	17.3	15.9	59.6	584103	1213147	37	N
14.6	16.1	17.4	16	65.1	584202	1213127	37	N
14.7	16.2	17.5	16.1	66.9	584304	1213127	37	N
14.8	16.3	17.6	16.2	55.7	584398	1213108	37	N
14.9	16.4	17.7	16.3	60.9	584437	1213018	37	N
15	16.5	17.8	16.4	66.8	584468	1212922	37	N
15.1	16.6	17.9	16.5	68.9	584497	1212826	37	N
15.2	16.7	18	16.6	48	584479	1212738	37	N
15.3	16.8	18.1	16.7	47.5	584390	1212774	37	N
15.4	16.9	18.2	16.8	52.1	584309	1212838	37	N
15.5	17	18.3	16.9	46.7	584233	1212792	37	N
15.6	17.1	18.4	17	55.2	584267	1212698	37	N
15.7	17.2	18.5	17.1	60.7	584316	1212608	37	N
15.8	17.3	18.6	17.2	61.7	584397	1212548	37	N
15.9	17.4	18.7	17.3	48.4	584413	1212463	37	N
16	17.5	18.8	17.4	44.1	584348	1212388	37	N
16.1	17.6	18.9	17.5	54.5	584356	1212292	37	N
16.2	17.7	19	17.6	59.8	584434	1212234	37	N
16.3	17.8	19.1	17.7	65.8	584534	1212242	37	N
16.4	17.9	19.2	17.8	59.6	584637	1212255	37	N
16.5	18	19.3	17.9	48.5	584688	1212187	37	N
16.6	18.1	19.4	18	55.2	584696	1212088	37	N
16.7	18.2	19.5	18.1	66.6	584739	1211999	37	N
16.8	18.3	19.6	18.2	72.7	584784	1211909	37	N
16.9	18.4	19.7	18.3	67.1	584809	1211812	37	N
17	18.5	19.8	18.4	66.9	584773	1211719	37	N

Table B: PSI calculation for kombolcha-Harbu road section

$PSI = 5 - 0.2397X^4 + 1.7741X^3 - 1.404X^2 - 1.5803X$

$X = \log(1 + Sv)$ And $Sv = 0.22704(IRI)^2$

Length(Km)	Avg	SV	X	PSI	Length(Km)	IRI Avg	SV	X	PSI
7.8	IRI 3.05	2.112	0.493	4.078	11.7	2.79	1.767	0.442	4.171
7.9	3.045	2.105	0.492	4.08	11.8	2.56	1.488	0.396	4.259
8	2.665	1.612	0.417	4.218	11.9	2.835	1.825	0.451	4.155
8.1	3.17	2.282	0.516	4.037	12	2.93	1.949	0.47	4.12
8.2	2.96	1.989	0.476	4.109	12.1	3.345	2.54	0.549	3.981
8.3	3.03	2.084	0.489	4.085	12.2	3.11	2.196	0.505	4.057
8.4	2.72	1.68	0.428	4.197	12.3	2.915	1.929	0.467	4.126
8.5	3.005	2.05	0.484	4.094	12.4	3.08	2.154	0.499	4.068
8.6	3.355	2.556	0.551	3.978	12.5	2.86	1.857	0.456	4.145
8.7	3.285	2.45	0.538	4	12.6	3.145	2.246	0.511	4.046
8.8	3.09	2.168	0.501	4.064	12.7	3.755	3.201	0.623	3.863
8.9	2.845	1.838	0.453	4.151	12.8	3.315	2.495	0.543	3.99
9	2.86	1.857	0.456	4.145	12.9	3.25	2.398	0.531	4.011
9.1	3.745	3.184	0.622	3.865	13	2.71	1.667	0.426	4.201
9.2	3.5	2.781	0.578	3.934	13.1	2.98	2.016	0.479	4.102
9.3	3.28	2.443	0.537	4.001	13.2	2.89	1.896	0.462	4.135
9.4	2.87	1.87	0.458	4.142	13.3	3.555	2.869	0.588	3.918
9.5	2.91	1.923	0.466	4.127	13.4	3.78	3.244	0.628	3.856
9.6	3.115	2.203	0.506	4.056	13.5	3.885	3.427	0.646	3.83
9.7	3.21	2.339	0.524	4.024	13.6	3.14	2.239	0.51	4.047
9.8	3.095	2.175	0.502	4.063	13.7	2.885	1.89	0.461	4.136
9.9	2.755	1.723	0.435	4.184	13.8	4.13	3.873	0.688	3.773
10	3.225	2.361	0.527	4.019	13.9	3.8	3.278	0.631	3.851
10.1	3.135	2.231	0.509	4.049	14	2.81	1.793	0.446	4.164
10.2	3.395	2.617	0.558	3.965	14.1	2.825	1.812	0.449	4.158
10.3	3.605	2.951	0.597	3.904	14.2	2.825	1.812	0.449	4.158
10.4	3.29	2.458	0.539	3.998	14.3	2.82	1.806	0.448	4.16
10.5	3.955	3.551	0.658	3.813	14.4	3.11	2.196	0.505	4.057
10.6	4.23	4.062	0.704	3.751	14.5	2.875	1.877	0.459	4.14
10.7	3.855	3.374	0.641	3.837	14.6	2.855	1.851	0.455	4.147
10.8	3.05	2.112	0.493	4.078	14.7	2.81	1.793	0.446	4.164

