ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

GEOSPATIAL PAVEMENT DISTRESS MAINTENANCE MANAGEMENT (CASE STUDY FROM ENTOTO TO CENTER OF CHANCHO TOWN ROAD SECTION)

By:

Ngiste Amare

A thesis submitted for the partial fulfilment of

Degree of Master of Science (MSC) in Civil Engineering

(Under Road and Transport Engineering Stream)

Main Advisor: **Dr. Bikila Tekilu**

Co-adviser: **Mr. Andenet Ashagrie**

September, 2020

Addis Ababa, Ethiopia

Addis Ababa University
School of Civil and Environmental Engineering
Road and Transport Engineering Stream

GEOSPATIAL PAVEMENT DISTRESS MAINTENANCE MANAGEMENT (CASE STUDY FROM ENTOTO TO CENTER OF CHANCHO TOWN ROAD SECTION)

By

Ngiste Amare

A thesis submitted for the partial fulfillment of
Degree of Master of Science (MSC) in Civil Engineering
(Under Road and Transport Engineering Stream)

Signed by the Examining Committee

Advisor	Dr. Bikila Teklu	signature_____	date _____
Co-Advisor	Mr. Andenet Ashagrie	signature _____	date _____
External examiner	Dr. Bedilu Habte	signature _____	date _____
Internal examiner	Dr. Ing. Robeam Solomon	signature _____	date _____
Chairperson	Dr. Ing. Mebruk Mohammed	signature _____	date _____

DECLARATION

This is certifying that this research is prepared by Ngiste Amare entitled to Geospatial pavement distress maintenance management (case study from Entoto to the center of Chancho town road section) submitted in fulfillment of the requirements for the degree of master of road and transportation in civil and environmental engineering. This research complies with the regulations of the university and meets the accepted standards concerning originality and quality.

Name Ngiste Amare

Signature _____

Place Addis Ababa Institute of Technology

Addis Ababa University, Addis Ababa.

Date September 2020

ABSTRACT

GIS and GPS based pavement distress and maintenance management are becoming a significant topic in the current pavement management industry and research. There exists pavement distress from Entoto – the center of Chancho town. GIS and GPS based analysis is important to manage the road section distresses by ranking for maintenance according to priorities.

This study examines pavement distress and maintenance management systems by using GIS and GPS tools or analysis and decision making. Also, the research evaluates the relationship between pavement distresses, slope factor, drainage, mobility, pavement performance, riding comfort, maintenance system, and recommended treatments.

Initially, interviews were conducted to know about overall information. Then conduct an observation and surveying to get the type, severity, and extent level of distresses. Capturing images were also taken to look through the condition of distresses, to get the geospatial coordinate points and their respective stations using a GPS map camera. Finally examine factors for maintenance prioritization (like AHP priority vector, PDI, and TBMC), use them as input data for weighted overlay analysis, and prioritize distresses for maintenance using GIS software.

The preliminary results of the research show that among a total of 126 road distresses, 33 were alligator cracks, 32 were potholes, 29 were patchings, 19 were ravelings, 8 were edge breaks, 3 were ruttings, 1 shoving, and 1 longitudinal crack. From the weighted overlay analysis result, distresses that lies in high detected areas maintained first and that lies in low detected areas maintained last.

The conclusion bound to be drawn that pavement distress maintenance management through a combined effect of maintenance priority factors using GIS software gives a better maintenance priority map. The traditional pavement distress maintenance management systems don’t consider it and use pavement condition data to give priorities for maintenance on the highway networks.

KEYWORDS: GIS, GPS map camera, pavement distress maintenance management, pavement distress maintenance priorities

ACKNOWLEDGMENTS

First I would like to provide my deepest appreciation to my Advisors, home and abroad, Dr. Bikila Teklu and Mr. Andenet Ashagrie for their kind and generous steering throughout this program. Their steering and support helped me vastly towards this work to be completed successfully. Additionally, their expertness has given me a lot of stimulation that is useful for my continued career development. Their experience and constructive comments on the analysis helped me to penetrate the depth of the flow mechanisms.

I want also to convey Dr.Alemgena Allene for his nice enthusiasm for his field and lots of plan share to me.

I am additionally glad for all the assistance given throughout the interviewing, by ERA (Ethiopian Road Authority) workers and AD (Alemgena District) workers. I would additionally wish to acknowledge and convey all those who have created contributions to my analysis.

I am nicely grateful for the sponsorship of my MSC provided by Mizan-Tepi University and the Ministry of Education.

Lastly and most significantly I would like to thank my families. Several thanks for your love, support, guidance, and inspiration. Nothing would have happened while not you.

CONTENTS

ABSTRACT i

ACKNOWLEDGMENTS ii

LIST OF TABLES vii

LIST OF FIGURES viii

ACRONYM OF TERMS ix

CHAPTER ONE 1

INTRODUCTION 1

1.1. Introduction 1

1.2. Statement of the problem 3

1.3. Objectives 4

1.3.1. General objective 4

1.3.2. Specific objectives 4

1.4. Research questions 4

1.5. Significance of the study 4

1.6. Scope of the study 5

1.7. Organization of the thesis 5

CHAPTER TWO 6

REVIEW OF LITERATURE 6

2.1. Introduction 6

2.2. Integrated use of GPS with GIS 6

2.3. Pavement Management Systems (PMS) 7

2.4. Pavement management system (PMS)/GIS Integration 7

2.5. Pavement management system (PMS)/GIS Case Studies 8

2.6. Current practices in pavement performance modeling and prioritization for maintenance 8

2.6.1. Analytic Hierarchy Process (AHP) 8
2.6.2. Pavement performance evaluation overview 15
2.7. Conceptual framework 17
CHAPTER THREE 19
METHODOLOGY 19
3.1. Description of the study area 19
3.2. Data collection procedures and techniques 21
3.3. Pavement distress maintenance management method and data used for the study 21
3.4. Data analysis methodology and interpretation 26
3.4.1. Road distress 26
3.4.2. Predict the road section condition and maintenance priorities 31
3.5. Research design 32
3.6. Study variables 32
CHAPTER FOUR 33
RESULTS AND DISCUSSION 33
4.1. Results and discussions 33
4.1.1. Pavement distresses along the section of the road 33
4.1.2. The relationship between slope, distress, and drainage 35
4.1.3. Pavement maintenance prioritization based on AHP 37
4.1.4. Pavement maintenance prioritization based on pavement performance condition 39
4.1.5. Pavement maintenance prioritization based on TBMC 41
4.1.6. Pavement distress maintenance prioritization map 41
4.1.7. Recommended treatments of each distress type 43
CHAPTER FIVE 44
CONCLUSION AND RECOMMENDATION 44

5.1. Conclusion 44
5.2. Recommendations 46
References 48
Appendix-A: Sample photos of distresses 52
A-1. Alligator cracks 52
A-2. Edge breaks 52
A-4. Longitudinal crack 53
A-5. Patching 54
A-6. Rutting 55
A-7. Raveling 55
A-8. Potholes 56
Appendix-B: Site GPS data 57
Appendix-C: Listed maintenance activities by category (ERA manual) 63
Appendix-D: IRI values and their specification (ERA) manual 64
Appendix-E: Maintenance Quantity Estimation and their respective activity numbers based on Condition Survey 64
E-1. Pothole 64
E-2. Raveling 65
E-3. Cracking 65
E-4. Edge damage 66
Appendix-F: Geospatial locations of the distresses 66
Appendix-G: Road distresses with slope category 71
Appendix-H: Interview form as a question for asking experts for pairwise comparison 71
Appendix-I: IRI and speed data of left and right-hand side road section 72
Appendix-J: severity and extent level of each distress and slope category 83
Appendix-K: density and TBMC 85

Appendix-L: IRI versus distance and IRI versus speed graph 87

Appendix-M: input parameters of maintenance priority in the weighted overlay model 89

Appendix-N: information produced by an identify icon 90

LIST OF TABLES

Table 2. 1. Saaty fundamental scale for pairwise comparison 13
Table 2. 2. Values of the random index for small problems 15
Table 3. 1. Edge damage severity and extent specification as per ERA manual ..... .27
Table 3. 2. Rutting severity and extent specification as per ERA manual 28
Table 3. 3. Alligator crack and Longitudinal crack severity and extent specification as per ERA manual 29
Table 3. 4. Raveling severity and extent specification as per ERA manual 30
Table 3. 5. Pothole severity and extent specification as per ERA manual 30
Table 4. 1. Road section distresses in each severity and extent category 33
Table 4. 2. Slope gradient vs No. of distresses 35
Table 4. 3. The pairwise comparison of expert judgment 37
Table 4. 4. Eigenvector and rank of criterion using the AHP model 37
Table 4. 5. Eigenvector and rank of alternatives based on severity level 38
Table 4. 6. Eigenvector and rank of alternatives based on extent level 38
Table 4. 7. Pavement maintenance prioritization based on PDI model 39
Table 4. 8. Left-hand side IRI Vs speed graph statistics summary 40
Table 4. 9. Right-hand side IRI Vs speed graph statistics summary 40
Table 4. 10. Pavement maintenance prioritization based on TBMC model 41
Table 4. 11. Recommended treatments 43

LIST OF FIGURES

Figure 2. 1. Structure of AHP 11
Figure 2. 2. Conceptual framework 18
Figure 3. 1. Map of the study area 20
Figure 3. 2. Methodology flow chart of the research 26
Figure 4. 1. Percent coverage of the distresses result 34
Figure 4. 2. Slope gradient Vs severity level No. of distresses 35
Figure 4. 3. Slope gradient Vs extent level No. of distresses 36
Figure 4. 4. Weighted overlay map of distresses for maintenance priority 42

ACRONYM OF TERMS

GIS	Geographic Information System
AD	Alemgena District
GPS	Global Positioning System
PDMS	Pavement Distress Management System
DEM	Digital Elevation Model
AHP	Analytic Hierarchal Process
PDI	Pavement Distress Index
ERA	Ethiopian Roads Authority
IRI	International Roughness Index
CI	Consistency Index
CR	Consistency Ratio
MDOT	Michigan Department of Transportation
TBMC	Treatment Based Maintenance Cost

CHAPTER ONE
INTRODUCTION

1.1. Introduction

Geospatial analysis is the processing of images, GPS, satellite photography and historical information, delineated explicitly in terms of geographic coordinates or implicitly, in terms of a street address, zip code, or forest stand symbol gathering, display, and manipulation as they are applied to geographic models. Pavement management is an applying of pavement repairs and maintenance to increase the worth and lifetime of a pavement network. Maintenance is a method of maintaining construction parts in a safe condition. A road maintenance management system has to be developed to assure the effectiveness of road maintenance.

The location and time information of geographic coordinates at any location on the surface of the earth was measured by such a satellite navigation system called Global Positioning System (GPS). After the GPS survey was complete, the survey data from GPS units can be downloaded using specialized software in various formats. A GIS-based shape or vector file and a grid-based ASCII (text) file that lists the X, Y, and Z coordinates of survey points are the most common formats of the survey data. Once the survey data were downloaded in these formats, they could be further customized and/or transformed for use on several platforms.

Geographic Information System (GIS) is a database software program that enables users to store and manipulate large amounts of data from GPS and other sources for maintaining and analyzing spatial features and also the relationships between options as they are outlined through geographic coordinates or measurements. Managing road net-work distress is a practical solution for environmental and economic problems.

So, time to time road distress management is necessary for managing the degree of deterioration of pavements and limiting maintenance costs.

Digital Elevation Model (DEM) is a generic term for digital topographic data in all its various forms. The generic DEM ordinarily implies elevations of the piece of land (bare earth z-values) destitute of vegetation and manmade options (Zhou, 2017).

The other important factor considered concerning the durability of Pavements is drainage. Effective drainage of both the surface and sub-surface layers is required to remove water from the pavement and prevent deterioration/failure of the pavement structure resulting from the entrance of water into the pavement layers. When the slope of a road increases, the surface runoff velocity on the road surface increases causing the volume of stagnant water on the road surface to decrease. Hence, the pavement experiences good drainage that leads to less occurrence of distress and answers to why road distress is associated with surface runoff (Nasir et al.,2016).

The study was allotted within the road segment from Entoto to the center of Chancho town. There is pavement distress in the road segment from Entoto to the center of Chancho town and needs maintenance (Rnmd, 2018). This research mainly focuses on road distress maintenance management activities using GIS software and making decisions for road repairs according to priorities. The relationship between pavement distresses, slope factor, drainage, mobility, pavement performance, riding comfort, maintenance system, and recommended treatments were also covered in this study.

1.2. Statement of the problem

The Ethiopian Roads Authority (ERA), on behalf of the Federal Democratic Republic of Ethiopia for the sole purpose of executing the Package–I: Heavy Routine Maintenance Road Projects under Entoto – center of Chancho town Heavy Routine Maintenance Project.

The existing road pavement has developed insufficient thickness following several years of trafficking. Due to this reason, the road users are repeatedly losing their vehicle tiers and spare parts so that the road segment needs immediate heavy maintenance (Rnmd, 2018).

Some entities have developed maintenance improvement plans (MIP'S) and have incorporated the use of GIS to track maintenance. The implementation of a MIP system can assist in the management of road maintenance and reduce the cost of maintaining the streets (Kmetz, 2011).

The usual way of the ERA pavement distress management system is by using the condition survey and defect identification manual. Despite, there is no GIS-based pavement distress maintenance management system in ERA, there is an increase in maintenance and construction cost due to lack of pavement distress management with appropriate time and condition. The reason could vary from lack of resources to simply not knowing the various strategies out there to manage road distress.

The cost to replace the road is larger than the cost to maintain it. So, managing the pavement distresses by prioritizing maintenance using the analytic hierarchical process and display the result as a weighted overlay map using the GIS software is necessary.

1.3. Objectives

1.3.1. General objective

Road distress location, severity and extent level identification, study variables relationship examination, and improvement of road distress maintenance management systems by identifying contributing factors that support decisions for road repairs according to priorities.

1.3.2. Specific objectives

- To examine the relationship between study variables (i.e. pavement distress, slope factor, drainage, mobility, pavement performance, riding comfort, maintenance system, and recommended treatment).
- To identify the contributing factors/criteria for maintenance prioritization
- To manage the road distresses by ranking for maintenance and display them as a weighted overlay map.

1.4. Research questions

The research questions of this study are summarized as follows:

- What is the relationship between pavement distress, slope factor, drainage, mobility, pavement performance, riding comfort, maintenance system, and recommended treatment?
- What are the contributing factors/criteria for maintenance prioritization?
- Which distresses are maintained first?

1.5. Significance of the study

The study makes a significant contribution, both in a theoretical and practical understanding of the road network distress maintenance system. It is also important to provide important information on social and economic issues. The results obtained from the study can be used to create an awareness of road distress maintenance management activities using GIS software.

For future developments, it plays a significant role in controlling the degree of deterioration, limiting the maintenance costs, making decisions for road repairs according to priorities, and to provide effective and safe management strategies and planning schedules.

1.6. Scope of the study

The study was allotted within the road segment from Entoto to the center of Chancho town. This research mainly focuses on road distress maintenance management activities using GIS software and making decisions for road repairs according to priorities. The relationship between pavement distress, slope factor, drainage, mobility, pavement performance, riding comfort, maintenance system, and recommended treatment was also covered in this study.

1.7. Organization of the thesis

This thesis consists of five chapters. Chapter one deals with an introduction of the study, objectives to be achieved, the significance, scope, research questions, and problem statement of the study. Chapter two deals with the connected literature reviewed and its corresponding conceptual framework. Chapter three describes a description of the study area, data collection techniques and procedures, materials and methods, research design, and study variables used for the research under study. Chapter four describes the results and discussions of the study. Finally, Chapter five deals with the conclusion and recommendation of the study.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. Introduction

Various types of research were carried out by several scholars and professors of civil engineering in this field, to find ways of using GPS and GIS for safe pavement management systems (PMS). The main expert body who is handling the system development of achieving a comprehensive PMS is originally an Australian consortium. It is always quite beneficial to learn from the acquired experience of the different departments of Transportation with their developed pavement management systems and the future directions of these systems all over the world.

2.2. Integrated use of GPS with GIS

There is a variety of the way during which GPS is employed aboard GIS. First, GPS may be used to identify or refine the geographical coordinates associated with satellite imagery. GPS is employed to scale back distortions and to boost the pointing accuracy of those pictures. The explosion in interest in GIS as a management tool has been among the event of a variety of enabling technologies, one of the more important of which is the Global Positioning System (GPS). While GIS technology offers tremendous capabilities for a lot of informed management higher cognitive processes, rendering competent decisions still depends on having reliable data (Flange and Gilbert, 2017).

GIS database has significant benefits and proven performance using an easy and cost-effective technique in road surface monitoring. This methodology reduces the training needed to method field data to be used in a dearly-won skilled GIS software package. Also, this methodology will increase productivity by streamlining workflows once aggregation field data and GPS data or working with geo-tagged road distress photos and processing these data in a geospatial context.

The method offered flexible data collection options to make information from the field-collected data, including geotagged photos in which only a hand-held GPS receiver and digital camera are used whereas personal computer or cable connections were not required (Fendi et al., 2014).

2.3. Pavement Management Systems (PMS)

Pavement management systems usually use pavement condition data to predict pavement performance and to develop optimum strategies for the future maintenance and rehabilitation of pavements on the road network. Until recently pavement condition knowledge has been gathered annually by groups of evaluators (Virginia department of transportation, 2012).

2.4. Pavement Management System (PMS)/GIS Integration

The spatial analysis capabilities of geographical data systems that match the geographical nature of the road networks, are thought-about to be the foremost applicable tools to reinforce pavement management operations, with options like the graphical show of pavement condition. The locations, severity levels, and the gradients of slopes along the roads were carried out in a spatial analysis manner.

The combination of the spatial information and GIS with success created maps can upgrade and improve the method of deciding road maintenance activities, from collecting data to making decisions for road repairs according to priorities and shows the precise locations of the distresses. The system is a collective effort utilizing the available technologies of GIS and its tools that are believed to be the best system of road maintenance management to be used in the future. GIS can also be applied to other systems as well but not limited to road management only. Examples that can be given are sewage, waste management, water management, and piping (Nasir et al., 2016).

GIS-based application is reliable and precise that used for effective monitoring and evaluation of the road network.

The system help decision-makers in taking decisions interactively with the aid of visualization of data in GIS without requiring any specialized technical skills that why it is user friendly (Flange and Gilbert, 2017).

2.5. Pavement Management System (PMS)/GIS case studies

Virtual reality (VR) can interact within the map that makes it more effective in GIS mapping as well. The full integration of GIS, VR, and the Internet can dramatically increase GIS capacity in spatial data visualization and analysis, and extend its decision support role in applications (Huang et al., 2001).

Many agencies interviewed to highlight their pavement management practices are constrained by limited budgets and personnel resources. They had a variety of reasons for investing even with those constraints in pavement management, including:

• Provides a rational engineering call for choosing comes. – Stark County

• Helps to identify the recommended treatments for the right roadways at the right time. – Edgar County

• Reduces political pressure to create bound treatment alternatives. – Champaign County

• Serves as a tool to help an organization secure more funding for pavement needs. – McHenry County “The cost (of pavement management) is worth it (Wolters et al., 2011).

2.6. Current practices in pavement performance modeling and prioritization for maintenance

Many freeway agencies around the country have undergone the event of pavement performance models or are within the method of doing this. Under this paper, a literature review of sources documenting pavement performance modeling and maintenance prioritization practices was conducted. The reviewed documents served as the foundation for an overview of performance modeling practice.

2.6.1. Analytic Hierarchy Process (AHP)

In several engineering applications, the evaluation of a set of alternatives in terms of several decision criteria concludes the final decision.

The analytic hierarchy method is a tough task and also looks to produce a good approach for decision making by correctly quantifying the appropriate data.

The nice mathematical properties of AHP attracted the interest of many research ers that the required input data are rather easy to obtain. It could be a call support tool that may be wont to solve complicated call issues. It uses a multi-level data structure of objectives, criteria, sub-criteria, and alternatives. The pertinent information is derived by employing a set of pairwise comparisons. These comparisons require the weights of importance of each decision criterion of the alternatives.

AHP uses a pairwise comparison that impressed the creation of several alternative decision-making strategies. It is the most widely accepted and is considered the most reliable multi-criterion decision-making method.

AHP is a theory and methodology for relative measurement that the exact measurement of some quantities are not interested, but rather on the proportions between them (Labib, 2014).

The process accomplishes these three steps:

1. State the objective: Rank the type of distress which can be maintained first.
2. Define the criteria: Severity 1, severity 2, severity 3, extent 1, extent 2, extent 3, performance, and maintenance cost.
3. Pick the alternatives: Alligator crackings (AC), Longitudinal cracking (LC), Edge breaks (EB), Ruttings (RU), Patchings (PA), Potholes (PO), Ravellings (RA), and shoving (SH).