10.9	3.145	2.246	0.511	4.046	14.8	3.3	2.472	0.541	3.995
11	2.955	1.983	0.475	4.111	14.9	2.755	1.723	0.435	4.184
11.1	2.865	1.864	0.457	4.144	15	2.91	1.923	0.466	4.127
11.2	3.46	2.718	0.57	3.946	15.1	3.255	2.405	0.532	4.01
11.3	2.68	1.631	0.42	4.212	15.2	3.1	2.182	0.503	4.061
11.4	2.75	1.717	0.434	4.186	15.3	3.335	2.525	0.547	3.984
11.5	3.08	2.154	0.499	4.068	15.4	3.575	2.902	0.591	3.912
11.6	2.855	1.851	0.455	4.147	15.5	3.44	2.687	0.567	3.952

15.6	3.03	2.084	0.489	4.085
15.7	3.04	2.098	0.491	4.081
15.8	2.88	1.883	0.46	4.138
15.9	3.1	2.182	0.503	4.061
16	3.135	2.231	0.509	4.049
16.1	3.095	2.175	0.502	4.063
16.2	3.1	2.182	0.503	4.061
16.3	3.47	2.734	0.572	3.943
16.4	4.825	5.286	0.798	3.649
16.5	3.08	2.154	0.499	4.068
16.6	3.385	2.601	0.556	3.969
16.7	3.165	2.274	0.515	4.039
16.8	2.755	1.723	0.435	4.184
16.9	2.625	1.564	0.409	4.233
17	2.68	1.631	0.42	4.212

Table C: Pavement serviceability ratting calculation fo kombolcha-Harbu road

length(Km)	IRI	PSR	length(Km)	IRI	PSR
0.1	4.535	1.538	3.9	3.19	2.182
0.2	3.85	1.838	4	3.47	2.028
0.3	3.22	2.165	4.1	3.63	1.946
0.4	2.895	2.355	4.2	3.165	2.196
0.5	3.145	2.207	4.3	2.595	2.547
0.6	3.345	2.095	4.4	2.745	2.449
0.7	3.145	2.207	4.5	2.76	2.44
0.8	3.065	2.254	4.6	3.05	2.262
0.9	3.34	2.098	4.7	3.06	2.257
1	3.105	2.23	4.8	3.3	2.12
1.1	3.405	2.063	4.9	4.415	1.587
1.2	3.025	2.277	5	2.875	2.368
1.3	3.595	1.964	5.1	2.915	2.343
1.4	7.815	0.655	5.2	2.815	2.405
1.5	4.855	1.415	5.3	2.79	2.421
1.6	4.69	1.477	5.4	3.27	2.137
1.7	7.465	0.718	5.5	2.82	2.402
1.8	4.23	1.665	5.6	3.225	2.162
1.9	3.855	1.835	5.7	2.89	2.359
2	3.215	2.167	5.8	2.7	2.478
2.1	3.19	2.182	5.9	2.85	2.383
2.2	3.31	2.115	6	3.415	2.058
2.3	3.115	2.225	6.1	3.415	2.058
2.4	3.13	2.216	6.2	7.015	0.807
2.5	3.66	1.931	6.3	3.125	2.219
2.6	3.07	2.251	6.4	3.28	2.131
2.7	3.14	2.21	6.5	3.115	2.225
2.8	3.025	2.277	6.6	2.805	2.411
2.9	3.095	2.236	6.7	3.01	2.286
3	2.77	2.433	6.8	2.57	2.563
3.1	2.475	2.627	6.9	2.785	2.424
3.2	2.585	2.553	7	3.34	2.098
3.3	2.99	2.298	7.1	3.165	2.196
3.4	2.725	2.462	7.2	2.795	2.418
3.5	2.885	2.362	7.3	2.58	2.556
3.7	3.535	1.994	7.5	2.84	2.389
3.8	4.37	1.605	7.6	2.915	2.343

length(Km)	IRI	PSR	length(Km)	IRI	PSR
7.8	3.05	2.262	11.7	2.79	2.421
7.9	3.045	2.265	11.8	2.56	2.57
8	2.665	2.501	11.9	2.835	2.392
8.1	3.17	2.193	12	2.93	2.334
8.2	2.96	2.316	12.1	3.345	2.095
8.3	3.03	2.274	12.2	3.11	2.227
8.4	2.72	2.465	12.3	2.915	2.343
8.5	3.005	2.289	12.4	3.08	2.245
8.6	3.355	2.09	12.5	2.86	2.377
8.7	3.285	2.128	12.6	3.145	2.207
8.8	3.09	2.239	12.7	3.755	1.884
8.9	2.845	2.386	12.8	3.315	2.112
9	2.86	2.377	12.9	3.25	2.148
9.1	3.745	1.888	13	2.71	2.472
9.2	3.5	2.013	13.1	2.98	2.304
9.3	3.28	2.131	13.2	2.89	2.359
9.4	2.87	2.371	13.3	3.555	1.984
9.5	2.91	2.346	13.4	3.78	1.871
9.6	3.115	2.225	13.5	3.885	1.821
9.7	3.21	2.17	13.6	3.14	2.21
9.8	3.095	2.236	13.7	2.885	2.362
9.9	2.755	2.443	13.8	4.13	1.709
10	3.225	2.162	13.9	3.8	1.862
10.1	3.135	2.213	14	2.81	2.408
10.2	3.395	2.068	14.1	2.825	2.399
10.3	3.605	1.958	14.2	2.825	2.399
10.4	3.29	2.126	14.3	2.82	2.402
10.5	3.955	1.788	14.4	3.11	2.227
10.6	4.23	1.665	14.5	2.875	2.368
10.7	3.855	1.835	14.6	2.855	2.38
10.8	3.05	2.262	14.7	2.81	2.408
10.9	3.145	2.207	14.8	3.3	2.12
11	2.955	2.319	14.9	2.755	2.443
11.1	2.865	2.374	15	2.91	2.346
11.2	3.46	2.034	15.1	3.255	2.145
11.3	2.68	2.491	15.2	3.1	2.233