Using AHP

1. Decompose the decision-making problem into a hierarchy
2. Build pairwise comparisons and establish priorities among the elements in the hierarchy
3. Synthesize judgments to get the set of weights for achieving your goal
4. Appraise and check the consistency of judgments

The basic procedure is as follows:

1. Develop ratings for each decision alternatives for each criterion by
   - developing a pairwise comparison matrix for each criterion
   - normalizing the resulting matrix
   - averaging the values in each raw to get the corresponding rating
   - calculating and checking the consistency ratio
2. Develop the weights for the criteria by
   - developing the pairwise comparison matrix for each criterion
   - normalizing the resulting matrix
   - averaging the values in each raw to get the corresponding rating
   - calculating and checking the consistency ratio

3. Calculate the weighted average rating for each decision alternative and choose the one with the highest score.

   - The information is then synthesized to determine relative rankings of alternatives.
   - Both qualitative and quantitative decision can be compared using informed judgments to derive weights and priorities.
   - One can think severity 1(S1) is the least important followed by severity 2 (S2), severity 3 (S3), and more important followed by extent 1 (E1), extent 2 (E2), extent 3 (E3), performance (PR) and, maintenance cost (MC).

Structure of the hierarchy

Decompose the decision-making problem into a hierarchy of criteria and alternatives.

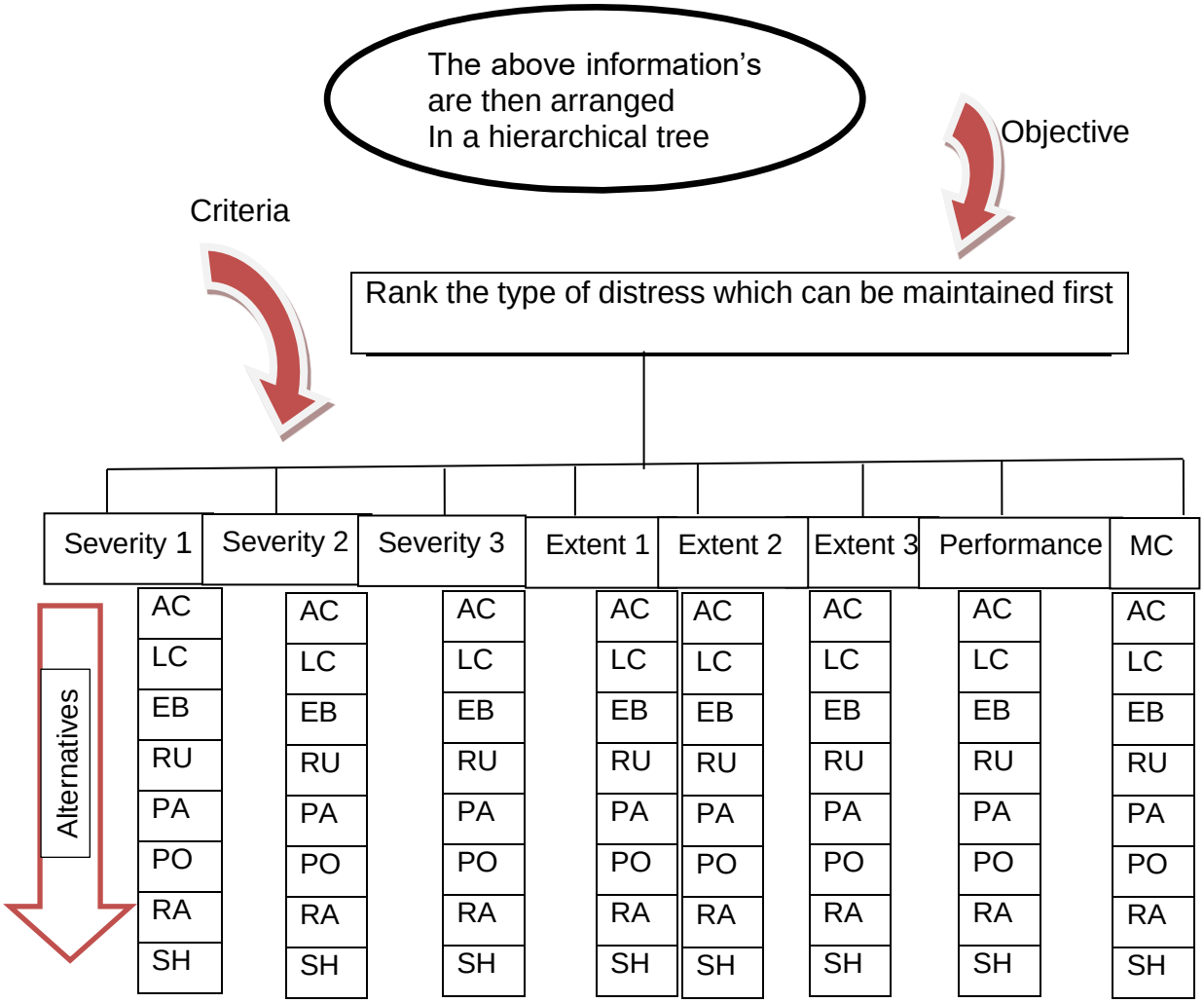


Figure 2. 1. Structure of AHP

Pairwise comparison matrix in the AHP

A decision-maker might run into troubles once asked to submit a rating within the style of a numerical vector for a large variety of alternatives. Does not it usually happen that they do not tend to decide among many alternatives?

Even worse, they do not tend to decide and eventually notice that it was not the simplest decision?

This is a matter of fact and originates from our cognitive limits and the impossibility of effectively comparing several alternatives at the same time.

An effective way to overcome this problem is to use pairwise comparisons. The reason for doing so is that this allows the decision-maker to consider two alternatives at a time.

Thus, the strategy is that of decomposing the original problem into many smaller sub-problems and deal with these latter ones.

Formally, the pairwise comparisons are collected into a pairwise comparison matrix, A = (aij) n×n, structured as follows:

$$A = \begin{bmatrix} a11 & a12 & \dots & a1n \\ a21 & a22 & \dots & a2n \\ \vdots & \vdots & \ddots & \vdots \\ an1 & an2 & \dots & ann \end{bmatrix}$$

aij > 0, expressing the degree of preference of xi to xj. More precisely, according to Saaty's theory, each entry is supposed to approximate the ratio between two weights (Dargahi, 2016).

$$aij \sim \frac{wi}{wj} \qquad \text{for all i, j}$$

Each somebody (decision maker) investigates the weights of the decision components within the hierarchy and incorporates their judgments by playing a pairwise comparison of those components. The upper level of each decision element is used to compare the elements of an inferior level of the hierarchy. That is, the alternatives are compared concerning the sub-criteria, the sub-criteria are compared concerning the criteria, and the criteria are compared with the goal.

Therefore, a group of pairwise comparison matrices is constructed by every decision-maker reflecting how necessarily decision components are important to them about the goal. Based on the saaty fundamental scale, pairwise comparison matrices are built from a comparison between the elements (Dargahi, 2016).
In keeping with this scale, the specified values of the pairwise comparison are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}.

Table 2. 1. Saaty fundamental scale for pairwise comparison

Intensity of importance	Definition	Explanation
1	Equal importance	The two elements have an equal contribution to the objective
3	Moderate importance	One element is slightly favored over another
5	Strong importance	One element is strongly favored over another
7	Very strong importance	One element is very strongly favored over another
9	Extreme importance	One element is extremely favored over another.
Intensities of 2, 4, 6, and 8 express an intermediate value of the defined intensity of importance defined above. Intensities 1.1, 1.2, 1.3, etc. expresses elements that are very close in importance with the defined ones.		

2.6.1.1. Determination of the consistency and the priority vector

Evaluate the criteria in pairs to determine the relative importance between them and their relative weight to the global goal. The evaluation begins by determining the relative weight of the initial criteria groups.

Here is a way to solve for the priority vector (eigenvector):

1. The pairwise comparison matrix is successively squared each time.
2. The raw sum of the squared matrix is then calculated and normalized
3. Do the iteration until the difference between the current eigenvector value and the previous eigenvector value is equal to zero.

In line with the result that given a pairwise comparison matrix A, its most eigenvalue, λmax, is equal to n if and only if the matrix is consistent (and bigger than n otherwise), Saaty [101] projected the Consistency Index:

Maximum Eigenvalue (λ_{max}) = $\mathrm{EV1} * \mathrm{T1} + \mathrm{EV2} * \mathrm{T2} + \cdots + \cdots + \cdots \mathrm{EVn} * \mathrm{Tn}$ [1]

Where:

EV1 ……. EVn is eigenvectors and T1 …… Tn is the total column sum of the matrix.

$$\mathrm{CI\ (A)} = \frac{\lambda\,\mathrm{max} - \mathrm{n}}{n-1} \qquad [2]$$

But, numerical studies showed that the expectation of CI of a random matrix of size n + 1 is on average, larger than the expected value of CI of a random matrix of order n. Consequently, CI is not truthful in examination matrices of various orders and needs to be rescaled. The Consistency Ratio (CR) is the rescaled version of CI. The CR of a given matrix of order n is obtained by dividing CI by a real number RI_n (Random Index) that is nothing else however an estimation of the common CI obtained from an outsized enough set of randomly generated matrices of size n. Hence,

$$\mathrm{CR\ (A)} = \frac{\mathrm{CI(A)}}{RI_n} \qquad [3]$$

Note that the generation of random matrices needs the definition of a delimited scale wherever the entries take values, for example, the interval [1/9, 9]. In line with Saaty [102], in follow, one ought to settle for matrices with values CR ≤ 0.1 and reject values bigger than 0.1. A worth of CR = 0.1 implies that the judgments are 10% as inconsistent as if they had been given every which way (Abulizi et al., 2016).

A wonderfully consistent decision-maker should always get CI=0, however, tiny values of inconsistencies are also tolerated. Specifically, if $CR(A) < 0.1$, a reliable result is expected from AHP and the inconsistencies are tolerable.

RI_n is Random Index, i.e. the consistency index when the entries of A are completely random. Table 2.2 displays the values of RI_n for small problems (n≤10) as shown below.

Table 2. 2. Values of the random index for small problems

N	2	3	4	5	6	7	8	9	10
RI_n	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

2.6.2. Pavement performance evaluation overview

Evaluations of pavements are conducted to figure out the structural and functional conditions of a route section for functions of a routine inspection. Primarily, the ride quality or surface texture of a route section assessment is important. At the network level, routine evaluations may be wont to develop performance models and order maintenance or rehabilitation efforts and funding.

2.6.2.1. IRI (International Roughness Index)

The first step in the pavement evaluation process is assessing the ride quality or surface texture of a route section that provides information about passengers' comfort of travel and the mobility condition of the pavement which is directly related to the pavement performance condition. In this study, IRI data were used to assess these two parameters by determining average IRI value and statistical analysis of the best linear fit relationship between IRI versus speed graph respectively. It is necessary to measure pavement roughness condition because pavement distresses have an impact on it.

The pavement performance condition is determined using IRI and PDI. ERA assigns IRIs into five categories (Rnmd, 2018). The IRI value of the pavement is calculated by using equation 4.

$$IRI = \frac{IRI1 + IRI2}{2} \qquad [4]$$

2.6.2.2. PDI (Pavement Distress Index)

PDI is the weighted summation of the product of severity and density of the selected pavement distresses. The associated weights of distresses were determined to support professional data.

That pavement distresses have the principal important impact on the roughness and surface defects of asphalt pavement. The quantitative index for the pavement distresses on every section is calculated by using equation 5 (Yeganeh et al., 2019).

$$\mathrm{PDI} = \sum_{i=1}^{n} \mathrm{wi}(\mathrm{si} * \mathrm{di}) \qquad [5]$$

Where PDI = pavement distress Index, i = distress kind, wi = weight for every distress si = severity of distress (high = 3, moderate = 2, low=1) and di = density of distress (in meter or sq. meter).

The PDI scale starts at zero for a distress free pavement condition and increases (without bound) as pavement condition worsens. MDOT assigns PDIs in three categories. Low (DI ≤ 20), medium (20 < DI <40), and high (DI ≥ 40). A PDI of 50 or higher corresponds to a distress level beyond which rehabilitation or reconstruction should be seriously considered (Wu et al., 2010).

Density calculation (Shahin and Kohn, 1981)**:**

The density of distresses measured in square meters (m^2):

$$\mathrm{Density} = \frac{\text{Amount of distress } (m^2)}{\text{Sample unit area } (\mathrm{m}^2)} * 100 \qquad [6]$$

The density of distresses measured in linear meters (longitudinal and transverse cracks):

$$\mathrm{Density} = \frac{\text{Amount of distress } (\mathrm{m})}{\text{Sample unit area } (m^2)} * 100 \qquad [7]$$

The density of distresses measured by the number of potholes:

$$\mathrm{Density} = \frac{\text{No.of potholes}}{\text{Sample unit area } (\mathrm{m}^2)} * 100 \qquad [8]$$

Where, the sample unit area is the area in which each distress type severity and extent level evaluations were made since carriageway defects were recorded in the carriageway section by measuring the affected area in each 500m section (Patterson, 2005).

Sample unit area = total width of the road (7m) x 500m = **3500m^2**

2.7. Conceptual framework

This conceptual framework is developed once reviewing completely different connected varieties of literature. It is chiefly developed supported proof found in several studies. Supported the findings that are gained from completely different studies, the study variables are mentioned and their inter-relationship coordination assessment is explained. Use pavement performance strategy as a driving force behind performance measurement.

Government agencies are typically mandated to own strategic plans with goals and objectives outlined inside those plans.

Performance measurement provides vital inputs to line priorities and it provides crucial data that helps agencies find potential issues and create corrections enroot to meeting goals and objectives.
Performance measurement could be an elementary element of a good manage ment strategy because it permits method management and improvement.

Transportation departments are lucky to own a wealth of information available to them concerning the services they supply and therefore the infrastructure they build, operate, and maintain if they fight to gather the information extensively.

However, during a data-rich atmosphere, the challenge is to work out however best to collect, analyze and gift the information so that it is significant to stakeholders, and this can be particularly vital for performance measures that are reportable to or utilized by a broad vary of audiences.

The choice of the recommended performance measure is a crucial step in developing a performance measurement method and implementing it as a management system.

Although the literature covers a wide variety of such experiments, this review will focus on the examination of the association between the pavement distresses, the slope factor, pavement performance, riding comfort, recommended treatment, maintenance system, mobility, and drainage.

While the literature presents these themes in a variety of contexts, this paper will primarily focus on geospatial pavement distress maintenance management maps, pavement performance evaluation, the slope factor and drainage condition of the road section, and maintenance information. Schematically the association is delineated as below.

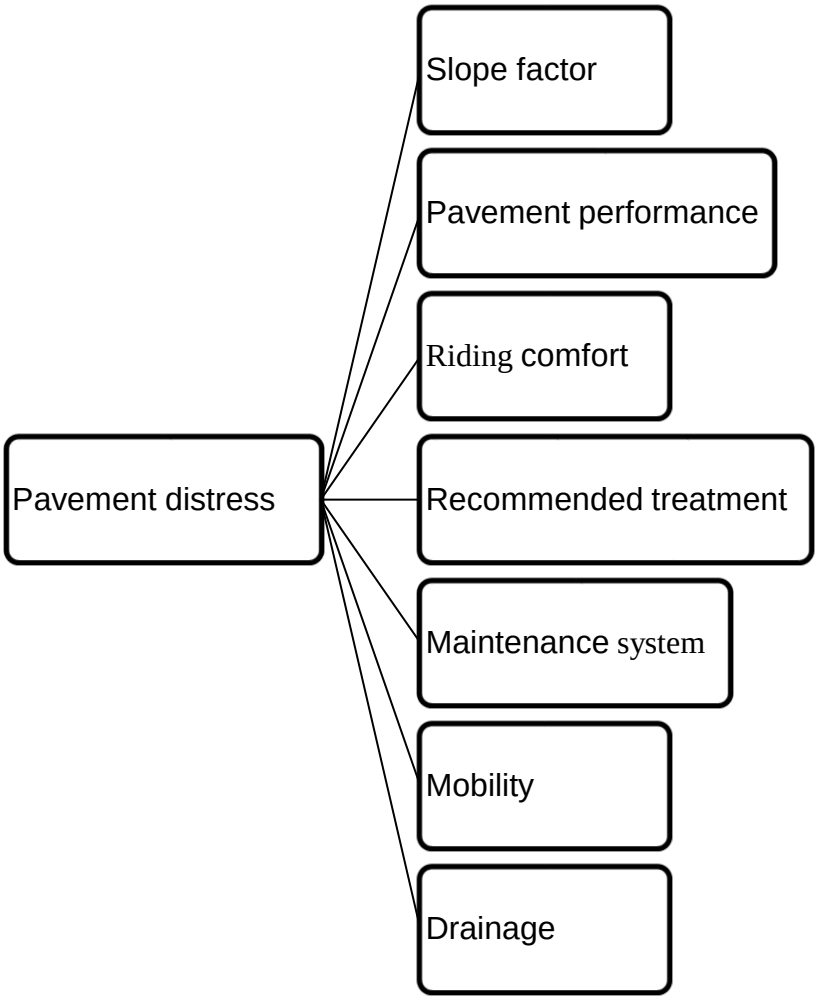


Figure 2. 2. Conceptual framework

CHAPTER THREE
METHODOLOGY

3.1. Description of the study area

Addis-Chancho has climatical zones that move as Weinadega climatical conditions. The project space usually has a rolling and mountains piece of ground. However, the piece of ground and therefore the condition of the project with relation to the road segments are in brief mentioned within the sub-sections of this text.

Addis - Chancho is a constructed road that is under the Alemgena District of ERA that starts from the Entoto and ends at the Center of Chancho town. The condition of the present constructed road is categorized as in a good condition. Moreover, the road section has incomprehensible tons of guideposts that are necessary for traffic safety.

The topography at begin of the project Entoto road section runs through a mountainous piece of ground step by step becomes rolling once heading to the tip of the project. In this road section, there are broken and missed guideposts and kilometer posts. Due to this reason, the vehicles that don't recognize the road section antecedently can get into an accident repeatedly. There exists pavement distress in the road section from Entoto to Center of Chancho town and needs maintenance.

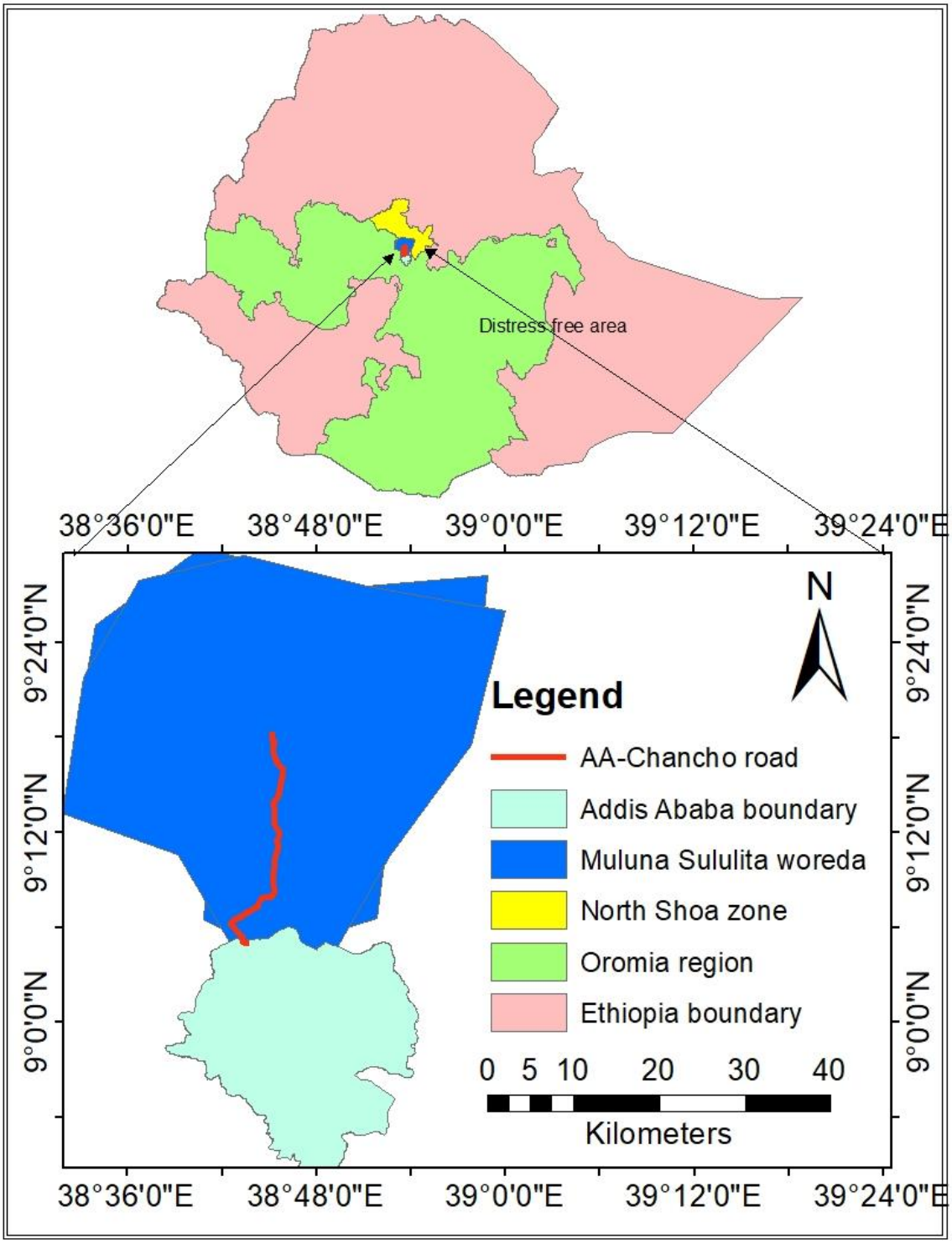


Figure 3. 1. Map of the study area

3.2. Data collection procedures and techniques

The data were collected from each primary and secondary sources. The primary information was collected from the location of pavement failure by exploitation techniques like; surveying, capturing images, and observation.