11.4	2.75	2.446	15.3	3.335	2.101
11.5	3.08	2.245	15.4	3.575	1.974
11.6	2.855	2.38	15.5	3.44	2.044

length(Km)	IRI	PSR
15.6	3.03	2.274
15.7	3.04	2.268
15.8	2.88	2.365
15.9	3.1	2.233
16	3.135	2.213
16.1	3.095	2.236
16.2	3.1	2.233
16.3	3.47	2.028
16.4	4.825	1.426
16.5	3.08	2.245
16.6	3.385	2.074
16.7	3.165	2.196
16.8	2.755	2.443
16.9	2.625	2.527
17	2.68	2.491

Table D: Measured rutting depth

Rutting section	Changes	Rutting depth at right wheel (mm)	Rutting depth at left wheel (mm)	Average rutting depth
Section-1	2+500	59.5	68.3	63.91
	2+520	55.8	54.1	54.93
	2+540	55.5	57.8	56.66
	2+560	53.8	53.1	53.47
	2+580	59.2	55.4	57.31
	2+640	53.8	49.1	51.41
	2+620	53.1	50.7	51.87
	2+640	54.5	52.3	53.39
	2+660	55.2	53.9	54.55
section-2	5+600	62.1	56.5	59.32
	5+620	60.1	53.6	56.83
	5+640	56.4	51	53.69
	5+660	57.5	60.6	59.05
	5+680	52.9	58.9	55.89
section-3	12+500	53.2	55.1	54.19
	12+520	54	63.4	58.69
	12+540	55.7	56.8	56.25
	12+560	56.8	64.2	60.5
	12+575	57	67	61.98
section-4	14+200	59.6	68.5	64.07
	14+220	57	56.4	56.69
	14+240	46.2	44.2	45.22
section-5	16+600	46.7	45.8	46.25
	16+620	57	56.4	56.71

Table E: Texture depth of kombolcha-Harbu road section (source; ERA condition survey report

Distance (km)	Texture lane-I	Texture lane-II	Speed (km/h)	Easting (m)	Northing (m)	Zone	Hemisphere
0	0.883	0.906	15.7	597682	1104098	37	N
0.1	0.917	0.933	41.6	597728	1104184	37	N
0.2	1	1	47.4	597781	1104268	37	N
0.3	1.16	1.128	50.9	597831	1104356	37	N
0.4	0.839	0.871	45.8	597857	1104452	37	N
0.5	0.911	0.929	41.9	597881	1104547	37	N
0.6	0.898	0.918	51.2	597902	1104644	37	N
0.7	0.92	0.936	57.8	597920	1104740	37	N
0.8	0.97	0.976	58.3	597945	1104838	37	N
0.9	0.991	0.993	46.6	597974	1104934	37	N
1	0.98	0.984	41.7	598055	1104990	37	N
1.1	0.999	0.999	34.1	598144	1105040	37	N
1.2	1.091	1.073	38.3	598230	1105088	37	N
1.3	0.982	0.986	34.9	598316	1105137	37	N
1.4	0.947	0.957	23.7	598404	1105188	37	N
1.5	0.835	0.868	24.3	598484	1105239	37	N
1.6	1.196	1.157	26.2	598467	1105332	37	N
1.7	0.844	0.875	22	598425	1105421	37	N
1.8	0.834	0.867	37.4	598396	1105516	37	N
1.9	0.931	0.945	36.1	598427	1105608	37	N
2	1.019	1.015	35.3	598500	1105675	37	N
2.1	1.089	1.071	32.2	598579	1105739	37	N
2.2	1.175	1.14	32.6	598652	1105804	37	N
2.3	1.032	1.025	40.8	598731	1105866	37	N
2.4	0.971	0.977	33.5	598807	1105929	37	N
2.5	0.997	0.998	26.7	598882	1105993	37	N
2.6	1.044	1.035	43.8	598959	1106054	37	N
2.7	0.95	0.96	51.3	599035	1106118	37	N
2.8	0.798	0.838	56.3	599111	1106183	37	N
2.9	0.791	0.833	55.8	599186	1106247	37	N
3	0.803	0.842	61.4	599263	1106310	37	N
3.1	0.867	0.894	63.5	599339	1106374	37	N
3.2	0.778	0.822	64.3	599413	1106438	37	N
3.3	0.8	0.84	64.8	599491	1106502	37	N
3.4	0.817	0.854	58.3	599568	1106567	37	N
3.5	0.846	0.877	54.5	599643	1106630	37	N