The secondary information like IRI data, ERA road maintenance technical specification and road condition survey manual were gained from ERA through the snowball sampling technique. The snowball sampling technique is a kind of non-random sampling during which one person recommends another, who recommends another, who recommends another, etc. it is a very important manner of characteristic hard-to-reach important information.

First, an initial interview was gone down in the AD workplace. Interviewees were volunteers, able to provide applicable answers, and provide direction concerning a lot of pavement failure location of the road section. They also provide photos of the road section.

Second, the road distress coordinates and their corresponding pictures were collected and captured from the place by using the GPS map camera. Once the GPS survey was complete, the survey information from GPS units is downloaded using specialized computer code in numerous formats. A GIS-based form or vector file and a grid-based ASCII (text) file that lists the X, Y, and Z coordinates of survey points are the commonest formats of the survey information. Then the computer code output result findings were analyzed, interpreted, and linked with pavement evacuation capabilities and slope factors.

Finally, the declaration of the analysis findings and suggestions supporting those findings were stated.

3.3. Pavement distress maintenance management method and data used for the study

A scientific and repeatable pavement distress maintenance management method development is a key element in the effective management of a pavement network.

The steps made below function as a guide for customizing a pavement distress maintenance management method.

Step 1: Outline the route network and collect inventory information

The first step of a pavement management method was outlined in the route network. A route network was comprised of a list of the physical characteristics of the roadways being managed. Once segments were outlined, the inventory data for every section were collected by either estimating the data or collecting all the required information. The precise kind of inventory data needed depends on what information is accustomed to support the selections.

Step 2: Collecting condition data

Pavement condition data is a significant consider any data-driven decision-making pavement management method. Inside the pavement management method, the condition data were accustomed to determine current maintenance and rehabilitation wants, to predict future wants, and to assess the impact on the network.

Condition data were collected by using both manual and machine-controlled data collection strategies. With either methodology, distress data were calculable or measured.

The visual survey was conducted through the whole section of the road for measuring and mapping out all the distresses known on the pavement surface. Distress data refers to the information that describes the kinds, extent, and severities of distresses on the pavement surface. The images of the distress were collected by using a GPS map camera and therefore the geographical coordinates of sampling locations were obtained by it throughout field investigations. The length, width, and depth of distresses were measured by using a meter. Those data were collected through visual inspections throughout condition surveys, record via visiting the road section by the pick-up, by walking on foot, and were analyzed to spot the distresses present.

GPS map camera

GPS map camera is a smartphone application that uses location-based data and ideas of increased reality to boost the user's expertise. Using a GPS map camera, the application is location-aware and the track of user location in real-time was kept.

Whenever the user points the phone in any direction, the application updates its camera read by displaying the label tags with extra data of the road distresses and places in that respective direction. Various distress data like their geospatial locations were extracted from the google information.

The information once gathered is then displayed to the live feed of a camera that helps the users to act in a very reliable manner.

The choice for reading the places in map view with the assistance of google maps is additionally offered. The application uses Wi-Fi. The road distress coordinate points were overlapped with the road shapefile gained from ERA. So, this shows that the validation of the camera.

The key reasons that forced to decide on a GPS map camera were:

License Free:

The license expenses do matter plenty, which isn't noticeable within the GPS map camera development owing to its free sourcing advantage.

Not labor-intensive:

Since it is a smartphone application, it doesn't need a lot of labor for work. It is merely done by 2 persons at a time. It doesn't need several crews for work at a time.

Save time and money:

Currently, smartphones are handled by many persons and their price is cheap relative to different instruments like differential GPS and total station. Thus this results in being cost-efficient. It doesn't take long to regulate, like differential GPS and total station (simply transfer the application from google play then install it), afterward open

the Wi-Fi association and also the camera to capture the photos (this saves time). Once we open the image properties and click on the detailed choice, the GPS coordinate values of the distress were displayed. Additionally, when we open the file data of the image, there is an associate open map choice. Click the open map choice one will see wherever the distress is within the google map of the road.

Ease within the application:

Any person will operate and it doesn't need a lot of professions to work in. It shows the situation and also the distance (that fars from the beginning point). It is dawn loaded simply and put in with none ambiguity.

Step 3: Predict condition

After the data, like locations, distress measures, and photos for the study area were collected, the database was created. Using the survey data, the severity and extent levels of the distress were known by employing a road condition survey manual (Patterson, 2005). With current pavement conditions assessed, actions were equipped with the data required to predict the longer-term condition of a section.

Step 4: Analyze the data

Data analysis is the method of the transfer order, structure, and aiming to the mass of collected knowledge. During this section potential outcomes of the findings are mentioned 'what the result means that'. While organizing and checking the consistency and completeness of the data, the information was entered by using a laptop (excel, micro soft access, and quantitative analysis). Then an outline of the data was compiled, analyzed, and presented by tables, figures, charts, maps, and graphs.

In general two methods of data analysis were used. They are qualitative and quantitative. Qualitative data analysis may be a search around for general statements regarding relationships among classes of information. In this method words, concepts, terms, symbols, etc. are used to construct a framework for communicating

the essence of what the information reveals, whereas quantitative methods use procedures and techniques to research knowledge numerically.

Step 5: Choose the recommended treatments

The fifth step in planning the pavement management method was to pick out acceptable treatments for the road section. The created information was exported and displayed in GIS and the result shows the locations and everything the data regarding the distresses. Recommended treatments were selected using alternating schedules or treatment trigger rules. The recommended treatments were then prioritized after ranking a lot of detected pavement areas or locations and provide acceptable maintenance in time.

Step 6: Report results

Research results were reported using different strategies to highlight vital factors that could assist decision-makers with their final choices. Data reporting is a good methodology of communication not solely the recommendations from the pavement management method however conjointly transferring connected data to decision-makers. Reports, tables, graphs, GIS-based maps, and charts were generated from the data to extract relevant information relating to any sections into consideration and those results were given by using them for the road network from Entoto to the center of Chancho town. The road distress conditions and their relationship with the slope factor (gradient) and drainage capability of pavement were also assessed by the study.

Additionally, the assessment performance ability of the pavements was mentioned. The combination of the spatial information and GIS with success created maps can upgrade and improve the method of deciding road maintenance activities, from collecting data to making decisions for road repairs according to priorities and shows the precise locations of the distresses within the road section from Entoto to the center of Chancho town. All the required information about the distresses which are filled in the attribute tables are displayed using an identify icon of the Arc GIS software.

Once the paper got approval the finding of the analysis was submitted and given to Addis Ababa University Institute of Technology Department of Civil Engineering.

Designing a pavement distress management method

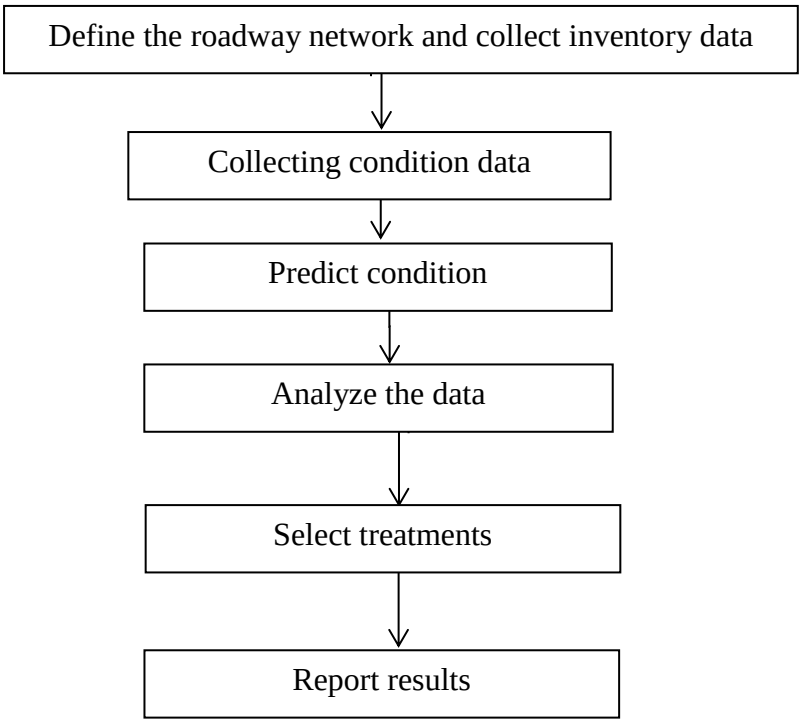


Figure 3. 2. Methodology flow chart of the research

3.4. Data analysis methodology and interpretation

3.4.1. Road distress

Pavement distress is any visible defect or style of deterioration on the surface of the pavement and is the most basic measure of the performance of an existing pavement. To completely describe pavement distress, the subsequent 3 factors should be considered.

Type: the kind of distress is set primarily by similar mechanisms of prevalence and look. By distinguishing the kinds of distress, a good deal of data is often inferred relating to the underlying causes of deterioration.

Severity: The severity of distress represents the criticality of the distress in terms of progression. Severe distresses would require extreme rehabilitation measures. **Amount:** the amount of every kind and severity level should be measured and expressed inconvenient terms.

3.4.1.1. Type, severity, and extent of distress

The condition survey will be measured in terms of the severity of distress or defect and the extent of the distress or defect. The severity and extent levels were recorded as a number from '0' (Good) to '3' (Poor) (Patterson, 2005). The intention is to assist in speedy repeatable surveys that can pick up the required data to provide the engineer with the overall condition of the road and estimate of the maintenance requirements

Severity: It is the measure of the distress in terms of rate.

Extent: The extent of the defect is the extent or area of the distress or defect. This is recorded with a number indicating the extent. '0' (no extent) to '3' (great extent). Carriageway defects were recorded in the Carriageway section by measuring the affected area in each 500m section (Patterson, 2005).

Table 3. 1. Edge damage severity and extent specification as per ERA manual

Severity	**Extent**
Width of damage 1 between 100mm and 150mm 2 between 150mm and 300mm 3 greater than 300mm	1 less than 20% of the section affected 2 between 20% and 50% of the section affected 3 greater than 50% of the section affected

Table 3. 2. Rutting severity and extent specification as per ERA manual

Severity	Extent
1 maximum rut depth between 10mm and 20mm 2 maximum rut depth between 20mm and 50mm 3 maximum rut depth greater than 50mm	1 less than 20% of the section affected 2 between 20% and 50% of the section affected 3 greater than 50% of the section affected

Note: the rut depth is to be measured at selected areas in the 500m sections and the maximum reading recorded.

Alligator cracking

It is a combination of a series of interconnected fatigue and block cracks of various stages of development. It can occur anywhere in the road lane and develops into a many-sided pattern that resembles chicken wire or alligator skin that must have a quantifiable area.

Severity levels of alligator cracking

Low

An area of cracks in the pattern is no further apart than 1 foot (0.328 m), may be sealed cracks with sealant in good condition, and a crack width that cannot be determined. The cracks are not spalled and with no or very few interconnecting cracks. Cracks are ≤ 0.25 in (6 mm) in mean width.

Medium

An area of interconnecting cracks forming a complete pattern is no further apart than 6 in (150 mm), maybe slightly spalled. Cracks are > 0.25 in (6 mm) and ≤ 0.75 in (19 mm) in mean width.

High

An area of interconnecting cracks forming a complete pattern is moderately or severely spalled. Cracks are > 0.75 in (19 mm) in mean width.

Based on the above description of each severity the overall severity of alligator cracking is determined by using a combination of the highest level of crack width and crack pattern.

Longitudinal cracking

It occurs predominantly parallel to the pavement and can occur anywhere in the road lane. Cracks occurring in the wheel path may be noteworthy.

Severity levels of longitudinal cracking

Low

Cracks with a mean width of < 6 mm. Sealed cracks with sealant in good condition and a width that cannot be determined.

Medium

Any crack with a mean width of > 0.25 in (6 mm) and ≤ 0.75 in (19 mm).

High

Any crack with a mean width > 0.75 in (19 mm).

Table 3. 3. Alligator crack and longitudinal crack severity and extent specification as per ERA manual

Severity	Extent
1 Any	1 less than 10% area cracked (wheel path) or less than 10% area cracked transverse or longitudinal 2 between 10% and 20% area cracked 3 greater than 20% area cracked

Many kinds of literature describe that it is best to use the alligator cracking severity and extent specification for patching.

Table 3. 4. Raveling severity and extent specification as per ERA manual

Severity	Extent
Percent of raveled area 1 less than 10% area raveled 2 between 10% and 20% area raveled 3 greater than 20% of the area raveled	1 less than 20% of the section affected 2 between 20% and 50% of the section affected 3 greater than 50% of the section affected

Table 3. 5. Pothole severity and extent specification as per ERA manual

Severity	Extent
1 Pothole depth only in the surfacing 2 2 or more potholes greater than 0.5m^2 in surface area or depth of pothole into the base course 3 2 or more potholes greater than 1m^2 in surface area or depth of pothole into the sub base	1 less than 1 pothole in the section 2 between 2 and 10 potholes in the section 3 more than 10 potholes in the section

Shoving

It is a longitudinal displacement of the pavement surface caused by breaking or accelerating vehicles. It may have associated vertical displacement and is usually located on hills or curves, or at intersections.

Severity levels of shoving

The severity levels of shoving are not applicable. However, the severity and extent levels of shoving can be defined by its effect on ride quality and percent of affected area respectively. It is measured by recording the number of occurrences and square meters of the affected area.

3.4.2. Predict the road section condition and maintenance priorities

After differentiating the kind, severity, and extent levels of distresses, the pavement conditions were predicted for the road section using PDI, IRI, and AHP analysis results of the distresses by using the formulas and as per the interpretations of results as stated in the literature review.

In this study contributing factors for the pavement distress maintenance prioritization were selected after assessing the study variables relationship. The study variables are picked out from the literature review which states at the network level. But the selected road section for this research is a single road section. So, it is necessary to select the maintenance priority factors among the study variables which were suitable for the selected road section.

The method of the analytic hierarchical process by analyzing the judgments gained from the experts of Alemgena District workers (12 experts), the performance index of distresses (by calculating pavement distress index for each distress type), and treatment based maintenance cost (by calculating the cost of maintenance for each distress type) were used as input parameters for maintenance prioritization in weighted overlay analysis. The treatment based maintenance cost (TBMC) of each distress type was computed by using equation 9.

Treatment based maintenance cost = Estimated quantity X Unit rate [9]

During this analysis, GIS was the main tool in mapping the road distresses. The coordinates of the distresses that were collected by GPS map camera were entered into the GIS software, then a full map of road distress was turn out. The data collected were presented in a table form and the road authority could determine the precise location of the distress with ease using the map as a guide.

The map created by GIS could show the present state of the road or road distresses supported the most recent data updated into the attribute table.

The slope gradient of a route was obtained simply by exporting and analyzing the spatial data of height (DEM) in GIS software. DEM of the study area is obtainable free from value on-line. One will simply browse from the net to induce free DEM. Then load to the Arc map document and put it aside.

The priorities for maintenance of road distress were done using a weighted overlay analysis of GIS software. Then the distresses were prioritized and ranked to provide acceptable maintenance on time.

Finally, the recommended treatments were identified by using the ERA road maintenance works manual and road condition survey manual.

3.5. Research design

This analysis was meant to answer the research questions and meet its objectives supported by the findings. For this study, descriptive, quantitative, and qualitative forms of analysis approach were adopted. The conclusion of the findings depends on the manipulation of this knowledge implies a quantitative and qualitative approach. The systematic identification of the practical problems, their solutions, and comparisons of the analysis results in a descriptive approach.

3.6. Study variables

The study variables of the research were pavement distress, gradient/ slope factor, pavement performance, riding comfort, recommended treatment, maintenance system, mobility, and drainage.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Results and discussions

After the data was collected as specified in the methodology section, it was analyzed using different mechanisms and methods. The analysis results of the findings were explained in the consecutive sub-sections.

4.1.1. Pavement distresses along the section of the road

At low levels of severity, pavement distress will have very little, if any, impact on the power of the pavement to hold traffic safely and efficiently. However, at higher levels of distresses, the rideability and structural capability of the pavement, and maybe even its safety, are often severely compromised. A total of 126 road distresses were detected from the field survey. They consist of 8 types of distress as stated in table 4.1.

Table 4. 1. Road section distresses in each severity and extent category

Type of distress	Severity level			Extent level		
	One	Two	Three	One	Two	Three
Edge breaks	1	4	3	8	0	0
Potholes	7	4	21	7	25	0
Ravelings	18	1	0	19	0	0
Ruttings	0	1	2	0	2	1
Alligator cracks	25	8	0	33	0	0
Patchings	9	14	6	29	0	0
Longitudinal crack	1	0	0	1	0	0
Shoving	1	0	0	1	0	0

From table 4.1, out of 8 edge break distresses 1 of them were under low, 4 of them were under medium and 3 of them were under high severity level.

All of them were extent level 1 distresses. Out of 32 potholes distress, 7 of them were under low, 4 of them were under medium and 21 of them were under high severity level. 7 and 25 of them are extent level 1 and extent level 2 respectively.

Out of 19 raveling distresses 18 of them were under low and 1 of them were under high severity level. All of them were extent level 1 distresses. Out of 3 ruttings distresses 2 of them were under high and 1of them was under medium severity level. 2 of them were under medium and 1 of them was under a high extent level. Out of 33 alligator crack distresses 25 of them were under low and 8 of them were under medium severity level. All of them were extent level 1. Out of 29 patchings distresses 9 of them were under low, 14 of them were under medium and 6 of them were under high severity level. All of them were at a low extent level. Both the severity and extent level of the longitudinal crack and shoving were under level 1.

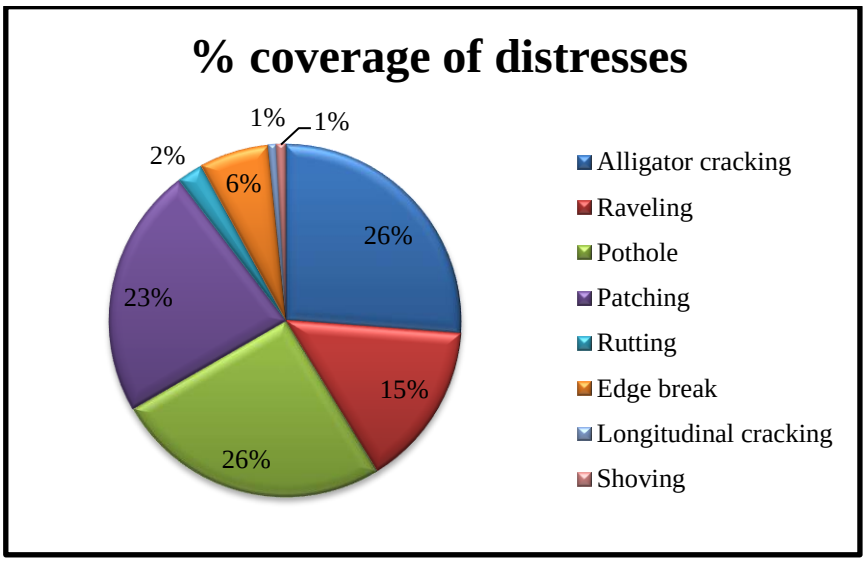


Figure 4. 1. Percent coverage of the distresses result

From figure 4.2, the road section was detected by alligator cracks, potholes, raveling, and patching at a higher percentage. Whereas shoving, longitudinal crack and edge break cover a small percentage of the road section. The geospatial location of each distress that present in the road section from Entoto to the center of Chancho town and their sample snapshotted photo of GPS map camera were displayed in appendix-F.

4.1.2. The relationship between slope, distress, and drainage

When the slope of a road increases, the surface runoff velocity on the road surface increases causing the volume of stagnant water on the road surface to decrease. Hence, the pavement experiences good drainage that leads to less occurrence of distress and answers to why road distress is associated with surface runoff. Table 4.2 displays the severity and extent based number of distresses within each slope category.