3.6	0.886	0.909	49.8	599719	1106695	37	N
3.7	0.846	0.877	49.3	599794	1106758	37	N
3.8	0.823	0.859	57	599870	1106822	37	N
3.9	0.843	0.874	62.5	599946	1106884	37	N
4	0.814	0.852	66	600029	1106935	37	N
4.1	0.791	0.833	47.7	600126	1106971	37	N
4.2	0.883	0.906	35.2	600217	1107003	37	N
4.3	0.882	0.905	53.9	600308	1107035	37	N
4.4	0.897	0.917	68.8	600401	1107066	37	N
4.5	0.888	0.91	73.9	600495	1107100	37	N
4.6	0.884	0.908	69.8	600589	1107135	37	N
4.7	1.004	1.003	66.5	600675	1107185	37	N
4.8	0.916	0.933	67.2	600753	1107247	37	N
4.9	0.882	0.906	57.5	600832	1107310	37	N
5	1.028	1.023	50.5	600907	1107371	37	N
5.1	0.865	0.892	62.3	600984	1107432	37	N
5.2	0.877	0.902	65.5	601062	1107493	37	N
5.3	0.876	0.901	67.9	601140	1107554	37	N
5.4	0.814	0.851	69.1	601219	1107616	37	N
5.5	0.94	0.952	71.7	601297	1107677	37	N
5.6	0.852	0.881	73.8	601375	1107739	37	N
5.7	0.845	0.876	73.4	601453	1107799	37	N
5.8	0.812	0.85	73.8	601529	1107860	37	N
5.9	0.81	0.848	73.7	601607	1107922	37	N
6	0.841	0.873	66.8	601682	1107987	37	N
6.1	0.825	0.86	51	601719	1108082	37	N
6.2	1.065	1.052	23.9	601742	1108173	37	N
6.3	0.799	0.839	48.9	601792	1108260	37	N
6.4	0.87	0.896	58.1	601849	1108338	37	N
6.5	0.909	0.927	66	601910	1108418	37	N
6.6	0.958	0.967	63.4	601967	1108500	37	N
6.7	0.986	0.988	72.1	602028	1108577	37	N
6.8	0.907	0.925	79.8	602087	1108657	37	N
6.9	0.906	0.924	77.6	602146	1108736	37	N
7	0.952	0.962	73	602206	1108817	37	N
7.1	0.896	0.917	67.8	602266	1108897	37	N
7.2	1.025	1.02	61.7	602305	1108988	37	N
7.3	0.994	0.995	62.2	602315	1109087	37	N
7.4	1.014	1.011	62.6	602327	1109184	37	N

7.5	1.002	1.002	60.6	602377	1109267	37	N
7.6	0.956	0.965	60.8	602438	1109347	37	N
7.7	1.032	1.025	61.2	602496	1109428	37	N
7.8	1.04	1.032	61.5	602533	1109519	37	N
7.9	0.945	0.956	66	602566	1109612	37	N
8	0.911	0.928	73.1	602599	1109705	37	N
8.1	0.924	0.939	74.3	602632	1109798	37	N
8.2	0.947	0.958	74.4	602671	1109887	37	N
8.3	0.929	0.943	74.5	602727	1109970	37	N
8.4	0.909	0.927	75.2	602785	1110051	37	N
8.5	0.898	0.918	74.5	602842	1110133	37	N
8.6	0.947	0.958	74.5	602899	1110213	37	N
8.7	0.962	0.97	74.5	602957	1110294	37	N
8.8	0.972	0.978	74.7	603015	1110376	37	N
8.9	0.969	0.975	75	603073	1110458	37	N
9	0.906	0.925	75	603130	1110539	37	N
9.1	0.931	0.945	74.9	603187	1110620	37	N
9.2	0.959	0.967	74.6	603245	1110700	37	N
9.3	0.957	0.966	74.4	603302	1110781	37	N
9.4	0.919	0.935	74.3	603359	1110863	37	N
9.5	0.989	0.991	73.9	603416	1110943	37	N
9.6	0.994	0.995	73.5	603473	1111024	37	N
9.7	0.95	0.96	73.4	603530	1111105	37	N
9.8	0.987	0.99	73.3	603588	1111187	37	N
9.9	0.999	0.999	73.2	603645	1111268	37	N
10	0.99	0.992	72.6	603701	1111348	37	N
10.1	1.046	1.037	72.5	603759	1111429	37	N
10.2	0.995	0.996	72.4	603815	1111510	37	N
10.3	0.981	0.985	69.3	603871	1111592	37	N
10.4	1.006	1.005	62	603930	1111672	37	N
10.5	0.918	0.934	63.7	603987	1111755	37	N
10.6	1.013	1.01	63.6	604055	1111824	37	N
10.7	0.981	0.985	65.6	604143	1111868	37	N
10.8	1.064	1.051	65.2	604241	1111890	37	N
10.9	1.033	1.026	67.1	604326	1111939	37	N
11	1.023	1.018	69.5	604384	1112021	37	N
11.1	1.01	1.008	65.7	604437	1112104	37	N
11.2	0.999	0.999	67.5	604519	1112154	37	N
11.3	0.953	0.963	73.5	604609	1112195	37	N

11.4	0.954	0.963	72.4	604699	1112238	37	N
11.5	0.936	0.949	69.8	604789	1112282	37	N
11.6	0.985	0.988	66.5	604879	1112326	37	N
11.7	1.045	1.036	66.7	604950	1112394	37	N
11.8	1.01	1.008	72.9	605015	1112468	37	N
11.9	0.953	0.962	76.5	605081	1112543	37	N
12	1.063	1.05	75	605147	1112616	37	N
12.1	0.978	0.983	71.6	605214	1112692	37	N
12.2	1.006	1.005	56.6	605278	1112766	37	N
12.3	1.053	1.043	65.6	605344	1112838	37	N
12.4	1.018	1.015	74.4	605410	1112912	37	N
12.5	1.027	1.021	76.1	605477	1112985	37	N
12.6	0.975	0.98	75.1	605543	1113060	37	N
12.7	1.01	1.008	75.7	605609	1113134	37	N
12.8	1.051	1.041	75.5	605677	1113209	37	N
12.9	1.058	1.046	74.9	605741	1113283	37	N
13	1.078	1.062	74.9	605807	1113356	37	N
13.1	1.109	1.087	74.9	605873	1113430	37	N
13.2	1.105	1.084	74.5	605939	1113504	37	N
13.3	1.156	1.125	74.5	605989	1113589	37	N
13.4	0.99	0.992	74.6	606029	1113680	37	N
13.5	0.984	0.988	74.4	606067	1113771	37	N
13.6	1.064	1.051	75	606106	1113863	37	N
13.7	0.99	0.992	74.8	606148	1113954	37	N
13.8	1.086	1.069	75	606187	1114044	37	N
13.9	0.94	0.952	74.7	606229	1114135	37	N
14	0.897	0.917	74.4	606268	1114225	37	N
14.1	0.902	0.922	74.6	606307	1114316	37	N
14.2	0.921	0.937	74.7	606347	1114407	37	N
14.3	0.933	0.946	74.5	606387	1114497	37	N
14.4	0.871	0.897	73.4	606427	1114589	37	N
14.5	0.905	0.924	73.9	606466	1114679	37	N
14.6	0.965	0.972	74.6	606504	1114771	37	N
14.7	1.046	1.037	75	606532	1114866	37	N
14.8	0.949	0.959	74.6	606558	1114961	37	N
14.9	1.044	1.035	74.4	606585	1115057	37	N
15	1.071	1.057	74.6	606620	1115149	37	N
15.1	0.949	0.959	73.5	606664	1115239	37	N
15.2	0.974	0.979	72.5	606724	1115316	37	N