Table 4. 2. Slope gradient vs No. of distresses

Slope gradient (%)	No. of distresses based on the severity			No. of distresses based on the extent		
	Severity 1	Severity 2	Severity 3	Extent 1	Extent 2	Extent 3
0-5	13	8	0	21	0	0
5 – 25	42	15	25	59	25	1
25 – 50	11	9	3	18	2	0
>50	0	0	0	0	0	0

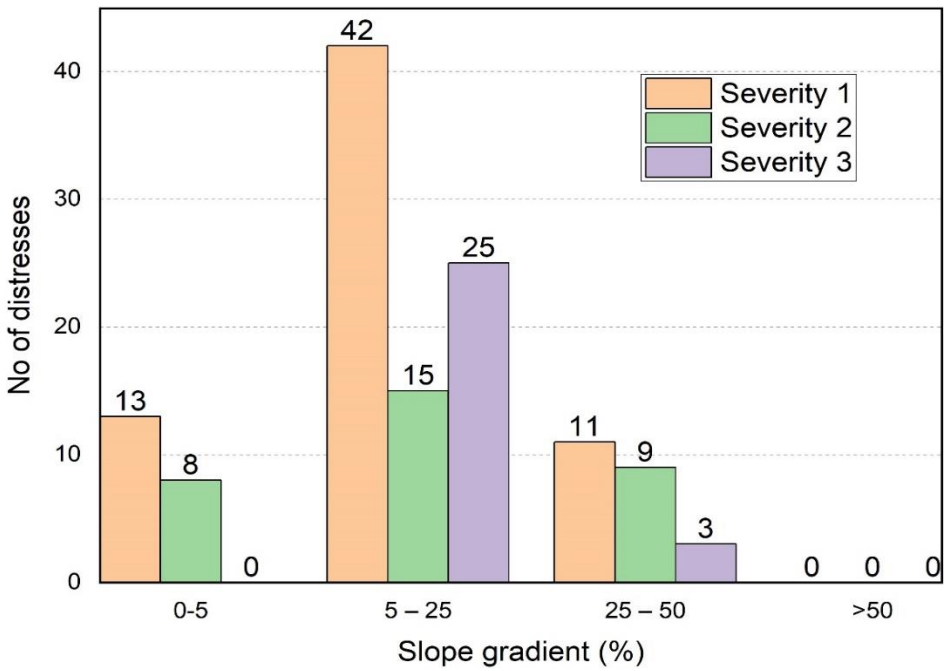


Figure 4. 2. Slope gradient Vs severity level No. of distresses

Based on figure 4.3, severity based highest number of distresses is detected between slope 5–25 %. The slopes 25-50 % and > 50% have no stagnant water due to the high gradient of the slopes (i.e. the pavement experiences good drainage), thus leading to less and no occurrence of distress respectively. Slope category 0-5 % has a low number of distresses. But, there is stagnant water due to the low gradient of slope (i.e. the pavement experiences poor draining ability) that shows distress occurrence has less relationship with the slope factor and drainage.

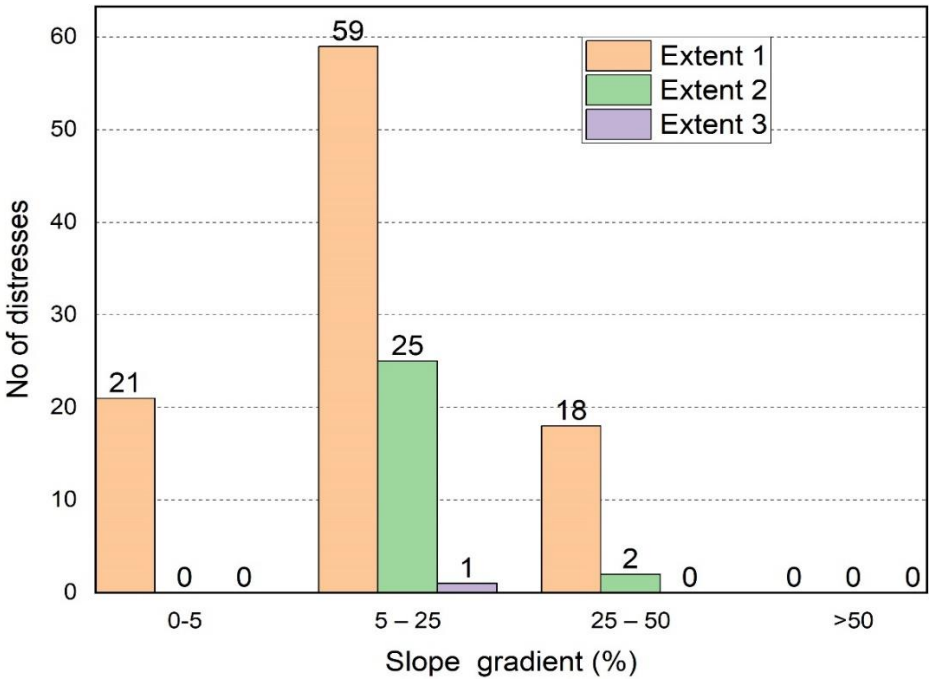


Figure 4. 3. Slope gradient Vs extent level No. of distresses

Based on figure 4.4, the extent based on the highest number of distresses is detected between the slope 5-25 %. The slopes 25-50 % and > 50% have no stagnant water due to the high gradient of the slopes (i.e. the pavement experiences good drainage), thus leading to less and no occurrence of distress respectively. Slope category 0-5 % has a low number of distresses. But, there is stagnant water due to the low gradient of slope (i.e. the pavement experiences poor draining ability) that shows distress occurrence has less relationship with the slope factor and drainage.

The severity and extent levels of each distress with their corresponding slope location were displayed in appendix-G.

Table 4. 3. The pairwise comparison of expert judgment

Criteria	S1	S2	S3	E1	E2	E3	PR	MC
Severity 1 (S1)	1	1/2	1/2.5	3	2.5	2	3	3.5
Severity 2 (S2)	2	1	1/2	4	3.5	3	4	4.5
Severity 3 (S3)	2.5	2	1	5	4.5	4	5	5.5
Extent 1 (E1)	1/3	1/4	1/5	1	1/2	1/2.5	1.6	2.3
Extent 2 (E2)	1/2.5	1/3.5	1/4.5	2	1	1/2	2	2.8
Extent 3 (E3)	1/2	1/3	1/4	2.5	2	1	2.5	3.3
Performance (PR)	1/3	1/4	1/5	1/1.6	1/2	1/2.5	1	1.5
Maintenance (MC)	1/3.5	1/4.5	1/5.5	1/2.3	1/2.8	1/3.3	1/1.5	1

4.1.3. Pavement maintenance prioritization based on AHP

Tables 4.4, 4.5, and 4.6 display the AHP priority rank of criterion and AHP priority rank of alternatives based on each criterion.

Table 4. 4. Eigenvector and rank of criterion using the AHP model

Type of criteria	Eigenvector	Rank
Severity 3	0.31	1
Severity 2	0.22	2
Severity 1	0.15	3
Extent 3	0.10	4
Extent 2	0.08	5
Extent 1	0.06	6
Performance	0.04	7
Maintenance cost	0.04	8

From table 4.4, among 8 criterias severity 3 takes the first, and maintenance cost takes the last consideration.

Table 4. 5. Eigenvector and rank of alternatives based on the severity level

Based on severity 1			Based on severity 2			Based on severity 3		
Type of distress	Eigen-vector	Rank	Type of distress	Eigen-vector	Rank	Type of distress	Eigen-vector	Rank
AC	0.406	1	PA	0.468	1	PO	0.524	1
RA	0.248	2	AC	0.211	2	PA	0.151	2
PO	0.12	3	EB	0.093	3	EB	0.077	3
PA	0.095	4	PO	0.059	4	RU	0.064	4
RU	0.034	5	RA	0.048	5	SH	0.049	5
EB	0.0332	6	SH	0.041	6	RA	0.0464	6
LC	0.0326	7	RU	0.04	7	AC	0.0461	7
SH	0.031	8	LC	0.04	8	LC	0.044	8

From table 4.5, based on severity 1, alligator cracks are maintained first and shoving maintained last. Based on severity 2, patchings are maintained first and longitudinal crack maintained last. Based on severity 3, potholes are maintained first and longitudinal crack maintained last.

Table 4. 6. Eigenvector and rank of alternatives based on extent level

Based on extent 1			Based on extent 2			Based on extent 3		
AC	0.284	1	PO	0.56198	1	SH	0.1283	1
PA	0.26	2	RU	0.08853	2	PO	0.1276	2
RA	0.151	3	AC	0.0583	3	RA	0.1276	3
EB	0.0863	4	LC	0.0583	4	PA	0.1276	4
PO	0.0862	5	RA	0.05822	5	RU	0.123	5
SH	0.046	6	PA	0.05822	6	AC	0.122	6
LC	0.044	7	EB	0.05822	7	EB	0.1219	7
RU	0.042	8	SH	0.05822	8	LC	0.1219	8

From table 4.6, based on extent 1, alligator cracks are maintained first and rutting maintained last. Based on extent 2, potholes are maintained first and shoving maintained last. Based on extent 3, shoving is maintained first and longitudinal crack maintained last.

4.1.4. Pavement maintenance prioritization based on pavement performance condition

4.1.4.1. Pavement distress index (PDI)

Table 4.7 shows the PDI values of each distress type and their respective priority rank. Appendix-K displays the density of each distress type which was substituted in the equation of PDI and gets PDI = **23.024** implies (this result shows) the selected road section has a medium performance.

Table 4. 7. Pavement maintenance prioritization based on the PDI model

Based on PDI		
Type of distress	PDI	Rank
AC (alligator cracks)	8.28	1
PA (patchings)	7.58	2
RA (ravelings)	6.38	3
PO (potholes)	0.61	4
EB (edge breaks)	0.15	5
SH (shoving)	0.007	6
RU (ruttings)	0.004	7
LC (longitudinal crack)	0.0037	8

From table 4.7, alligator cracks were maintained first rather than others and the longitudinal crack was maintained later. Based on the TBMC, ruttings were maintained first rather than others and the longitudinal crack was maintained later.

4.1.4.2. International roughness index (IRI)

Averaging the left-hand side and right-hand side values of IRI as shown in appendix-I and get IRI value of 3.603 (i.e. IRI = 3.603). This result implies that the pavement has good ride quality in which the pavement performance has a direct relationship with it. Tables 4.8 and 4.9 show the left-hand side and right-hand side statistics summary of the IRI Vs speed graph respectively.

Table 4. 8. Left-hand side IRI Vs speed graph statistics summary

	Intercept	Slope	Statistics
	Value	Value	Adjacent R-square
Speed	50.60218	-1.04837	0.05766

Table 4. 9. Right-hand side IRI Vs speed graph statistics summary

	Intercept	Slope	Statistics
	Value	Value	Adjacent R-square
Speed	37.01203	1.56692	0.05978

From tables 4.8 and 4.9, derive the formulas to form the relationship between pavement roughness and speed to examine the mobility condition of the road section.

For the left-hand side of the road section:

$$Speed = 50.60218 – 1.04837IRI \quad [10]$$

Equation 10 shows that when IRI increases the speed decreases. This implies that IRI and speed are inversely related. Thus the mobility of the road segment is negatively affected by the IRI.

For the right-hand side of the road section:

$$Speed = 37.01203 + 1.56692IRI \quad [11]$$

Equation 11 shows that when IRI increases the speed also increases. This implies that IRI and speed are directly related. Thus the mobility of the road segment is positively affected by the IRI.

4.1.5. Pavement maintenance prioritization based on TBMC

Maintenance prioritization was put based on maintenance cost required and decide what maintenance would be accomplished and what maintenance would have to wait later. Table 4.10 shows the TBMC values of each distress and their respective priority rank.

Table 4. 10. Pavement maintenance prioritization based on TBMC model

Based on TBMC		
Type of distress	TBMC	Rank
RU (ruttings)	789936	1
RA (ravelings)	333837	2
PA (patchings)	131195.9	3
AC (alligator cracks)	115741.5	4
PO (potholes)	12535.18	5
EB (edge breaks)	6501.474	6
SH (shoving)	406.802	7
LC (longitudinal crack)	204.542	8

From table 4.10, ruttings were maintained first rather than others and the longitudinal crack was maintained later.

4.1.6. Pavement distress maintenance prioritization map

After assessing the study variables relationship, contributing factors for pavement distress maintenance prioritization were:

- Severity and extent level based priority vector of each distress using AHP
- Performance condition of each distress type using PDI
- Treatment based maintenance cost (TBMC)

After compiling those maintenance priority parameters, use them as input parameters for weighted overlay analysis of the criterion weights by using GIS software as shown in appendix-M. Those inputs are added into the model, reclassified, add those reclassified parameters into a weighted overlay table and click the ok button to run the analysis. Then right-click on the weighted overlay and run it. Finally, right-click on the weighted overlay map and select add to display to get the last maintenance priority map as shown in figure 4.1.

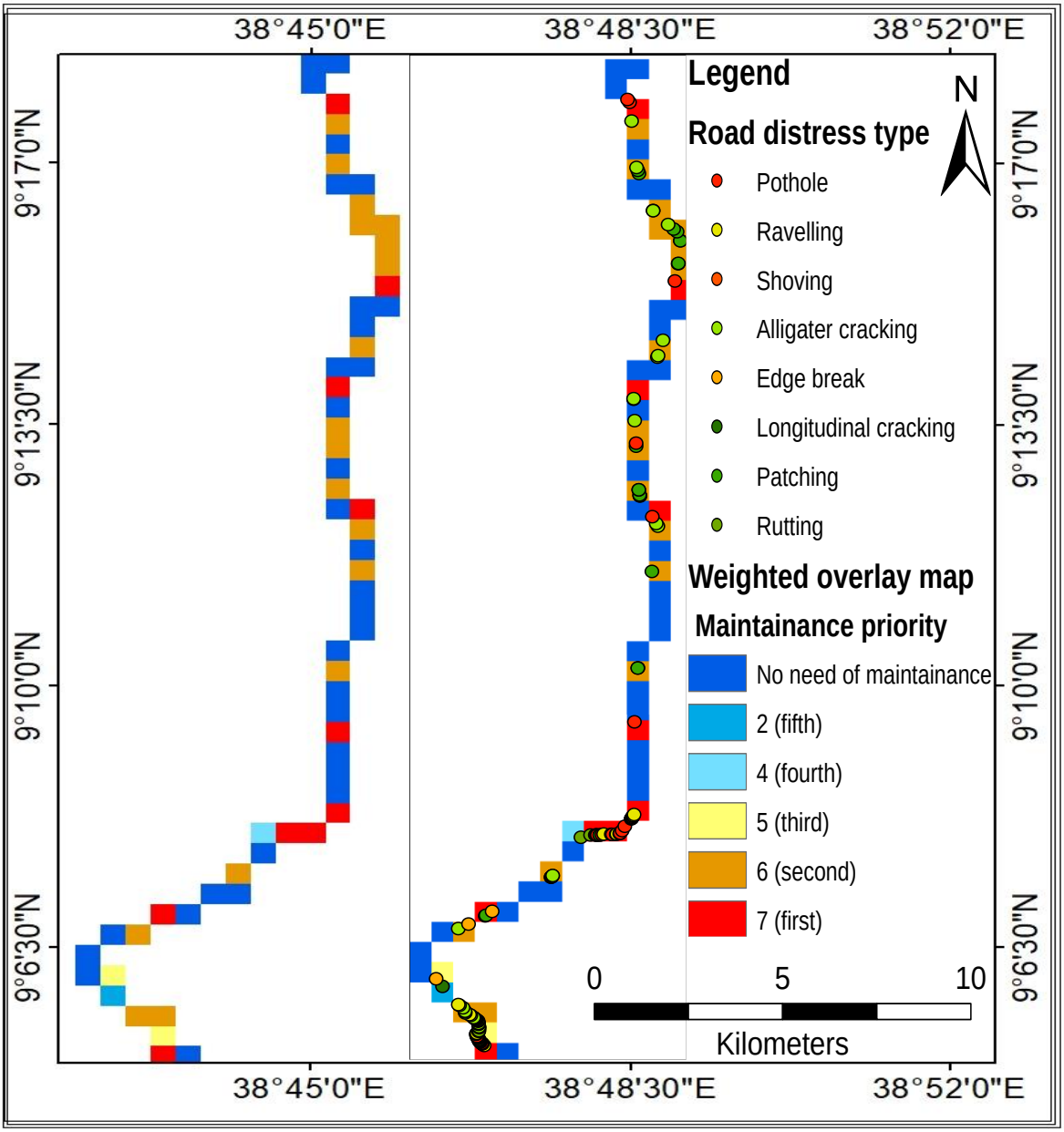


Figure 4. 4. Weighted overlay map of distresses for maintenance priority

From figure 4.1, distresses that lies in high detected areas (red color), which have higher scores (7), give priority (maintained first) and that lies in low detected areas (blue color), which have lower scores (2), maintained last.

4.1.7. Recommended treatments of each distress type

Table 4.11 shows the recommended treatments for each distress type.

Table 4. 11. Recommended treatments

Type of distress	Severity, Extent	Recommended treatment
Alligator cracks	All	Asphalt patching(single surface treatment)
Edge breaks	All	Asphalt patching (hot mini mix)
Longitudinal crack	1,1	crack sealing
Patching	All	Asphalt patching (double surface treatment)
Potholes	3,2	Pothole base failure repair
	Others	Pothole reinstatement (DST)
Ravelings	All	Asphalt patching (double surface treatment)
Ruttings	All	Asphaltic concrete overlay (DBST)
Shoving	1,1	Patch (single surface treatment)

Based on table 4.11, the road authority planned the schedule and provide the recommended treatments on time. On-time distress maintenance management is necessary to control the rate of deteriorations, to limit maintenance and construction costs, to reduce smoke which is removed from the vehicles that have an impact on the environmental pollution, to increase mobility, riding comfort, and save travel time of the road users which answers the question of why geospatial pavement distress maintenance management have economic, environmental and social importance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This study summarizes the pertinent information of the research and reflects on the goals set and success in meeting them. Recommendations for future work are also provided.

5.1. Conclusion

Information about the pavement distress maintenance management using GIS and GPS is generally kept by foreign countries, but not much has been reported in the literature. Therefore, the main objective of this study was to create an awareness of the pavement distress maintenance management according to priorities using GIS software to fill this gap.

This study evaluates the use of Arc GIS software to manage pavement distress maintenance using PDI, TBMC, and AHP vector as input parameters to run the weighted overlay analysis after assessing the relationship between study variables.

The scope of this thesis was limited to assessing the study variables relationship and selecting suitable parameters that are suitable to run the weighted overlay analysis for the selected road section pavement distress maintenance priority.

The required road condition data for pavement distress maintenance management like, length, width, depth, GPS coordinates and photos of the distresses, were collected during the condition survey that was taken from Entoto to the center of Chancho town.

Initially, interviews were conducted to know about overall information. Then conduct an observation and surveying to get the required information on road distresses. The prioritized distresses for maintenance were accomplished with the help of a weighted overlay analysis of GIS software.

The performance evaluations of pavement distress were done based on the suggestions of most recent studies using PDI and IRI methodologies that were available in the literature. Based on the analysis obtained from the geospatial pavement distress maintenance management, the following conclusions and recommendations are presented.

1. During the condition survey, a total of 126 road distresses were detected along the road section. From the weighted overlay analysis result, distresses that lies in high detected areas (red color) maintained first and that lies in low detected areas (blue color) maintained last.
2. The selected road section has good performance, riding comfort, and mobility conditions.
3. Digitalizing the input parameters needed and the result obtained by weighted overlay analysis of GIS software is successful in terms of prioritizing pavement distresses for maintenance.
4. The software graphically illustrates where the road distresses are located and also distresses rank for maintenance.

Generally, GIS and GPS based pavement distress maintenance management is important to reduce the rate of pavement deterioration, limit maintenance costs, and the cost to replace the road by providing the appropriate maintenance on time.

5.2. Recommendations

Pavement performance can be increased by maintaining the distresses on time. Hence, other parameters and methods could be selected that are expected to increase pavement performance rather than the PDI, treatment based maintenance cost, severity, and extent based AHP model result.

The presented results along with the selected parameters of the weighted overlay analysis model can be a benchmark for extended research. According to an observation made during this research, the following recommendations can be reached that can be conducted for better pavement distress maintenance management using GIS software. This can be done to get results with minimum errors.

- Further studies can be done on all essential parameters of the weighted overlay model including traffic volume and accident conditions of the pavement using a weighted overlay model in GIS software. Neglecting traffic volume and accident conditions of the pavement in the weighted overlay analysis model might have caused unsatisfactory output in the result. This is one of the limitations of this research which should be considered for future works.
- The modeling of pavement performance using PDI was difficult as there is no experience and manual in the country hence further materials and methods should be studied for modeling using PDI.
- Give more attention to TBMC maintenance priority and consider the budget constraint as another factor.
- The government ought to provide the connection between higher institute researches, ERA, and AACRA workers to validate the research and alleviate the problems of pavement distress maintenance management systems.
- The government ought to aware of the system on how to provide an updated data storage system and give greater concern in the promotion and awareness creation among a society that the research alleviates the problems that are faced to get accurate data from them and give the information voluntarily.

- Use study variables that are not used as input parameters in this study to prioritize different sections of the road rather than a single road section.
- Give greater attention to GIS and GPS based pavement distress maintenance management system.

Finally, this study recommends pavement distress maintenance management using GPS and Arc GIS software, the transformation of research findings into real products to solve rural and urban pavement distress maintenance management problems.

References

Flange A. and Gilbert C., (2017), 'Implementation of Geographic Information System application in the Maintenance Management of Roads in Ghana: A Case Study of Roads in Kumasi Metropolis', *American Journal of Geographic Information System*, 2017(3), pp. 90–102. DOI: 10.5923/j.ajgis.20170603.02.

Abulizi Nueraihemaitijiang, Kawamura Akira, Tomiyama Kazuya, and Fujita Shun, (2016), 'Measuring and evaluating of road roughness conditions with a compact road profiler and ArcGIS', Journal of Traffic and Transportation Engineering (English Edition). Elsevier Ltd, 3(5), pp. 398–411. DOI: 10.1016/j.jtte.2016.09.004.