15.3	1.049	1.039	64	606770	1115404	37	N
15.4	0.919	0.935	60.3	606768	1115502	37	N
15.5	0.864	0.891	62.4	606778	1115600	37	N
15.6	0.833	0.866	66.3	606792	1115699	37	N
15.7	0.852	0.881	66.4	606808	1115797	37	N
15.8	0.845	0.876	68.1	606831	1115893	37	N
15.9	0.867	0.894	67.1	606869	1115984	37	N
16	0.854	0.884	63.8	606926	1116065	37	N
16.1	0.845	0.876	60.1	606975	1116152	37	N
16.2	0.921	0.937	58.3	607017	1116241	37	N
16.3	0.971	0.977	45.2	607090	1116306	37	N
16.4	0.955	0.964	43.8	607087	1116402	37	N
16.5	0.982	0.986	51.2	607003	1116450	37	N
16.6	0.922	0.938	58.9	606909	1116487	37	N
16.7	0.932	0.946	60.5	606847	1116564	37	N
16.8	0.885	0.908	59.7	606796	1116649	37	N
16.9	0.941	0.953	54.4	606746	1116734	37	N
17	0.886	0.908	50.9	606700	1116822	37	N

Table F: measured number, depth and width of potholes along kombolcha-Harbu road

Station	No of potholes	Width of representative potholes(m)			Depth of representative potholes(m)		
		High severity pothole-I	Medium severity Pothole-II	Low severity Pothole-III	High severity pothole-I	Medium severity Pothole-II	Low severity Pothole-III
0+000-1+000	24	1.2	0.82	0.54	0.16	0.090	0.053
1+000-2+000	16	0.93	0.74	0.67	0.082	0.071	0.043
2+000-3+000	28	1.84	0.98	0.47	0.130	0.079	0.065
3+000-4+000	13	1.1	0.96	0.76	0.097	0.094	0.035
4+000-5+000	18	0.87	0.76	0.42	0.025	0.023	0.056
5+000-6+000	8	0.75	0.59	0.42	0.062	0.037	0.021
6+000-7+000	39	0.91	0.76	0.41	0.039	0.036	0.042
7+000-8+000	17	1.45	0.90	0.33	0.12	0.054	0.032
8+000-9+000	11	1.24	0.93	0.51	0.096	0.055	0.037
9+000-10+000	13	1.09	0.91	0.62	0.081	0.049	0.044
10+000-11+000	16	0.96	0.77	0.51	0.063	0.046	0.039
11+000-12+000	19	1.43	1.08	0.66	0.095	0.084	0.038
12+000-13+000	21	1.11	0.52	0.45	0.087	0.058	0.048
13+000-14+000	3	0.82	0.68	0.53	0.076	0.053	0.034
14+000-15+000	5	0.96	0.68	0.57	0.071	0.060	0.055
15+000-16+000	12	0.92	0.78	0.64	0.07	0.061	0.051
16+000-17+000	10	0.84	0.82	0.72	0.073	0.047	0.04
Total	273						

Table-G: measured edge cracking for kombolcha-Harbu road section

No	Station	Position of edge Crack	Length(m)	Width(m)	Edge crack Area(m^2)
1	0+650	left	0.34	0.012	0.004
2	3+200	left	1.12	0.9	1.008
3	3+420	left	1.54	1.3	2.002
4	3+870	right	0.84	0.7	0.588
5	5+140	left	2.5	1.3	3.25
6	5+600	left	2.1	1.6	3.36
7	6+410	left	0.98	0.56	0.549
8	6+560	right	1.6	0.85	1.36
9	6+700	right	1.85	1.2	2.22
10	7+000	left	1.75	1.1	1.925
11	7+460	right	1.54	1.5	2.31
12	8+500	left	0.76	1	0.76
13	8+700	right	1.4	0.94	1.316
14	8+800	right	1.52	1	1.52
15	8+950	right	1.76	0.79	1.39
16	9+100	left	3.5	1.5	5.25
17	9+600	right	1.4	1.24	1.736
18	9+850	left	1.56	1.22	1.903
19	11+450	left	1.35	1.5	2.025
20	13+200	left	1.56	1.11	1.732
21	13+880	right	1.43	0.6	0.858
22	14+300	right	2.65	1.8	4.77
23	14+550	left	1.85	1.5	2.775
24	14+820	left	1.52	1.2	1.824
25	15+450	left	2.56	1.45	3.712
26	16+200	left	1.43	0.65	0.93
27	16+450	left	2.76	1.6	4.416
28	16+650	left	1.65	1.12	1.848
29	16+800	right	2.22	1.4	3.108
	total				60.45

Appendix-B

`1. Polynomial Regression analysis result for IRI and PSI:

Order 0
PSI = 3.147

Order 1
PSI = 16.443 - (3.280 * IRI)

Order 2
PSI = 55.017 - (22.589 * IRI) + (2.414 * IRI ^2)

Order 3
PSI = 322.966 - (225.231 * IRI) + (53.448 * IRI ^2) - (4.280 * IRI ^3)

Regression Results:

Order	MSres	MSincr
0	0.151	0.151
1	0.00238	0.149
2	0.000222	0.00216
3	0.0000166	0.000206

Regression Results: Incremental

Order	Rsqr	F	P
0	0.000		
1	0.984	5745.202	<0.001
2	0.0142	885.413	<0.001
3	0.00133	1113.828	<0.001

Regression Results: Overall

Order	Rsqr	F	P
0	0.000		
1	0.984	5745.202	<0.001
2	0.999	31233.614	<0.001
3	1.000	278657.791	<0.001

Assumption Testing:

Order	Normality(P)	Constant Variance(P)
0	0.00000111	0.000000432
1	1.240E-013	0.150
2	4.789E-012	0.0325
3	0.000000291	0.00269

2. Polynomial Regression analysis result for IRI and PSR:

Order 0
PSR = 2.180

Order 1
PSR = 3.520 - (0.413 * IRI)

Order 2
PSR = 4.490 - (0.885 * IRI) + (0.0508 * IRI ^2)

Order 3

PSR = 4.863 - (1.158 * IRI) + (0.114 * IRI ^2) - (0.00440 * IRI ^3)

Regression Results:

Order	**MSres**	**MSincr**
0	0.0920	0.0920
1	0.00436	0.0877
2	0.0000327	0.00433
3	0.000000391	0.0000323

Regression Results: Incremental

Order	**Rsqr**	**F**	**P**
0	0.000		
1	0.953	3338.092	<0.001
2	0.0468	21877.120	<0.001
3	0.000346	13548.503	<0.001

Regression Results: Overall

Order	**Rsqr**	**F**	**P**
0	0.000		
1	0.953	3338.092	<0.001
2	1.000	233893.987	<0.001
3	1.000	13041256.676	<0.001

Assumption Testing:

Order	**Normality(P)**	**Constant Variance(P)**
0	7.209E-014	0.000000200
1	0.0000000109	0.0350
2	1.144E-013	0.0213
3	4.630E-013	0.374

3. Polynomial Regression analysis result for length vs Avg texture depth

Order 0
Col 12 = 0.953

Order 1
Col 12 = 0.929 + (0.00284 * Col 9)

Order 2
Col 12 = 0.920 + (0.00616 * Col 9) - (0.000195 * Col 9^2)

Order 3
Col 12 = 1.010 - (0.0587 * Col 9) + (0.00938 * Col 9^2) - (0.000375 * Col 9^3)

Regression Results:

Order	**MSres**	**MSincr**
0	0.00574	0.00574
1	0.00558	0.000165
2	0.00559	-0.0000147
3	0.00434	0.00125

Regression Results: Incremental

Order	**Rsqr**	**F**	**P**
0	0.000		
1	0.0344	6.022	0.015
2	0.00317	0.554	0.458
3	0.220	49.589	<0.001

Regression Results: Overall

Order	**Rsqr**	**F**	**P**
0	0.000		
1	0.0344	6.022	0.015
2	0.0376	3.280	0.072
3	0.258	19.349	<0.001

Assumption Testing:

Order	**Normality(P)**	**Constant Variance(P)**
0	0.154	0.000000200
1	0.00944	0.0959
2	0.00680	0.0645
3	0.000486	0.128

4. Polynomial Regression analysis result for Age vs Rutting

Order 0
Col 5 = 43.500

Order 1
Col 5 = -489.860 + (0.264 * Col 1)

Order 2
Col 5 = -52711.548 + (51.943 * Col 1) - (0.0128 * Col 1^2)

Order 3
Col 5 = 54657391.420 - (81160.717 * Col 1) + (40.172 * Col 1^2) - (0.00663 * Col 1^3)

Regression Results:

Order	MSres	MSincr
0	0.826	0.826
1	0.0668	0.759
2	0.0576	0.00918
3	0.0271	0.0305

Regression Results: Incremental

Order	Rsqr	F	P
0	0.000		
1	0.927	114.705	<0.001
2	0.0170	2.435	0.157
3	0.0328	10.025	0.016

Regression Results: Overall

Order	Rsqr	F	P
0	0.000		
1	0.927	114.705	<0.001
2	0.944	67.713	<0.001
3	0.977	99.407	<0.001

Assumption Testing:

Order	Normality(P)	Constant Variance(P)
0	0.723	0.109
1	0.0255	0.00145
2	0.808	0.0883
3	0.264	0.296

5. Polynomial Regression analysis result for Age vs IRI

Order 0
Col 7 = 5.556
Order 1
Col 7 = -390.008 + (0.196 * Col 1)
Order 2
Col 7 = -13385.925 + (13.057 * Col 1) - (0.00318 * Col 1^2)
Order 3
Col 7 = -4791700.897 + (7106.073 * Col 1) - (3.513 * Col 1^2) + (0.000579 * Col 1^3)

Regression Results:

Order	MSres	MSincr
0	0.423	0.423
1	0.00181	0.421
2	0.000945	0.000860
3	0.000784	0.000161