Baskin Arthur, Reinke Robert E., Nelson William, Brown Mark, Hartmann Ben, and Dickey Spencer, (2017), 'User Manual', (October).

Dargahi Daryanaz, (2016) 'Prize : an R package for prioritization estimation based on analytic hierarchy process', pp. 1–15.

Department of Transportation, (2017), 'Pavement Management Visual Distress Survey Manual'.

Devlin, G. J., McDonnell, K. and Ward, S., (2008), 'Timber haulage routing in Ireland: an analysis using GIS and GPS', *Journal of Transport Geography*, 16(1), pp. 63–72. DOI: 10.1016/j.jtrangeo.2007.01.008.

ERA (2013) '"Technical Specification for Road Maintenance"'.

Federal Highway Administration, (2009), 'What is pavement preservation ? Why are pavement-preservation projects especially suited for the fiscal stimulus program ? How do I select projects for preservation ?'

Fendi Karwan Ghazi, Adam Sarhat Mustafa, Kokkas Nick and Smith Martin, (2014), 'An approach to produce a GIS database for road surface Monitoring', *APCBEE Procedia*. Elsevier B.V., 9, pp. 235–240. DOI: 10.1016/j.apcbee.2014.01.042.

Florida Department of Transportation, (2017), 'Flexible Pavement Condition Survey Handbook', (October).

Huang Bo, Jiang Bin and Li Hui, (2001), ‘An integration of GIS, virtual reality and internet for visualization, analysis, and exploration of spatial data’, International Journal of Geographical Information Science, 15(5), pp. 439–456. DOI: 10.1080/13658810110046574.

Ibraheem Asma Thamir and Falih Abd Al-Razzaq, (2012), 'Applying Geographic Information System (GIS) for maintenance strategy selection', 2012(January), pp. 44–54.

Jiaqi Wang, Shunxin Yang, Ming Liu, and Jianchuan Cheng, (2005), ‘Mobile data collection methods used in the pavement management system’, (July).

Klutho Steven, (2013), ‘An Overview of Analytic Hierarchy Process Contents’, pp. 1–45.

Kmetz Robert J., (2011), ‘GIS-Based Pavement Maintenance : A Systematic Approach’.

Labib A., (2014), Introduction to the Analytic Hierarchy Process, Learning from Failures. DOI: 10.1016/b978-0-12-416727-8.00003-5.

Loprencipe Giuseppe and Pantuso Antonio, (2017) ‘A specified procedure for distress identification and assessment for urban road surfaces based on PCI’, Coatings, 7(5). DOI: 10.3390/coatings7050065.

Mohammed Hussein and Elhadi Ahmed, (2009), ‘Gis, a Tool for Pavement Management’, *Network*, (February).

Nasir Nor A. M., Maulud Khairul N. A., and Yusoff Nur I.M., (2016) ‘Geospatial analysis of road distress and the relationship with slope factor’, Journal of Engineering Science and Technology, 11(5), pp. 655–665.

Oregon department of transportation, (2018), ‘pavement data collection manual, (April).

Patterson AEJ, (2005), 'Appendix A Severity and Extent Codes for the Condition Survey Quality Statement', (October).

Qiming Zhou, (2017) 'Digital elevation model and digital surface model', ResearchGate. DOI: 10.1002/9781118786352.wbieg0768.

Radopoulou, S. C. and Brilakis, I., (2016), 'Improving Road Asset Condition Monitoring', Transportation Research Procedia. Elsevier B.V.

Rnmd Alemgena, (2018), package – i : heavy routine maintenance projects under (Addis – Chancho – Fitche).

Rydholm Timothy C. and Luhr David R., (2015), 'Visualizing Pavement Management Data at the Project Level'.

Teomete, E., Amin Viren R., Ceylan Halil and Smadi Omar, (2005), 'Digital Image Processing for Pavement Distress Analyses', Transportation Research, (August 2005).

Triantaphyllou Evangelos and H. Mann Stuart, (1995), 'Using the Analytic Hierarchy Process for decision making', *International Journal of Industrial Engineering*, 2(1), pp. 35–44.

Virginia department of transportation, (2012), 'a Guide to evaluating pavement distress through the use of digital images', (November).

Wolters Angela, Zimmerman Kathryn, Schattler Kerrie and Rietgraf Ashley, (2011), 'implementing pavement management systems for local agencies implementation guide.

Wu Zheng Ph.D., P.E., L. Groeger Jonathan, L. Simpson Amy Ph.D., P.E., Hicks R. Gary Ph.D., and P.E., (2010), 'Performance Evaluation of Various Rehabilitation and Preservation Treatments', p. 90. Available at: http://www.fhwa.dot.gov/pavement/preservation/pubs/perfeval/perfeval.pdf.

Yeganeh Sayna Firoozi, Mahmoudzadeh Ahmadreza, Azizpour Mohammad Amin and Golroo Amir, (2019) ‘Validation of smartphone-based pavement roughness measures’, pp. 1–9. Available at: http://arxiv.org/abs/1902.10699.

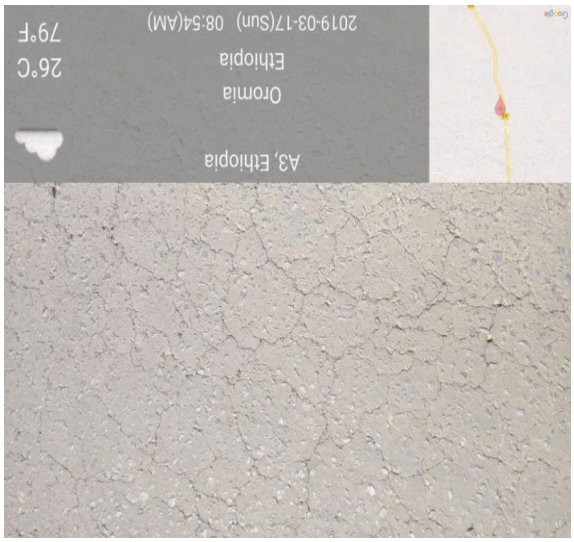
Shahin.Y and Kohn.D, (1981) 'Pavement maintenance management for roads and parking lots' U.S. ARMY construction engineering research laboratory, p. 227.

List of appendixes

Appendix

Appendix-A: Sample photos of distresses

A-1. Alligator cracks





Severity, extent (1, 1)

Severity 2

A-2. Edge breaks





Severity, extent (1, 1)

Severity 2

A-3. Shoving



Severity 3



Severity, extent (1, 1)

A-4. Longitudinal crack



Severity, extent (1, 1)

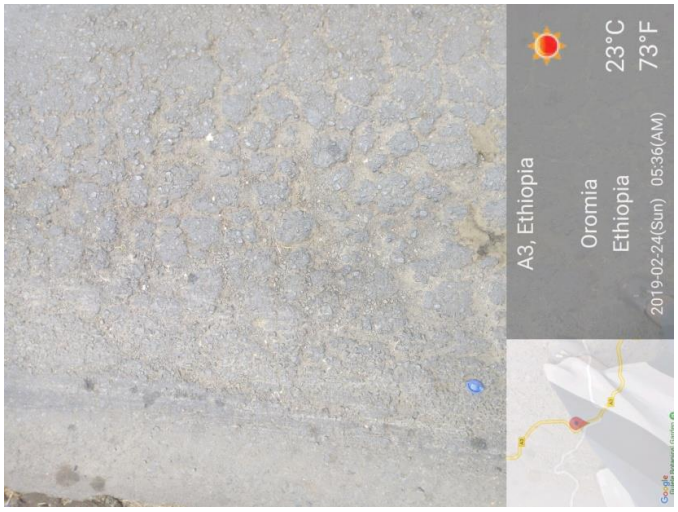
A-5. Patching



Severity, extent (1, 1)



Severity 2

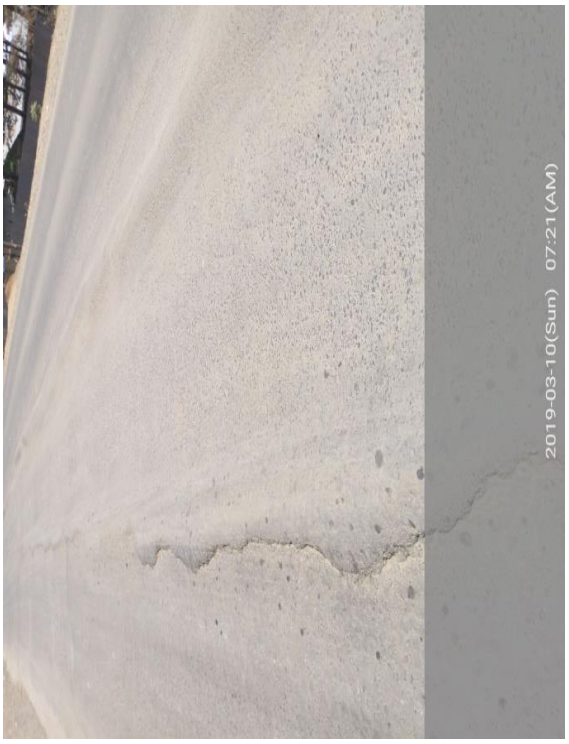


Severity 3

A-6. Rutting

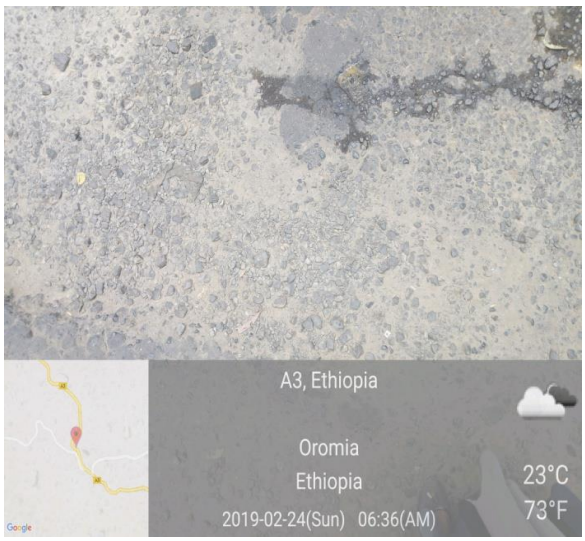


Severity, extent (2, 2)



Severity, extent (3, 3)

A-7. Raveling



Severity, extent (1, 1)



Severity 2

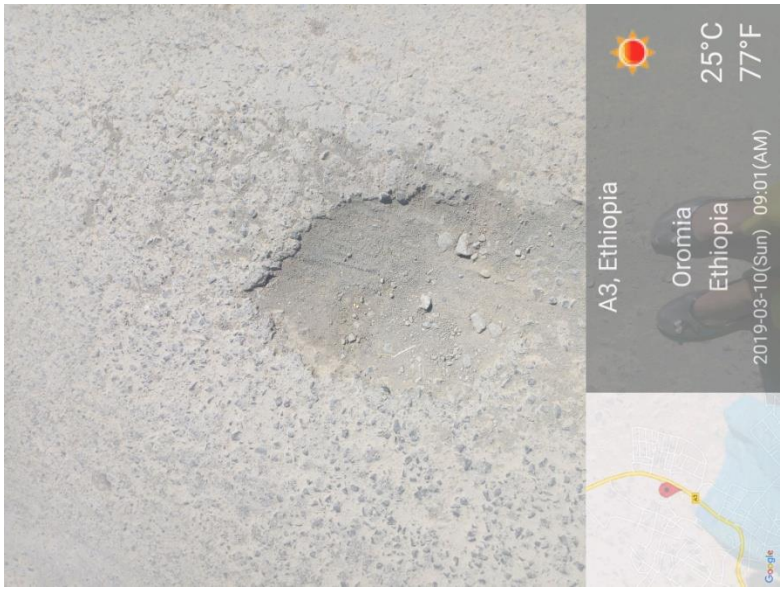
A-8. Potholes



Severity, extent (1, 1)



Severity, extent (2, 2)



Severity 3

Appendix-B: Site GPS data

Table B-1. GPS coordinates of the distresses

Type of Distress								
Edge Break								
		Location			Measurement			% of the section affected
No	Station	Latitude	Longitude	Elevation	Length (m)	Width (mm)	Depth (m)	
1	0+310	9.08513	38.721922	2848.1	2.6	380	0.09	0.52
2	0+343	9.085432	38.721881	2900.5	7	300	0.16	1.4
3	0+354	9.08553	38.721799	2855.8	6.5	100	0.1	1.3
4	0+425	9.086186	38.721621	2850.9	6.1	170	0.015	1.22
5	0+982	9.090489	38.721086	2817.5	7.3	300	0.09	1.46
6	3+200	9.099452	38.712745	2773.9	2.4	600	0.02	0.48
7	5+300	9.111817	38.719548	2755.1	3.3	300	0.15	0.66
8	6+000	9.114699	38.724514	2751.2	1.75	670	0.07	0.35

Type of Distress								
Pothole								
		Location			Measurement			
No	Station	Longitude	Latitude	Elevation	Length(m)	Width(m)	Depth (mm)	Area (m^2)
1	0+226	9.084844	38.722537	2846.9	2.1	2.4	100	5.04
2	0+245	9.084759	38.722386	2845.2	1.3	1.2	50	1.56
3	0+268	9.084844	38.722194	2852.1	2.2	0.6	80	1.32
4	0+268	9.084829	38.722179	2852.2	1	0.9	100	0.9
5	0+276	9.084868	38.722104	2848.7	1.2	1.3	160	1.56
6	0+373	9.085699	38.721752	2845.9	2	2.3	10	4.6
7	0+471	9.086432	38.721243	2831.8	1	1.3	170	1.3
8	0+727	9.08838	38.721806	2840.6	0.5	0.8	80	0.4
9	5+800	38.723022	9.113676	2746.2	5.3	0.4	50	2.12
10	9+200	38.746113	9.131897	2687.2	4.4	2.4	80	10.56

11	9+200	38.746235	9.131802	2687	1.1	1	90	1.1
12	9+200	38.746532	9.131864	2684.7	3.5	2.4	100	8.4
13	9+300	38.747467	9.132087	2684.9	1.4	1.2	120	1.68
14	9+500	38.749485	9.132102	2682	3.3	1.2	120	3.96
15	9+600	38.749695	9.132175	2671.9	1.8	1.3	80	2.34
16	9+600	38.750477	9.13203	2657.7	4	3.9	100	15.6
17	9+700	38.751125	9.132258	2647	2.6	1.5	80	3.9
18	9+800	38.751289	9.132368	2645.8	2.3	0.8	30	1.84
19	9+800	38.751698	9.132921	2643.2	0.9	0.8	60	0.72
20	9+900	38.75235	9.133846	2602.3	3.2	1.4	80	4.48
21	10+200	38.753635	9.135527	2638.9	2.3	1.7	60	3.91
22	10+200	38.753738	0.135653	2638.3	1.6	1.1	70	1.76
23	10+200	38.753792	9.135777	2638.7	2	1.6	60	3.2
24	10+200	38.753887	9.13591	2638.9	1.3	0.8	70	1.04
25	10+300	38.75404	9.136136	2639.3	0.6	0.5	50	0.3
26	12+700	38.754219	9.157425	2595.69	1.5	0.9	60	1.35
27	18+100	38.757996	9.203672	2570	1.1	1.1	20	1.21
28	20+000	38.754513	9.220268	2555.9	1	0.4	25	0.4
29	21+100	38.753876	9.230154	2528.19	1	0.6	30	0.6
30	24+300	38.762691	9.256827	2574.1	0.4	0.4	20	0.16
31	29+200	38.753124	9.297111	2597.8	1.2	1	200	1.2
32	29+300	38.752674	9.297718	2593.4	1.3	0.35	15	0.455

Type of Distress									
Raveling									
			Location			Measurement			
No	Station	Latitude	Longitude	Elevation	Length (m)	Width (m)	Area (m^2)	% of the section affected	% of raveled areas
1	0+186	9.084458	38.72286	2852.1	12.42	3.1	38.502	2.48	1.10
2	0+364	9.085631	38.721831	2845.7	2.8	2.5	7	0.56	0.20
3	0+443	9.086348	38.721513	2844.2	10.2	3.9	39.78	2.04	1.14
4	0+471	9.086395	38.721218	2843.6	2.8	2.1	5.88	0.56	0.17
5	0+542	9.086984	38.721112	2835.1	8.6	2	17.2	1.72	0.49
6	0+560	9.087096	38.721239	2833.3	7.4	1.2	8.88	1.48	0.25
7	0+575	9.087199	38.721318	2831.6	34.4	7.3	251.12	6.88	7.17
8	0+638	9.087572	38.721823	2838.3	20.4	4.4	89.76	4.08	2.56
9	0+996	9.090548	38.720959	2812.8	30	2.4	72	6.00	2.06
10	1+000	9.090857	38.720597	2817.1	70	7	490	14.00	14.00
11	1+200	9.091321	38.719753	2800.7	36.8	3.7	136.16	7.36	3.89
12	2+100	9.092046	38.718896	2787.2	7	1.8	12.6	1.40	0.36
13	2+300	9.093685	38.717434	2775.1	10	1.6	16	2.00	0.46
14	9+200	9.131827	38.746391	2686.3	21	7	147	4.20	4.20
15	9+300	9.131912	38.747097	2685.5	15.8	5.3	83.74	3.16	2.39
16	9+400	9.132258	38.747807	2684.4	2.7	1.8	4.86	0.54	0.14
17	9+700	9.131978	38.750626	2650.9	19.5	7	136.5	3.90	3.90
18	10+300	9.136272	38.754108	2639.4	46.5	7	325.5	9.30	9.30
19	10+300	9.136508	38.754303	2639.2	8.55	3.3	28.215	1.71	0.81

Type of distress								
Rutting								
		Location			Measurement			% of the section affected
No	Station	Latitude	Longitude	Elevation	Length (m)	Width (m)	Depth (mm)	
1	8+100	9.131509	38.74306	2707	100	7	25	20
2	9+100	9.131949	38.74511	2693	200	7	80	40
3	9+600	9.132034	38.74974	2664.7	500	7	70	100

Type of Distress									
Alligator Cracking									
		Location			Measurement				% of crack area
No	Station	Latitude	Longitude	Elevation	Length (m)	Width (m)	Crack width(mm)	Area (m^2)	
1	0+317	9.085243	38.721931	2850.7	17.7	1	5	17.7	0.51
2	0+379	9.085759	38.721739	2843.7	48.9	1.25	10	61.125	1.75
3	0+659	9.087771	38.721849	2832.6	9	2.6	5	23.4	0.67
4	0+756	9.088664	38.721965	2849.3	3.8	1.6	0.25	6.08	0.17
5	0+826	9.089319	38.721958	2848.4	21	1.5	7.5	31.5	0.90
6	0+844	9.089476	38.721878	2821.2	30.7	1.5	2.5	46.05	1.32
7	0+896	9.089919	38.721644	2815.8	9.8	2.3	5	22.54	0.64
8	0+913	9.090009	38.721503	2816.8	25	1.63	2.5	40.75	1.16
9	0+963	9.090364	38.721218	2811	50.5	1.3	2.5	65.65	1.88
10	1+000	9.090723	38.720833	2811.5	16.2	1.2	10	19.44	0.56
11	1+000	9.090788	38.720756	2816.8	43.2	7	10	302.4	8.64
12	1+100	9.091225	38.720085	2805.1	14	1.6	5	22.4	0.64
13	2+100	9.091775	38.718883	2793.6	14	2.6	2.5	36.4	1.04
14	2+100	9.092159	38.718871	2786.1	22.2	1.2	2.5	26.64	0.76
15	2+200	9.092942	38.718406	2780.4	19.4	1	2.5	19.4	0.55
16	2+300	9.093449	38.717627	2770	90	1.5	5	135	3.86
17	5+100	9.110913	38.717352	2814.5	8.3	1.1	2.5	9.13	0.26
18	7+600	9.122368	38.736843	2723.3	6.9	0.8	2.5	5.52	0.16

19	7+600	9.12273	38.737217	2713.9	6.4	0.6	2.5	3.84	0.11
20	17+800	9.20156	38.759243	2563	20	1.1	7.5	22	0.63
21	17+900	9.20216	38.758892	2569.19	5	0.7	10	3.5	0.10
22	18+700	9.208448	38.755398	2560.19	13	1.2	10	15.6	0.45
23	18+800	9.20974	38.755211	2563	9	1	5	9	0.26
24	20+600	9.225353	38.754253	2551.69	11	0.8	5	8.8	0.25
25	21+100	9.230282	38.753975	2564.5	24	1	2.5	24	0.69
26	22+300	9.23966	38.759056	2577.4	33	1.3	2.5	42.9	1.23
27	22+400	9.239994	38.759251	2578.5	10	1.7	10	17	0.49
28	22+800	9.243464	38.760258	2582	7	1.5	5	10.5	0.30
29	25+300	9.265914	38.763889	2599.3	4	1.8	5	7.2	0.21
30	25+800	9.269568	38.761299	2602.5	9	1.2	2.5	10.8	0.31
31	26+400	9.27269	38.758114	2611.3	35	1.5	2.5	52.5	1.50
32	27+500	9.282429	38.754642	2581.9	12	2.2	5	26.4	0.75
33	28+700	9.29291	38.753525	2582.19	23	6	2.5	138	3.94