Regression Results: Incremental

Order	Rsqr	F	P
0	0.000		
1	0.996	2334.435	<0.001
2	0.00205	9.192	0.016
3	0.000489	2.639	0.148

Regression Results: Overall

Order	Rsqr	F	P
0	0.000		
1	0.996	2334.435	<0.001
2	0.998	2234.230	<0.001
3	0.999	1795.597	<0.001

Assumption Testing:

Order	Normality(P)	Constant Variance(P)
0	0.878	0.109
1	0.903	0.0389
2	0.765	0.400
3	0.0481	0.0209

6. Polynomial Regression analysis result for Age vs edge cracking

Order 0
Col 6 = 49.446

Order 1
Col 6 = -3443.209 + (1.728 * Col 1)

Order 2
Col 6 = 157744.243 - (157.785 * Col 1) + (0.0395 * Col 1^2)

Order 3
Col 6 = -18282061.857 + (27214.595 * Col 1) - (13.505 * Col 1^2) + (0.00223 * Col 1^3)

Regression Results:

Order	MSres	MSincr
0	33.008	33.008
1	0.173	32.835
2	0.0276	0.145
3	0.0271	0.000467

Regression Results: Incremental

Order	Rsqr	F	P
0	0.000		
1	0.995	1899.379	<0.001
2	0.00405	48.493	<0.001
3	0.0000934	1.138	0.321

Regression Results: Overall

Order	Rsqr	F	P
0	0.000		
1	0.995	1899.379	<0.001
2	0.999	5985.433	<0.001
3	0.999	4059.523	<0.001

Assumption Testing:

Order	Normality(P)	Constant Variance(P)
0	0.848	0.109
1	0.476	0.557
2	0.000115	0.484
3	0.00134	0.0234

H D M - 4

HIGHWAY DEVELOPMENT & MANAGEMENT

Annual Road Condition (Bituminous Pavements)

Study Name: **kombolcha to Harbu road section**

Run Date: **28-03-2017**

Annual Road Condition (Bituminous Pavements)

Section Details:

ID: KO-H-1-3 Km | Description: Kombolcha-Habru road section | Road Class: Link

Length: 17.00km | Width: 6.70m | Rise + Fall: 15.00m/km | Curvature: 80.00deg/km

Alternative: Periodic maintenance-patching and crack sealing

					Bituminous Pavement													
					End of Year Condition													
Year	MT AADT	ESAL (millions/Elane) YE4		Pavement Type	Average Structural Number SNPK	Roughness IRI (m/km) RI	Cracking Area (%) All Structural ACA	Wide Structural ACW	Transverse Thermal ACT	Total Cracking ACRA	Ravelled Area (%) ARV	Potholes Number per km NPT	Area (%) APOT	Edge-break Area (m²/km) AEB	Rutting Mean Rut Depth (mm) RDM	Std. Dev of Rut Depth RDS	Texture Depth (mm) TD	Skid Resistance SFC50
2016	985	0.18	Before works	STAP	4.53	4.54	32.68	0.00	0.00	32.68	17.49	291	0.43	41.38	42.15	12.65	0.60	0.50
			After works	STAP	4.53	4.38	32.68	0.00	0.00	32.68	17.49	291	0.00	41.38	42.15	12.65	0.60	0.50
2017	1009	0.18	Before works	STAP	4.49	4.70	61.13	0.00	0.00	61.13	30.05	302	0.00	42.74	42.37	12.71	0.52	0.50
			After works	STAP	4.49	4.70	61.13	0.00	0.00	61.13	30.05	302	0.00	42.74	42.37	12.71	0.52	0.50
2018	1034	0.19	Before works	STAP	4.37	4.99	82.39	0.00	0.00	82.39	16.94	326	0.01	44.18	42.63	12.79	0.46	0.50
			After works	STAP	4.37	4.99	82.39	0.00	0.00	82.39	16.94	226	0.01	44.18	42.63	12.79	0.46	0.50
2019	1059	0.19	Before works	STAP	4.31	5.22	94.06	0.00	0.00	94.06	5.25	348	0.01	45.69	42.92	12.88	0.43	0.50
			After works	STAP	4.31	5.22	94.06	0.00	0.00	94.06	5.25	348	0.01	45.69	42.92	12.88	0.43	0.50
2020	1086	0.20	Before works	STAP	4.28	5.42	98.95	0.00	0.00	98.95	0.33	367	0.01	47.28	43.23	12.97	0.39	0.50
			After works	STAP	4.28	5.42	98.95	0.00	0.00	98.95	0.33	367	0.01	47.28	43.23	12.97	0.39	0.50
2021	1112	0.20	Before works	STAP	4.26	5.59	99.26	0.00	0.00	99.26	0.00	417	0.01	48.96	43.55	13.07	0.37	0.50
			After works	STAP	4.26	5.59	99.26	0.00	0.00	99.26	0.00	417	0.01	48.96	43.55	13.07	0.37	0.50
2022	1140	0.21	Before works	STAP	4.26	5.76	99.23	0.00	0.00	99.23	0.00	428	0.01	50.72	43.87	13.16	0.35	0.50
			After works	STAP	4.26	5.76	99.23	0.00	0.00	99.23	0.00	428	0.01	50.72	43.87	13.16	0.35	0.50