Type of Distress									
Patching									
		Location			Measurement				% of crack area
No	Station	Latitude	Longitude	Elevation	Length (m)	Width (m)	Crack width(mm)	Area (m^2)	
1	0+271	9.084858	38.722163	2849.3	3.4	2.3	20	7.82	0.22
2	0+322	9.085215	38.722021	2853.2	3.4	2	30	6.8	0.19
3	0+359	9.085572	38.721783	2846.3	7.7	1.3	30	10.01	0.29
4	0+380	9.085779	38.721757	2846.1	10	1.7	20	17	0.49
5	0+820	9.089248	38.721881	2838	3.5	1.1	20	3.85	0.11
6	0+938	9.090193	38.721366	2813.8	11	2.4	0.25	26.4	0.75
7	5+800	9.113781	38.723225	2753.4	1.72	1.6	0.25	2.752	0.08
8	7+600	9.122381	38.736923	2740.2	6.9	1.5	5	10.35	0.30
9	7+600	9.122487	38.736946	2713.4	10.8	1.7	0.25	18.36	0.52
10	7+600	9.122584	38.737122	2699.9	18.7	7	5	130.9	3.74
11	7+600	9.122708	38.737251	2711.3	3.6	2.2	60	7.92	0.23

12	9+300	9.131925	38.747059	2684.8	4	2.1	10	8.4	0.24
13	10+200	9.135688	38.753735	2639.7	7	1.7	10	11.9	0.34
14	10+200	9.135672	38.753757	2638.5	16.6	2.4	15	39.84	1.14
15	14+100	9.169581	38.755001	2606.5	6.5	2.4	10	15.6	0.45
16	14+100	9.169565	38.754959	2606.5	12.5	2.8	10	35	1.00
17	16+600	9.191325	38.757996	2584.9	4	1.8	10	7.2	0.21
18	18+700	9.208341	38.755447	2559.5	12.6	3.5	5	44.1	1.26
19	18+700	9.208593	38.755325	2560.19	20	5	17.5	100	2.86
20	18+800	9.209768	38.755203	2564.6	8	3.5	10	28	0.80
21	19+900	9.219565	38.75457	2558.5	5.5	3.5	10	19.25	0.55
22	24+700	9.260716	38.763435	2593.6	20	1.2	10	24	0.69
23	24+700	9.260785	38.763477	2591.6	30	1.3	7.5	39	1.11
24	25+300	9.265908	38.763901	2599.6	5.8	1.2	10	6.96	0.20
25	25+500	9.267902	38.763142	2598.6	7	3.4	7.5	23.8	0.68
26	25+600	9.268513	38.762417	2600.3	50	1.2	5	60	1.71
27	26+400	9.272708	38.75811	2609.9	19	1.6	5	30.4	0.87
28	27+400	9.281065	38.755131	2579.1	3	2.9	5	8.7	0.25
29	27+400	9.2818	38.754925	2581.1	4.7	1.4	7.5	6.58	0.19

Type of Distress							
Longitudinal Cracking							
		Location			Measurement		
No	Station	Latitude	Longitude	Elevation	Length (m)	Crack width(m)	Area (m^2)
1	3+000	9.097726	38.714075	2767.3	2.6	1.5	-

Type of Distress							
Shoving							
		Location			Measurement		
No	Station	Latitude	Longitude	Elevation	Length (m)	Width(m)	Area (m^2)
1	0+406	9.086028	38.721714	2849	4.1	1.1	4.51

Appendix-C: Listed maintenance activities by category (ERA manual)

Table C-1. Maintenance activities

Category	Scope	Ref.No	Activity name	Unit
Routine maintenance	Pavement	210	Asphalt patching (seal coat)	SqM
		211	Asphalt patching (single surface treatment)	SqM
		212	Asphalt patching (double surface treatment)	SqM
		213	Asphalt patching (cold mix)	CuM
		214	Asphalt patching (hot mini- mix)	CuM
		215	Crack sealing (individual cracks)	LinM
		216	Pothole reinstatement (double surface treatment)	SqM
		217	Pothole reinstatement (cold mix)	CuM
		218	Pothole reinstatement (hot mini-mix)	CuM
		219	Pothole (base failure repair)	CuM

Appendix-D: IRI values and their specification (ERA) manual

Table D-1. IRI values and their specifications

IRI value m/km	Specification
< 2	Excellent
2 – 4	Good
4 – 6	Fair
6 - 10	Poor
> 10	Bad

Appendix-E: Maintenance Quantity Estimation and their respective activity numbers based on Condition Survey

E-1. Pothole

Quantity	**Severity**			
Extent	**M^2 or M^3**	**1**	**2**	**3**
	1	$0.5m^2$ Act 216	N/A	N/A
	2	$5m^2$ Act 216	$0.5m^3$ Act 217/8	$15m^3$ Act 219
	3	$15m^2$ Act 216	$1.5m^3$ Act 217/8	$4.5m^3$ Act 219

E-2. Raveling

Quantity	Severity			
Extent	M^2	Any		
	1	100 Act 210/11		
	2	300 Act 210/11		
	3	700 Act 210/11		

E-3. Cracking

Quantity	Severity			
Extent	M^2	Any		
	1	100 Act 210/11		
	2	300 Act 210/11		
	3	700 Act 210/11		

E-4. Edge damage

Quantity	Severity			
Extent	M^3	1	2	3
	1	0.25 Act 213/4	0.75 Act 213/4	 Act 213/4
	2	0.75 Act 213/4	2.25 Act 213/4	 Act 316
	3	1.75 Act 316	5.25 Act 316	14 Act 316

Appendix-F: Geospatial locations of the distresses

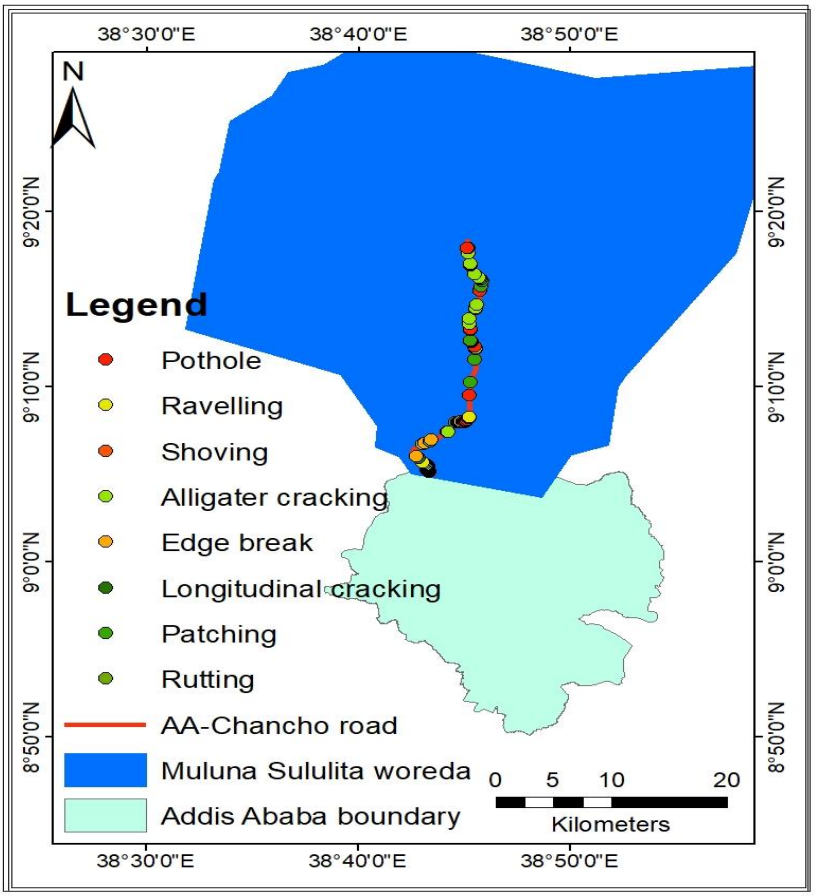


Figure F-1. Location of all distress points on the road section

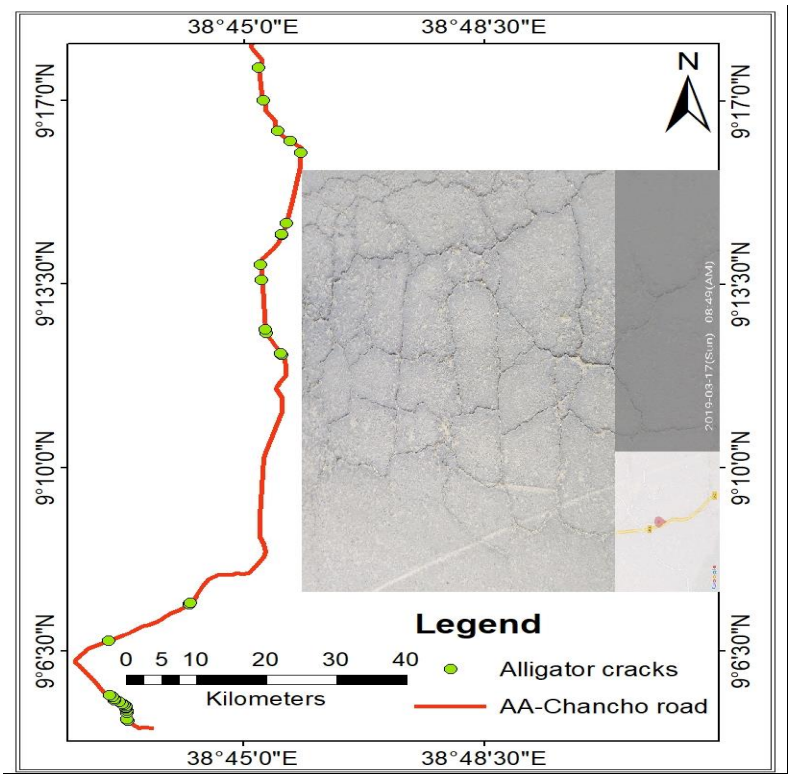


Figure F-2. Location of alligator cracks displayed by linking the photos of the distress with Arc GIS

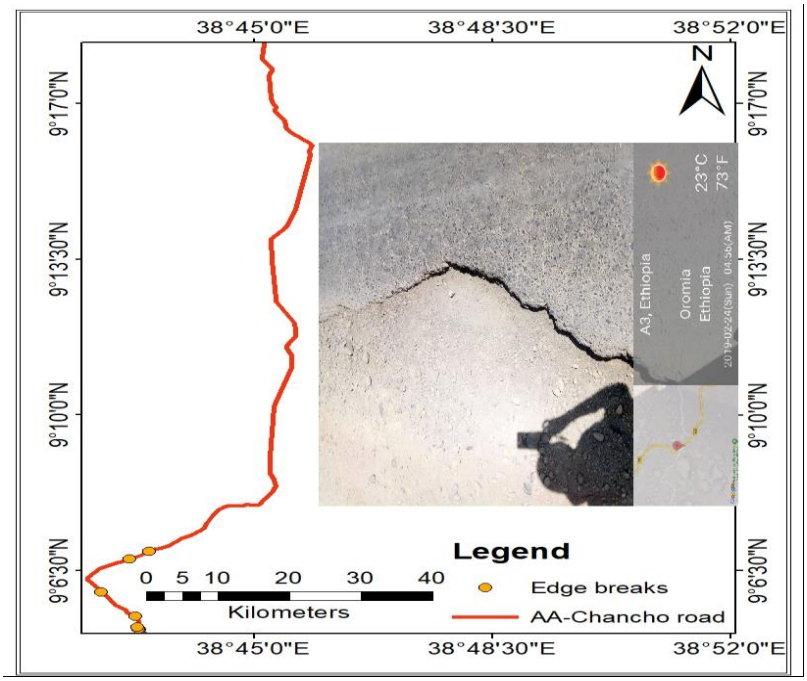


Figure F-3. Location of edge breaks displayed by linking the photos of the distress with Arc GIS

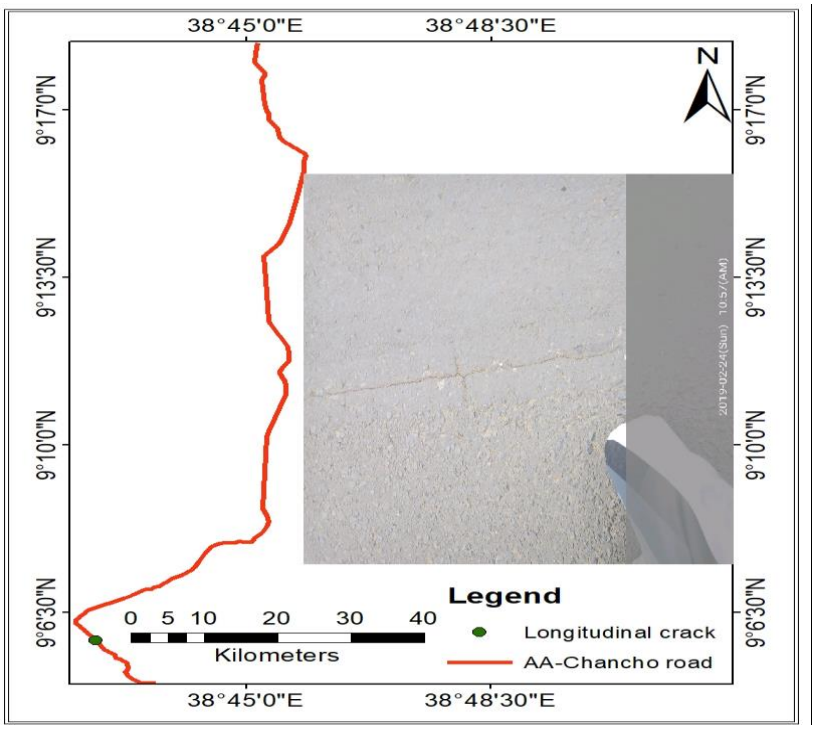


Figure F-4. Location of longitudinal crack displayed by linking the photos of the distress with Arc GIS

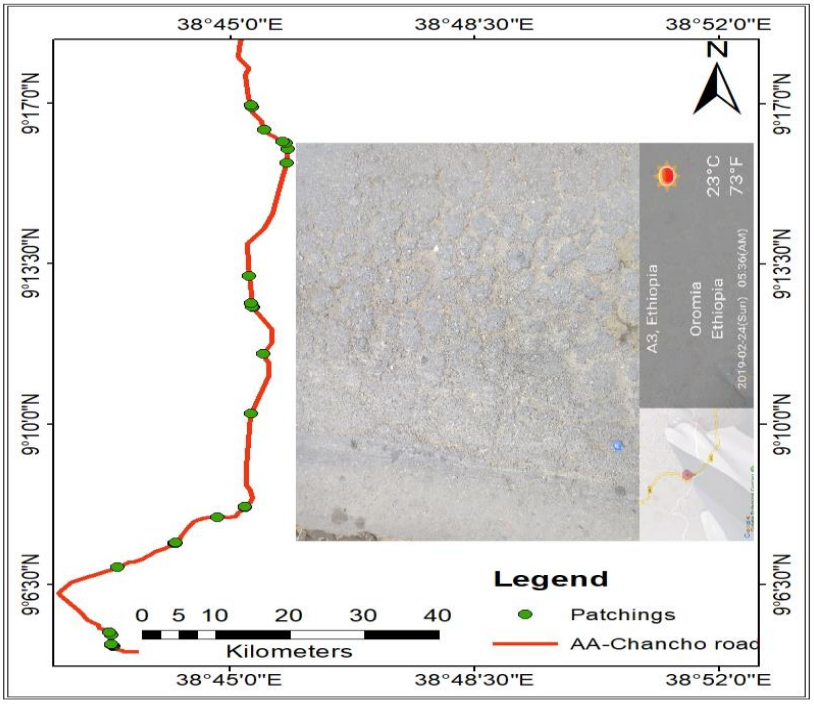


Figure F-5. Location of patchings displayed by linking the photos of the distress with Arc GIS

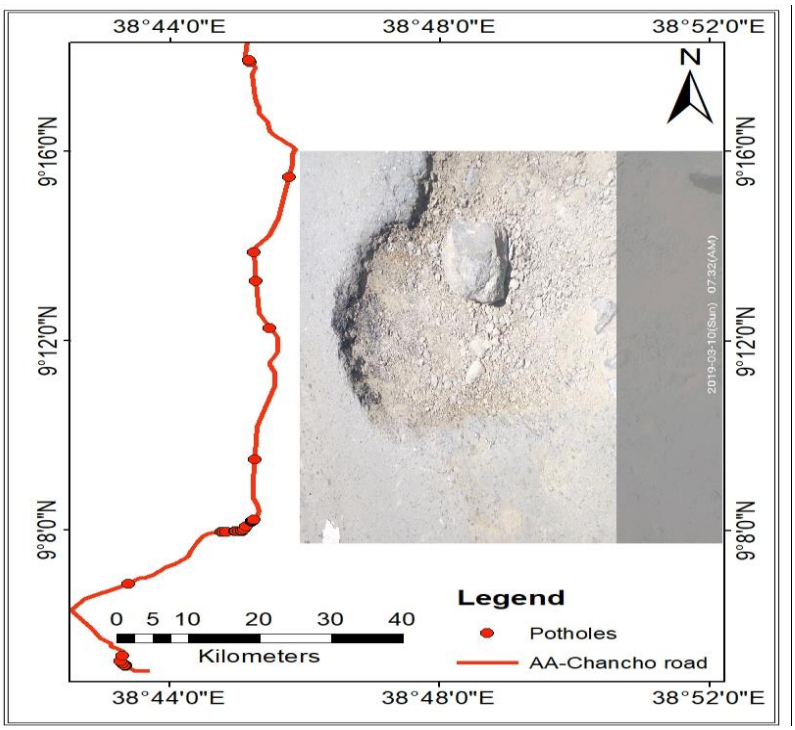


Figure F-6. Location of potholes displayed by linking the photos of the distress with Arc GIS

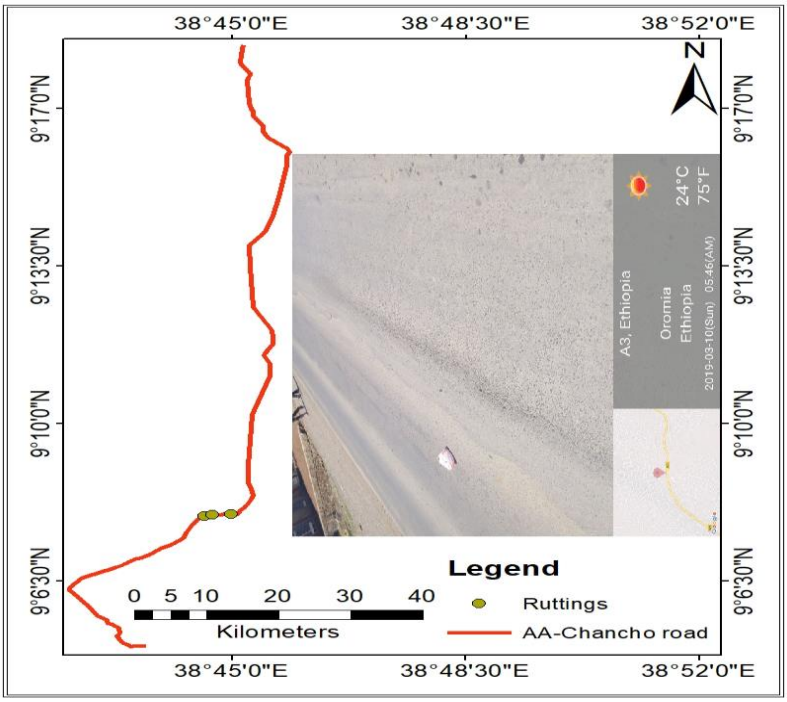


Figure F-7. Location of ruttings displayed by linking the photos of the distress with Arc GIS

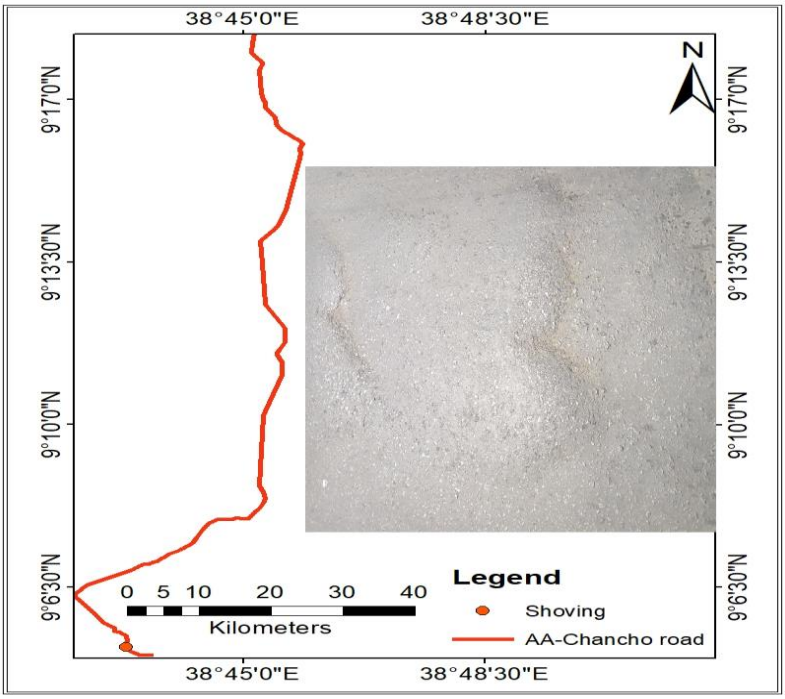


Figure F-8. Location of shoving displayed by linking the photos of the distress with Arc GIS

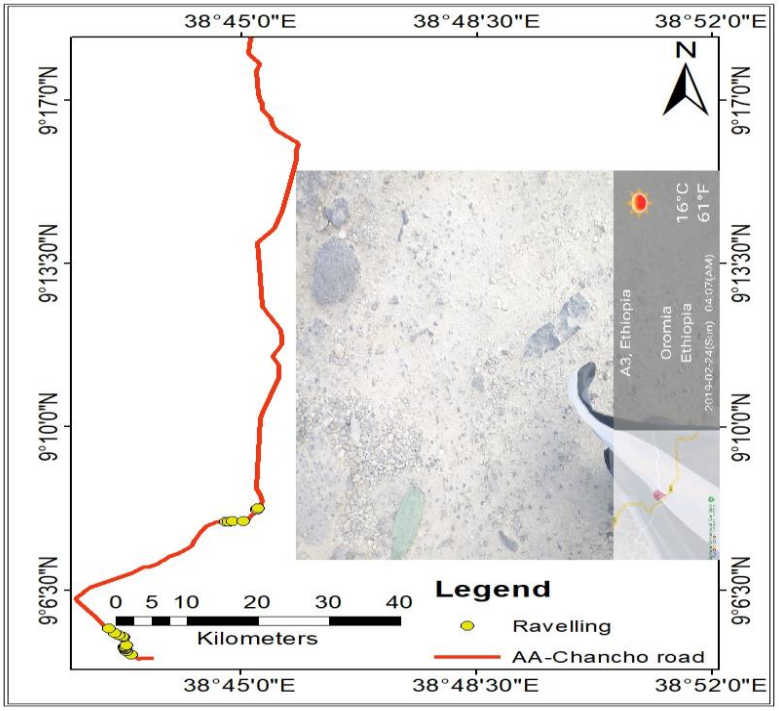


Figure F-9. Location of ravelings displayed by linking the photos of the distress with Arc GIS

Appendix-G: Road distresses with slope category

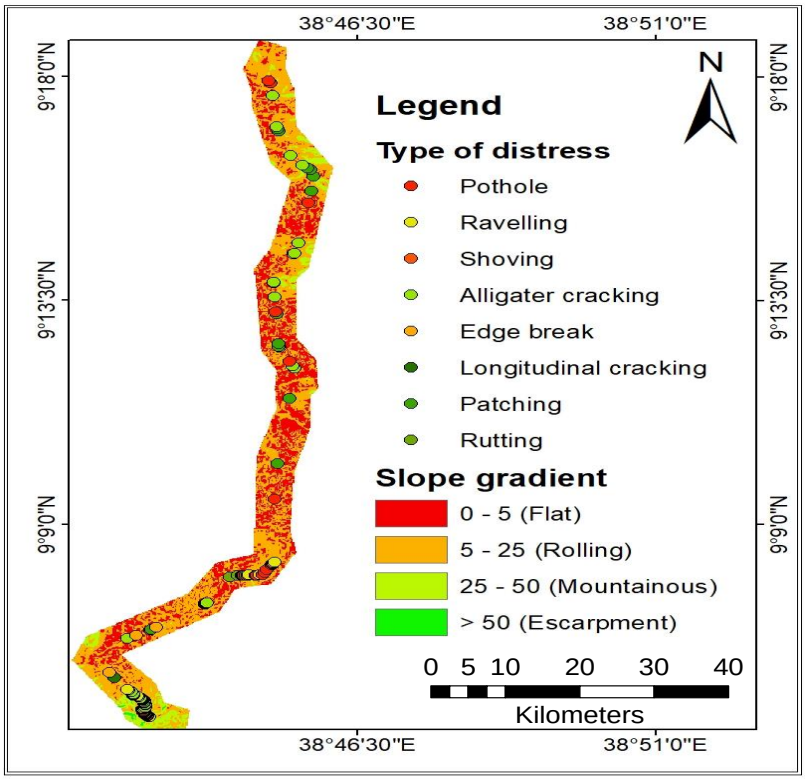


Figure 4. 5. Road distresses with their corresponding slope factor

Appendix-H: Interview form as a question for asking experts for pairwise comparison

Table H-1. For criterion

Criteria	S1	S2	S3	E1	E2	E3	PR	MC
S1								
S2								
S3								
E1								
E2								
E3								
PR								
MC								

Table H-2. For alternatives

Alternatives	AC	LC	EB	RU	PA	PO	RA	SH
AC								
LC								
EB								
RU								
PA								
PO								
RA								
SH								

Appendix-I: IRI and speed data of left and right-hand side road section

LHS		
Distance (km)	IRI (m/km)	Speed (km/hr)
0.1	3.4	34.5
0.2	3.6	35.6
0.289	3.8	33.8
0.389	2.6	26.6
0.489	2.5	30.5
0.589	2.5	40.9
0.689	3.2	41.3
0.789	3.1	43.6
0.889	2.8	47.3
0.989	3.2	46.1
1.089	3.6	46.7
1.189	2.9	47
1.289	2.5	46

RHS		
Distance (km)	IRI (m/km)	Speed (km/hr)
0.100	0	10.5
0.200	4.3	18.4
0.300	3	10.8
0.400	4.2	37.9
0.500	3.9	43
0.600	4.2	46.6
0.700	2.8	21.1
0.800	0	12.7
0.900	0	11.8
1.000	0.1	15.6
1.100	3.2	34.7
1.200	3.3	41.8
1.300	4.8	41.1

1.389	2.8	39
1.489	2.7	45.1
1.589	3.2	47.3
1.689	3.9	47.1
1.789	3.4	45.8
1.889	3.5	37.4
1.989	3.9	49
2.089	4.2	51
2.189	4.7	51.3
2.289	6.3	48.7
2.389	4.2	51.2
2.489	4.9	50.6
2.589	`3.8	51.2
2.689	3.5	50.7
2.789	3	50.7
2.889	3.9	51.6
2.989	2.5	50.4
3.089	3.1	52.3
3.189	4.1	51.7
3.289	4	51.6
3.389	3.7	50.8
3.489	3.8	53
3.589	3.2	52.1
3.689	2.8	50.8
3.789	3.8	53.5
3.889	4.7	52.7
3.989	3.9	52.5
4.089	3.1	52.5
4.189	3.2	52.5

1.400	3.5	48.6
1.500	4.5	50.8
1.600	4.1	51.8
1.700	2.8	51.4
1.800	2.8	47.9
1.900	3.1	47.8
2.000	3.3	52.4
2.100	2.9	51.6
2.200	3	49.8
2.300	2.4	52.2
2.400	3.4	52.7
2.500	4.4	45.8
2.600	3.2	46.9
2.700	3.8	48.6
2.800	4.3	45
2.900	2.9	47.2
3.000	3.2	41.9
3.100	2.9	33
3.200	2	40.1
3.300	2.4	42.1
3.400	2.5	41.9
3.500	2.2	40.5
3.600	2.4	42.1
3.700	2.8	40.2
3.800	3	28.4
3.900	0.3	12.4
4.000	3	39.2
4.100	3	50.5
4.200	2.9	48.2

4.289	3.9	48.3
4.389	3.2	37.4
4.489	5	40.5
4.589	4.1	46.5
4.689	4	49.5
4.789	4.8	50.1
4.889	5.1	47.1
4.989	1.4	18
5.089	4.2	38.4
5.189	4.9	48.3
5.289	4.2	50
5.389	3.4	51
5.489	4.1	50.2
5.589	3.5	51.9
5.689	3.4	47.1
5.789	4.3	42
5.889	4.9	42.7
5.989	4.5	47.7
6.089	3.6	51.3
6.189	5.3	41
6.289	4.6	29.5
6.389	4.3	49.7
6.489	3.8	52.2
6.589	4.3	49
6.689	3.9	48.3
6.789	3.9	47.3
6.889	3.9	51.1
6.989	3	49.2
7.089	3.1	50

4.300	3.1	44.5
4.400	2.9	40.6
4.500	2.5	32.6
4.600	0	14.4
4.700	3.1	28
4.800	2.7	25.5
4.900	3.5	32.8
5.000	2.6	39.8
5.100	2.6	45.9
5.200	3.2	40.5
5.300	3.6	43.8
5.400	2.6	40.3
5.500	3.1	51.5
5.600	2.2	54.6
5.700	2.8	55.6
5.800	3	53
5.900	3.8	52.9
6.000	2.6	51.1
6.100	2.9	53.2
6.200	3.6	53.7
6.300	4.2	52.3
6.400	2.9	51.6
6.500	7	37
6.600	3.3	30.7
6.700	8.6	44.8
6.800	4.1	45.8
6.900	2.7	49.1
7.000	2.9	47.3
7.100	3.1	46.4

7.189	3.2	49.7
7.289	3.4	49.5
7.389	3.7	49.6
7.489	3.2	49.4
7.589	4.1	52.5
7.689	3.9	49
7.789	3.4	49.6
7.889	4.7	46.5
7.989	2.9	49.3
8.089	4.3	49.9
8.189	5.1	49.9
8.289	3.8	42.3
8.389	5.9	33.9
8.489	1.1	12.4
8.589	4.7	42.1
8.689	4.2	40.6
8.789	4.8	39.2
8.889	3.8	51.1
8.989	5.8	50.7
9.089	4.3	50.3
9.189	4.9	48.5
9.289	4.4	43.7
9.389	4.7	43.5
9.489	4.1	40.8
9.589	3.7	43.3
9.689	4.7	49.5
9.789	9.1	36.3
9.889	4.7	38.1
9.989	4.7	44.7

7.200	3.3	48.8
7.300	3.6	47.2
7.400	2.7	39.7
7.500	0.5	15.7
7.600	2.9	34.3
7.700	3	37.1
7.800	2.4	17.2
7.900	1.6	11.8
8.000	4.5	36.2
8.100	1.4	13.6
8.200	6.2	31
8.300	7.4	45.4
8.400	6.1	47.6
8.500	8.1	38.9
8.600	1.9	16.8
8.700	9.9	30.2
8.800	4.7	37.7
8.900	3.9	49.2
9.000	3.2	51.7
9.100	2.7	56.7
9.200	2.4	34.4
9.300	0	17.1
9.400	3	34.1
9.500	2.6	39.6
9.600	1.6	22.1
9.700	3.6	35.5
9.800	2.4	44.7
9.900	3.1	49.2
10.000	3.4	51.2

10.089	3.8	37.1
10.189	4.5	46.6
10.289	3.7	52.6
10.389	4.5	51.8
10.489	4	45.5
10.589	4.8	31.5
10.689	5.2	43.7
10.789	5.9	43.8
10.889	6	30.8
10.989	3.8	39.5
11.089	3.7	48.3
11.189	4.3	48.6
11.289	3.6	48.9
11.389	4.3	45.8
11.489	4.1	41.3
11.589	4	36.6
11.689	5.5	36.7
11.789	6.2	35.8
11.889	3	36.6
11.989	3.6	41.2
12.089	4.1	42.7
12.189	3.3	42.3
12.289	3.7	45.3
12.389	3.4	46.2
12.489	3.3	45.4
12.589	3.6	38.5
12.689	5.4	41.4
12.789	5.7	45.5
12.889	9.2	49.4

10.100	3.8	49.2
10.200	3.1	44.0
10.300	4.4	41.8
10.400	3.8	50.9
10.500	3.4	53.2
10.600	3.5	47.1
10.700	3.0	46.9
10.800	3.0	51.9
10.900	2.9	53.1
11.000	2.4	52.4
11.100	2.5	50.1
11.200	2.5	52.4
11.300	3.2	52.7
11.400	2.9	52.0
11.500	2.9	53.3
11.600	2.9	52.8
11.700	3.3	53.7
11.800	2.6	54.6
11.900	2.8	54.0
12.000	3.8	52.8
12.100	4.5	51.2
12.200	2.9	49.3
12.300	2.9	45.3
12.400	2.6	46.0
12.500	2.8	41.7
12.600	2.6	29.5
12.700	0.0	17.2
12.800	2.7	25.8
12.900	0.0	9.6

12.989	6.9	52.3
13.089	4.7	46.6
13.189	3.8	19.8
13.289	3.5	40.3
13.389	3.1	47.3
13.489	5.5	48.9
13.589	4.6	40.2
13.689	4.6	37.8
13.789	4.4	42
13.889	3.2	46.3
13.989	5.5	37.8
14.089	6	36.6
14.189	7.8	43.3
14.289	4.1	45.5
14.389	4	43
14.489	4.1	39.5
14.589	3.3	41.7
14.689	3.9	51.4
14.789	5	51.2
14.889	6.7	46.7
14.989	5.6	52.7
15.089	5.3	52.1
15.189	4.2	34.1
15.289	4.2	34.6
15.389	6.4	47.8
15.489	7.6	43.9
15.589	15.7	33
15.689	13.1	31.2
15.789	4.3	43.6

13.000	3.9	26.1
13.100	3.5	31.2
13.200	0.3	13.0
13.300	2.5	27.7
13.400	3.0	28.8
13.500	2.4	30.1
13.600	3.5	30.8
13.700	1.5	24.8
13.800	1.4	25.2
13.900	0.6	23.1
13.939	0.0	10.9
14.039	2.0	24.0
14.139	2.9	31.3
14.239	6.5	30.8
14.339	0.2	14.5
14.439	0.0	16.4
14.539	0.0	15.0
14.639	1.8	23.5
14.739	4.6	34.5
14.839	3.0	38.8
14.939	6.7	49.0
15.039	4.2	49.3
15.139	3.5	48.6
15.239	3.1	51.7
15.339	3.5	53.3
15.439	5.4	51.1
15.539	3.1	51.8
15.639	3.6	53.1
15.739	2.5	33.6

15.889	3.6	49
15.989	8	44.4
16.089	5.1	49.2
16.189	3	43.8
16.289	3.7	30.1
16.389	5.8	48.1
16.5	6.4	51.2
16.6	4.3	45.5
16.689	3.6	50.5
16.789	2.7	53.8
16.889	3.6	51.4
16.989	3.1	50.9
17.089	2.6	50.6
17.189	3	50.2
17.289	4	52.6
17.389	2.7	51.7
17.489	2.8	50.5
17.589	2.9	50.1
17.689	2.9	50.8
17.789	3.1	51.5
17.889	3.5	52.7
17.989	4.1	49.1
18.089	3.5	51.6
18.189	4	50.7
18.289	2.9	49
18.389	2.2	48.5
18.489	2.3	50.9
18.589	2.8	50.7
18.689	2.7	50.7

15.839	2.9	39.6
15.939	3.1	48
16.039	3.7	48.2
16.139	2.7	53.8
16.239	2.8	54.2
16.339	4.0	52.8
16.439	3.4	53.3
16.539	3.6	52.1
16.639	3.4	54.4
16.739	3.2	52.9
16.839	2.9	51.1
16.939	3.8	47.0
17.039	3.0	51.2
17.139	3.2	52.6
17.239	2.9	52.7
17.339	2.8	53.2
17.439	2.8	53.3
17.539	2.8	32.1
17.639	4.4	37.5
17.739	3.4	48.7
17.839	3.1	51.3
17.939	2.5	50.3
18.039	2.8	51.7
18.139	2.6	50.1
18.239	4.5	53.1
18.339	3.3	51.3
18.439	7.0	48.0
18.539	2.5	48.7
18.639	2.1	44.6

18.789	2.8	48.9
18.889	2.6	49.6
18.989	3	48.4
19.089	3	51.3
19.189	3.6	50.3
19.289	3.1	52.2
19.389	3	50.3
19.489	2.6	48.9
19.589	2.6	49.3
19.689	2.6	50.9
19.789	2.4	50.8
19.889	2.2	53.5
19.989	2.3	52.4
20.089	2.5	50.5
20.189	2.5	49.1
20.289	2.6	46.9
20.389	2.9	45.2
20.489	3.3	49.2
20.589	3.6	51.3
20.689	3.2	48.1
20.789	3.1	51.8
20.889	3.1	51.9
20.989	3.5	50.7
21.089	2.9	49.3
21.189	3.1	50.2
21.289	3	50.5
21.389	2.8	51.5
21.489	3.2	51.6
21.589	3.2	52.6

18.739	2.3	35.9
18.839	4.0	32.5
18.939	1.2	17.5
19.039	3.9	33.9
19.139	4.5	35.8
19.239	3.0	29.6
19.339	2.4	22.7
19.439	6.5	37.7
19.539	3.9	38.9
19.639	11.8	36.3
19.739	13.9	31.2
19.839	0.1	17.8
19.939	2.1	30.7
20.039	3.4	46.2
20.139	3.9	49.6
20.239	3.0	51.1
20.339	3.2	53.3
20.439	3.6	54.0
20.539	3.1	53.4
20.639	2.9	54.0
20.739	2.6	52.7
20.839	2.7	53.3
20.939	3.0	54.1
21.039	2.5	53.8
21.139	4.1	53.1
21.239	5.8	33.9
21.339	10.9	34.3
21.439	4.6	41.9
21.539	4.2	36.8

21.689	3.1	51.2
21.789	2.6	46.7
21.889	3.3	47.8
21.989	3.9	46
22.089	4.3	50.3
22.189	3.1	51.9
22.289	3	51.2
22.389	3.1	48.4
22.489	2.8	47.3
22.589	3	47.3
22.689	3.2	49
22.789	2.7	46.8
22.889	3.6	41.8
22.989	3.2	48.7
23.089	2.6	49.8
23.189	3.7	45.2
23.289	2.9	46.5
23.389	2.5	49.2
23.489	2.4	50.3
23.589	2.8	51.2
23.689	2.8	50.6
23.789	3.2	46.3
23.889	3	46.4
23.989	2.7	48.9
24.089	3.6	47.9
24.189	2.7	47.7
24.289	2.7	49.2
24.389	3.6	48.4
24.489	3.2	44.7

21.639	2.7	40.6
21.739	3.2	45.2
21.839	2.7	52.2
21.939	2.8	53.8
22.039	2.8	54.1
22.139	2.6	52.7
22.239	2.5	54.3
22.339	2.5	55.6
22.439	5.5	52.2
22.539	4.3	51.9
22.639	2.9	51.2
22.739	2.8	51.0
22.839	2.9	51.6
22.939	2.5	52.2
23.039	3.2	51.0
23.139	3.6	52.1
23.239	2.7	49.8
23.339	2.4	50.2
23.439	2.4	51.5
23.539	2.7	49.7
23.639	2.7	43.9
23.739	3.7	44.7
23.839	13.5	30.9
23.939	4.6	37.5
24.039	5.7	49.7
24.139	5.5	53.2
24.239	4.0	50.5
24.339	4.0	47.5
24.439	9.9	35.2

24.549	3.1	43
24.649	3.6	38.8
24.749	3.4	35.2
24.849	3.4	36.5
24.949	3.4	38.6
25.049	2.9	45.2
25.149	3	46.2
25.249	2.8	47.1
25.349	2.7	47.6
25.449	2.5	47.1
25.549	2.6	45.4
25.649	2.1	47.1
25.749	2.4	49
25.849	2.8	49.3
25.949	2.6	49.9
26.049	2.5	52.2
26.149	2.5	51.6
26.249	2.4	50
26.349	2.2	48.8
26.449	2.4	49.7
26.549	2.8	49.8
26.649	2.6	51.3
26.749	2.9	51
26.849	2.6	51.1
26.949	3	49.9
27.049	2.7	47.8
27.149	2.8	49.2
27.249	3.2	50.7
27.349	2.6	52.9

24.539	6.5	45.1
24.639	4.1	50.2
24.739	5.4	44.2
24.839	5.3	46.9
24.939	6.1	47.7
25.039	10.2	45.2
25.139	4.8	49.6
25.239	6.2	52.9
25.339	6.9	53.4
25.439	3.2	52.7
25.539	5.8	51.8
25.639	3.7	54.3
25.739	3.9	53.6
25.839	5.2	53.3
25.939	3.2	52.8
26.039	4.0	54.2
26.139	3.3	52.5
26.239	7.0	49.2
26.339	4.1	48.9
26.439	5.1	50.0
26.539	2.9	44.2
26.639	1.8	24.5
26.739	2.7	36.6
26.839	2.6	43.1
26.939	3.1	50.8
27.039	3.9	49.6
27.139	2.8	51.4
27.239	2.9	51.1
27.339	4.7	49.1

27.449	2.9	52.2
27.549	2.7	50.5
27.649	2.8	52.4
27.749	2.1	52.6
27.849	2.7	52.2
27.949	2.6	53.1
28.049	2.4	52.2
28.149	2.9	51.7
28.249	2.7	50.4
28.349	2.2	50.2
28.449	2.2	52.6
28.549	2.8	50.7
28.649	2.3	51.8
28.749	3.1	51.3
28.849	2.6	51.6
28.949	2.9	50.8
29.049	2.7	47.7
29.149	4.3	48.9
29.249	3.2	49.9
29.349	2.7	45.3
Average	**3.723**	