2023	1168	0.22	Before works	STAP	4.26	5.94	99.20	0.00	0.00	99.20	0.00	449	0.01	52.57	44.20	13.26	0.33	0.50
			After works	STAP	4.26	5.94	99.20	0.00	0.00	99.20	0.00	449	0.01	52.57	44.20	13.26	0.33	0.50
2024	1197	0.22	Before works	STAP	4.26	6.13	99.17	2.93	0.00	99.17	0.00	466	0.01	54.53	44.52	13.36	0.31	0.50
			After works	STAP	4.26	6.13	99.17	2.93	0.00	99.17	0.00	466	0.01	54.53	44.52	13.36	0.31	0.50
2025	1227	0.23	Before works	STAP	4.26	6.32	99.14	16.14	0.00	99.14	0.00	485	0.01	56.59	44.85	13.46	0.30	0.49
			After works	STAP	4.26	6.32	99.14	16.14	0.00	99.14	0.00	485	0.01	56.59	44.85	13.46	0.30	0.49
2026	1258	0.24	Before works	STAP	4.26	6.51	99.11	46.61	0.00	99.11	0.00	505	0.02	58.77	45.19	13.56	0.28	0.49
			After works	STAP	4.26	6.51	99.11	46.61	0.00	99.11	0.00	505	0.00	58.77	45.19	13.56	0.28	0.49

Section Details:

ID: KO-H-1-3 Km — Description: Kombolcha-Habru road section — Road Class: Link

Length: 17.00km — Width: 6.70m — Rise + Fall: 15.00m/km — Curvature: 80.00deg/km

Alternative: Rehabilitation-partial thin overlay

					Bituminous Pavement													
					End of Year Condition													
Year	MT AADT	ESAL (millions/Elane) YE4		Pavement Type	Average Structural Number SNPK	Roughness IRI (m/km) RI	Cracking Area (%)				Ravelled Area (%) ARV	Potholes		Edge-break Area (m²/km) AEB	Rutting		Texture Depth (mm) TD	Skid Resistance SFC50
							All Structural ACA	Wide Structural ACW	Transverse Thermal ACT	Total Cracking ACRA		Number per km NPT	Area (%) APOT		Mean Rut Depth (mm) RDM	Std. Dev of Rut Depth RDS		
2016	985	0.18	Before works	STAP	4.53	4.54	32.68	0.00	0.00	32.68	17.49	291	0.43	41.38	42.15	12.65	0.60	0.50
			After works	STAP	4.53	4.39	32.68	0.00	0.00	32.68	16.43	291	0.00	41.38	42.15	12.65	0.60	0.50
2017	1009	0.18	Before works	STAP	4.49	4.71	61.13	0.00	0.00	61.13	28.45	321	0.00	42.74	42.37	12.71	0.52	0.50
			After works	STAP	4.49	4.73	61.13	0.00	0.00	61.13	26.96	321	0.00	42.74	42.37	12.71	0.52	0.50
2018	1034	0.19	Before works	STAP	4.37	5.01	82.39	0.00	0.00	82.39	16.95	332	0.00	44.18	42.63	12.79	0.46	0.50
			After works	STAP	4.37	5.03	82.39	0.00	0.00	82.39	15.46	332	0.00	44.18	42.63	12.79	0.46	0.50
2019	1059	0.19	Before works	STAP	4.31	5.26	94.06	0.00	0.00	94.06	5.26	346	0.00	45.69	42.92	12.88	0.43	0.50
			After works	STAP	4.31	5.28	94.06	0.00	0.00	94.06	3.77	346	0.00	45.69	42.92	12.88	0.43	0.50
2020	1086	0.20	Before works	STAP	4.28	5.47	98.95	0.00	0.00	98.95	0.34	387	0.00	47.28	43.23	12.97	0.39	0.50
			After works	STAP	4.28	5.47	98.95	0.00	0.00	98.95	0.34	387	0.00	47.28	43.23	12.97	0.39	0.50
2021	1112	0.20	Before works	STAP	4.26	5.65	99.27	0.00	0.00	99.27	0.00	402	0.00	48.96	43.55	13.07	0.37	0.50
			After works	STAP	4.26	5.65	99.27	0.00	0.00	99.27	0.00	402	0.00	48.96	43.55	13.07	0.37	0.50

2022	1140	0.21	Before works	STAP	4.26	5.82	99.24	0.00	0.00	99.24	0.00	416	0.00	50.72	43.87	13.16	0.35	0.50
			After works	STAP	4.26	5.82	99.24	0.00	0.00	99.24	0.00	416	0.00	50.72	43.87	13.16	0.35	0.50
2023	1168	0.22	Before works	STAP	4.26	6.00	99.22	0.00	0.00	99.22	0.00	424	0.00	52.58	44.20	13.26	0.33	0.50
			After works	STAP	4.26	6.00	99.22	0.00	0.00	99.22	0.00	424	0.00	52.58	44.20	13.26	0.33	0.50
2024	1197	0.22	Before works	STAP	4.26	6.19	99.19	2.93	0.00	99.19	0.00	448	0.00	54.54	44.52	13.36	0.31	0.50
			After works	STAP	4.26	6.19	99.19	2.93	0.00	99.19	0.00	448	0.00	54.54	44.52	13.36	0.31	0.50
2025	1227	0.23	Before works	STAP	4.26	6.38	99.16	16.14	0.00	99.16	0.00	478	0.00	56.60	44.85	13.46	0.30	0.49
			After works	STAP	4.26	6.29	83.02	0.00	0.00	83.02	0.00	478	0.00	56.60	44.85	13.46	0.30	0.49
2026	1258	0.24	Before works	STAP	4.31	6.56	94.36	16.34	0.00	94.36	2.08	495	0.00	58.79	45.15	13.55	0.28	0.49
			After works	STAP	4.31	6.46	78.02	0.00	0.00	78.02	2.08	495	0.00	58.79	45.15	13.55	0.28	0.49