27.439	3.1	50.7
27.539	5.8	48.0
27.639	4.4	46.2
27.739	4.3	38.8
27.839	3.8	34.9
27.939	2.9	38.4
28.039	4.3	48.8
28.139	4.5	48.4
28.239	3.8	49.0
28.339	4.5	50.4
28.439	3.9	52.4
28.539	4.6	49.8
28.639	3.6	40.9
28.650	5.1	31.6
28.750	5.4	33.9
28.850	3.2	33.9
28.950	2.6	30.2
29.050	3.4	38.4
29.150	3.4	41.7
29.250	3.8	35.1
29.350	3	40.7
Average	3.483	

Appendix-J: severity and extent level of each distress and slope category

Table J-1. Severity level of each distress based on the slope gradient:

Slope gradient (%)					
Type of distress	Severity	0-5	5-25	25-50	> 50
Ravelling	1	0	14	4	0
	2	0	0	1	0
	3	0	0	0	0
Shoving	1	0	1	0	0
	2	0	0	0	0
	3	0	0	0	0
Rutting	1	0	0	0	0
	2	0	1	0	0
	3	0	2	0	0
Pothole	1	4	3	0	0
	2	1	2	1	0
	3	0	19	2	0
Patching	1	3	7	1	0
	2	5	7	1	0
	3	0	4	1	0
Longitudinal cracking	1	0	1	0	0
	2	0	0	0	0
	3	0	0	0	0
Edge break	1	0	2	1	0
	2	0	3	2	0
	3	0	0	0	0
Alligator cracking	1	6	14	5	0
	2	2	2	4	0
	3	0	0	0	0

Table J-2. Extent levels of each distress based on slope gradient

Slope gradient (%)					
Type of distress	Extent	0-5	5 - 25	25– 50	>50
Raveling	1	0	14	5	0
	2	0	0	0	0
	3	0	0	0	0
Shoving	1	0	1	0	0
	2	0	0	0	0
	3	0	0	0	0
Rutting	1	0	0	0	0
	2	0	2	0	0
	3	0	1	0	0
Pothole	1	5	1	1	0
	2	0	23	2	0
	3	0	0	0	0
Patching	1	8	18	3	0
	2	0	0	0	0
	3	0	0	0	0
Longitudinal cracking	1	0	1	0	0
	2	0	0	0	0
	3	0	0	0	0
Edge break	1	0	8	0	0
	2	0	0	0	0
	3	0	0	0	0
Alligator cracking	1	8	16	9	0
	2	0	0	0	0
	3	0	0	0	0

Appendix-K: density and TBMC

Table K-1. The density of distress in meter

Type of distress	Severity	Distress amount length (m)	Sample unit area (m^2)	Density (m)
Edge break	1	6.5	3500	0.19
	2	20.4	3500	0.58
	3	6.75	3500	0.19
Rutting	1	0	3500	0.000
	2	0.1	3500	0.003
	3	0.7	3500	0.020
Longitudinal crack	1	2.6	3500	0.074

Table K-1.1. The density of distress in square meter

Type of distress	Severity	Distress mount (m^2)	Sample unit area (m^2)	Density (m^2)
Raveling	1	1420.70	3500	40.59
	2	490	3500	14.00
	3	0	3500	0.00
Alligator cracking	1	810.6	3500	23.2
	2	472.565	3500	13.5
	3	0	3500	0.0
Patching	1	331.962	3500	9.48
	2	365.53	3500	10.44
	3	53.4	3500	1.53
Shoving	1	4.51	3500	0.129

Table K-1.2. The density of distress in No. of potholes

Type of distress	Severity	No. of pothole	Sample unit area (m^2)	Density (No. of pothole)
Pothole	1	8	3500	0.23
	2	4	3500	0.11
	3	20	3500	0.57

Table K-2. Treatment based maintenance cost

Distress type	Activity name	Unit	Estimated quantity	Unit rate	Total amount (ETB)
AC	Asphalt patching (SST)	m2	1283.165	90.2	115741.5
EB	Asphalt patching (Hot-mini-mix)	m3	0.96195	6758.64	6501.474
LC	Crack sealing	Lm	2.6	78.67	204.542
PA	Asphalt patching (DST)	m2	750.892	174.72	131195.9
PO	Pothole reinstatement (DST)	m2	67.225	163.49	12535.18
	Pothole base failure Repair	m3	1.9854	777.96	
RA	Asphalt patching (DST)	m2	1910.697	174.72	333837
RU	Asphaltic concrete overlay (DBST)	m2	5600	141.06	789936
SH	Asphalt patching (SST)	m2	4.51	90.2	406.802

Appendix-L: IRI versus distance and IRI versus speed graph

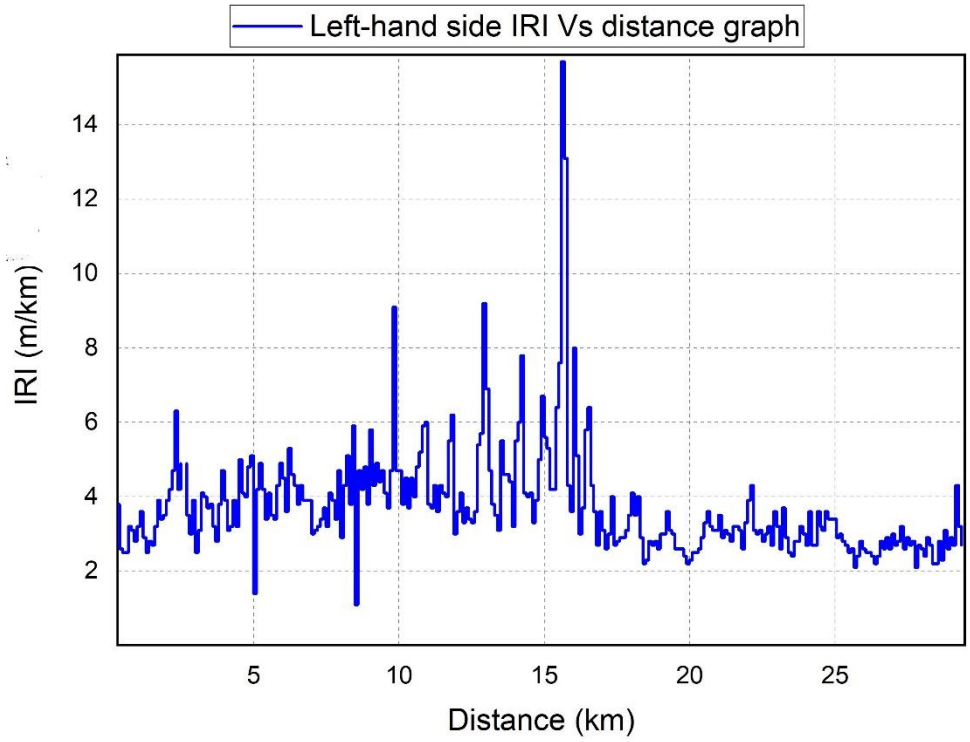


Figure L-6. Left-hand side IRI graph

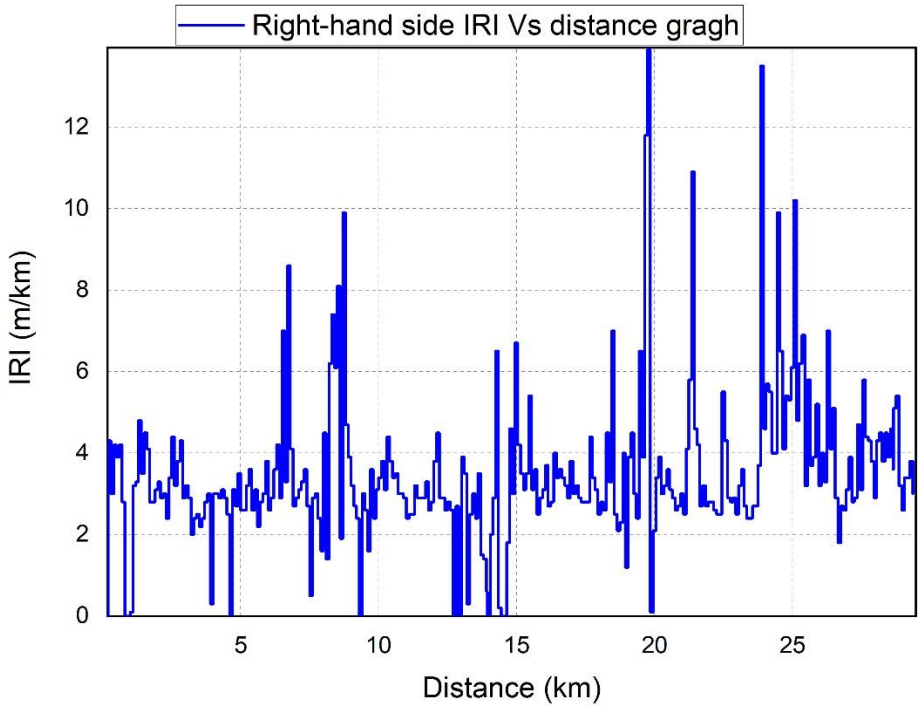


Figure L-2. Right-hand side IRI graph

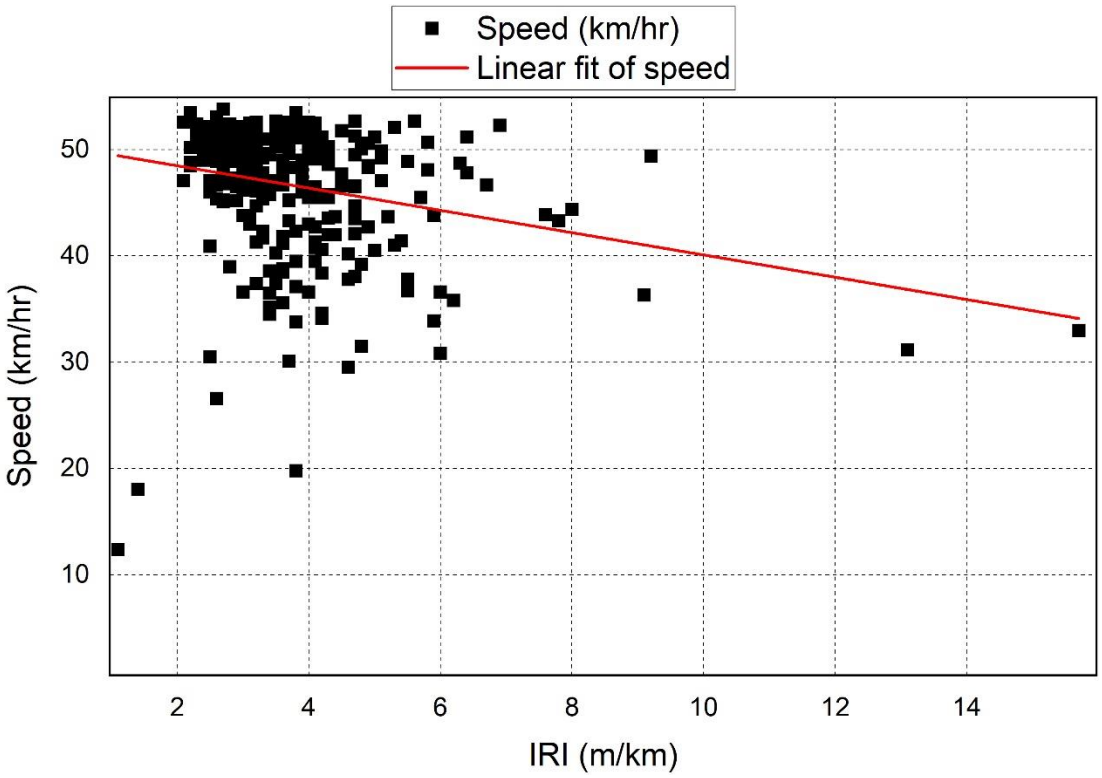


Figure L-3. Left-hand side IRI Vs speed graph

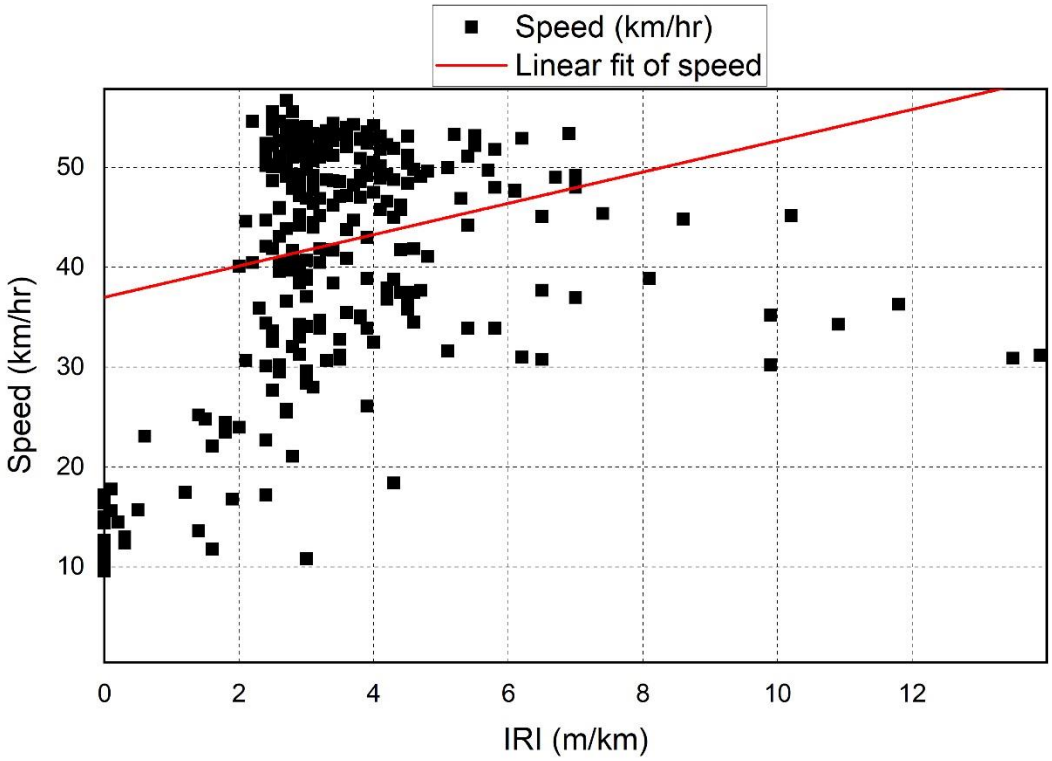
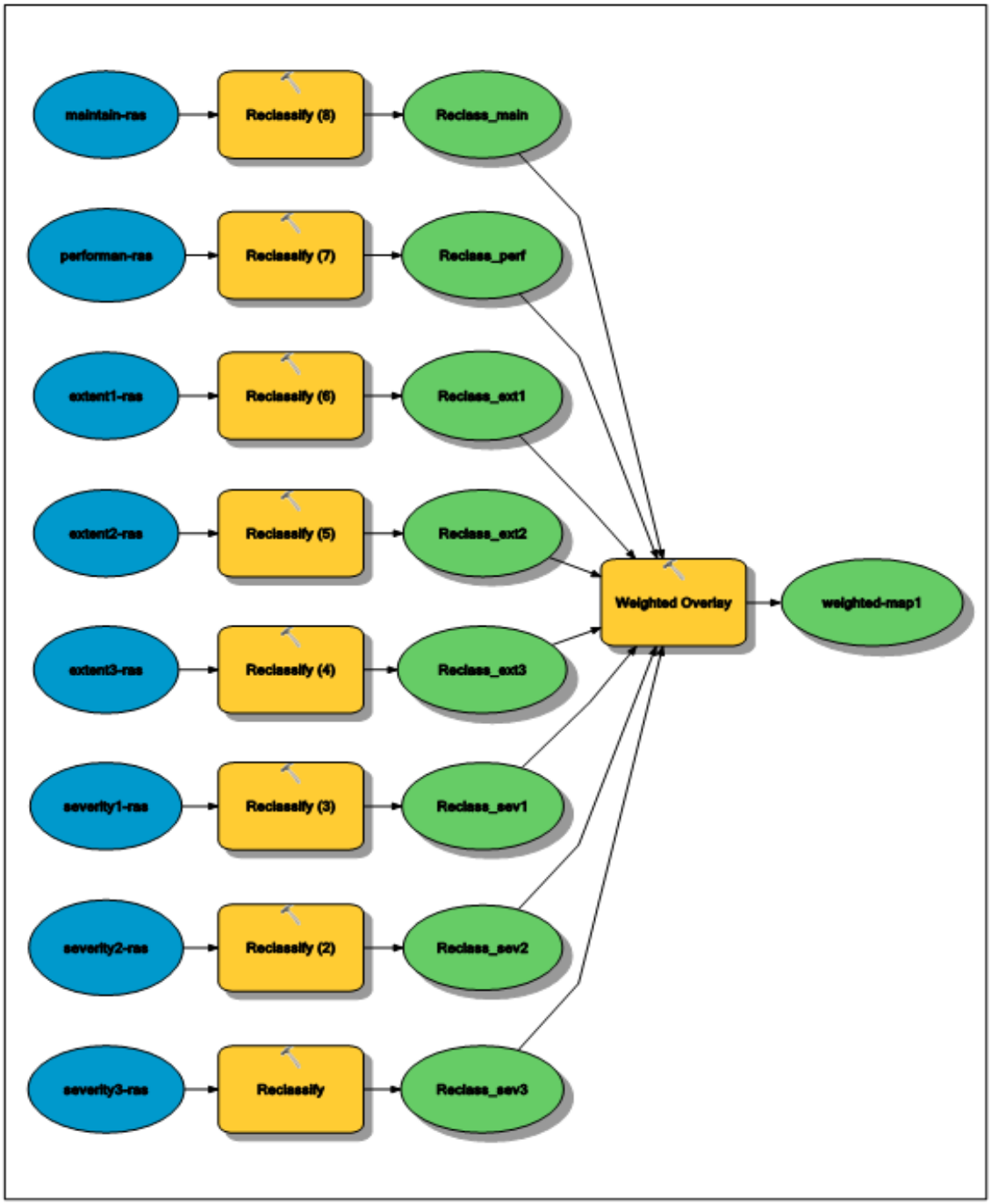


Figure L-4. Right-hand side IRI Vs speed graph

Appendix-M: input parameters of maintenance priority in the weighted overlay model



weighted overlay

Appendix-N: information produced by an identify icon

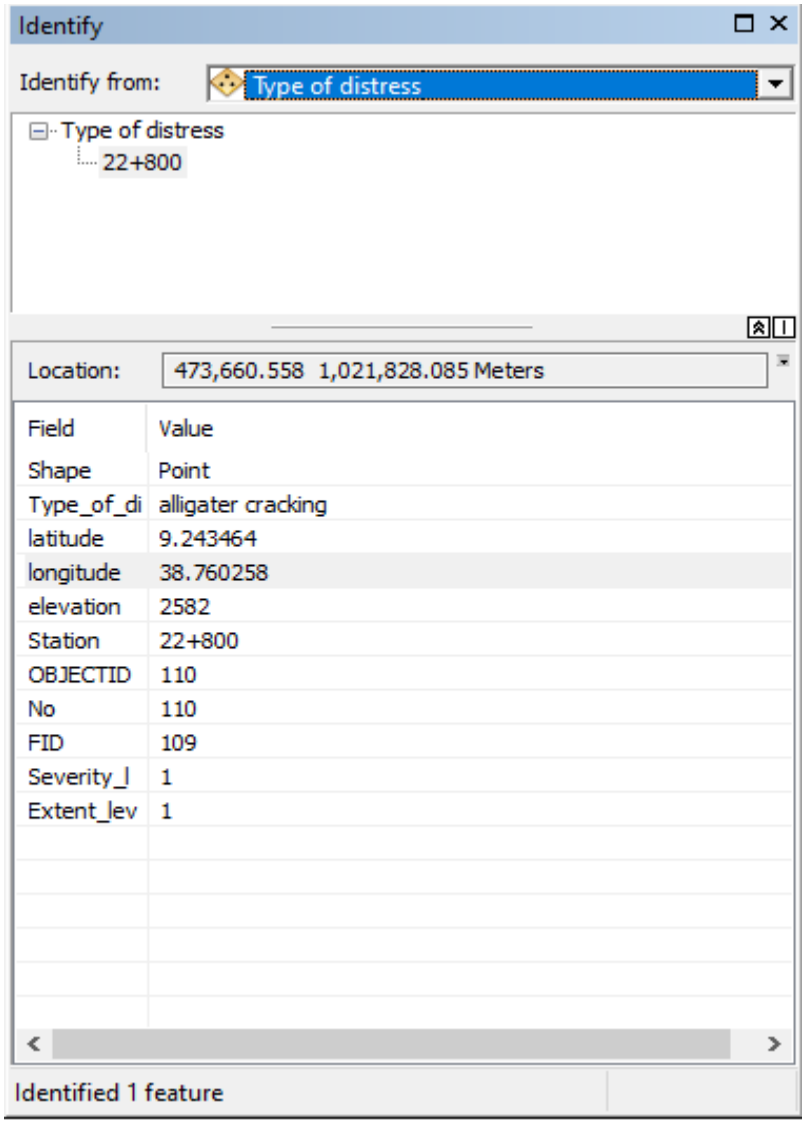


Figure-N. Detail information of an alligator crack