ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Determining Priority for Maintenance Program of Asphalt Roads Based on Multi-Criteria Decision Making

(a Case Study in Addis Ababa City)

A Thesis in Road and Transport Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Determining Priority for Maintenance Program of Asphalt Roads Based on Multi-Criteria Decision Making (a Case Study in Addis Ababa City)**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled “Determining Priority for Maintenance Program of Asphalt Roads Based on Multi-Criteria Decision Making (a Case Study in Addis Ababa City)” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Solomon Bogale

ABSTRACT

The gap between financing need and the fund allocated for maintenance of roads especially asphalt roads places responsible agencies in difficult situations to manage the maintenance hence, a ranking procedure for scheduling the maintenance program is required to optimize the limited fund. In this research, as determining the road maintenance priority is considered as a multi-criteria decision making problem, a comprehensive assessment framework of pavement maintenance project prioritization decision was developed through Analytic Hierarchy Process (AHP). The AHP is a frequently used decision making tool for multiple-criteria problems in transportation and pavement management field. The most commonly accepted criteria of influencing decision making in pavement maintenance management are established from important literatures, and accordingly nine factors are identified through pilot questionnaire surveys and justified through interviewing expertise in the field. The factors were: average annual daily traffic (AADT), vehicle composition, type of distress, severity, extent, project cost, accident rate, drainage condition and land use. Questionnaire surveys of AHP pair-wise comparison among the nine criteria were undertaken with experts and experienced people in pavement maintenance to weight the factors and it was found that accident rate and AADT of a road link play the most significant role by taking the highest share of 21.7% and 19.8% respectively. Next, sample of road sections, which are managed by Addis Ababa City Road Authority (AACRA), were considered and a complex matrix was then developed to evaluate the pavement maintenance priority score (PMPS) and decide which road links to be maintained first according to prescribed criteria. The result showed that from the selected roads for the case study, link R8 (which is the road from Berberetera to Molamaru) had the priority to be maintained. Then comparison was made between the AACRAs' maintenance project priority rank and the priority rank that was made using the model in this research and the result showed a huge difference in ranks of alternatives.

Key terms: *Maintenance, priority, multi-criteria decision making, Analytic Hierarchy Process (AHP), Pavement Maintenance Priority Score (PMPS).*

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ACRONYMS

AACRA	Addis Ababa City Road Authority
AASHTO	American Association of State Highway and Transport Officials
AHP	Analytic Hierarchy Process
CI	Consistency Index
ELECTRE	Elimination and choice translating reality
ERA	Ethiopian Road Authority
FHWA	U.S. Federal Highway Administration
GIS	geographic information system
HDM-IV	Highway Development and Management tool
M&R	maintenance and rehabilitation
M,R&R	maintenance, rehabilitation and reconstruction
MCDA	Multi – criteria decision analysis
ORF	Office of the Road Fund
PMPS	Pavement Maintenance Priority Score
PMS	Pavement Management Systems
SMART	Simple Multi-attribute Rating Technique
TOPSIS	Techniques for Order Preference by Similarity to Ideal Solution
WLC	whole life costing approach
WPM	Weighted product model
WSDOT	Washington State Department of Transportation
WSM	Weighted sum model

CHAPTER ONE

INTRODUCTION

1.1 Background

During the planning and design stages, highways are developed to incorporate all the necessary safety criteria to ensure safe and comfortable driving under all weather conditions. As these facilities begin to deteriorate under normal use, a good maintenance strategy has been proven to be the most effective tool to ensure that the facilities continue to operate as originally intended and to provide the desired level of service. In addition, a good maintenance strategy will lessen the impacts of deterioration or consumption and extend the service life of the facility, allowing resources that would otherwise be expended to reconstruct or rehabilitate the facility to be used for other purposes.

In developing countries like Ethiopia, an effective and efficient methodology has not been employed and the selection and prioritization of projects has largely relied on assumptions rather than a systematic quantification of road project attributes (Alemayehu, 2000). Decision making bodies who are responsible for maintenance of immense lengths of roadways and associated facilities, transportation agencies frequently have to decide which sections of highways, from the road network, need immediate attention and which can be deferred. A variety of factors influence this decision, the pavement condition is only one of these factors, although it is an important one. Economic, political, and a host of other factors must be evaluated before project selection may be made.

Many maintenance project selection systems evaluated and ranked pavement maintenance projects based on such factors as the current road surface condition (pavement condition) and traffic, where these systems were project-level systems to evaluate project priorities, and did not consider future pavement conditions, nor addressed network-level planning issues such as the limited budgets (Kulkarni, 2002)

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

Road management should be supported by adequate funding. Most of the time the allocated fund didn't met the financing need. In other words, there is a lack of funding for effective road management. Empirical evidence shows that the Ethiopian government's ability to provide necessary fund has been inadequate over the years (Road Fund, 2015). The budget for the maintenance management of the city roads should increase because the price of construction materials and labor cost are constantly increasing. The gap between financing need and the fund allocated brings governments difficult to manage the road maintenance, thus a ranking procedure is required to optimize this limited fund.

There are many factors that influence the decision making process in pavement management including the prioritization of pavement maintenance and funding, hence, identifying the factors affecting pavement maintenance prioritization through literature review is the initial step in this research. Next, a number of road sections which are managed by AACRA will be subjected into criteria with diverse matrix that serve as multi-objective decision making technique. Therefore, a Multi-Criteria Decision Making (MCDM) approach is necessary to ensure a satisfactory trade-off between conflicting factors and the optimization of the results.

Determining the road maintenance priority is considered as a multi-criteria decision making problem. It considers factors that are directly related to pavement damage such as pavement condition and average daily traffic. In addition, several procedures have been suggested by Saputro (2011), Putri (2011) and Moazami, 2011) and Dan Munthe (2012) regarding these problems. However, these procedures did not take non-technical factors, which are indirectly related to pavement condition, into consideration such as accident rate, availability of fund and political influences. In this regard, a study by Alie (2006) reveals that the legislature politicians have strong intervention in determining the road maintenance program.

This paper generally suggests a comprehensive assessment framework that enables to take a number of major technical and nontechnical aspects into consideration. The AHP (Saaty T. L., 2001) method is used to evaluate and rank these roads with respect to prescribed Criteria. The AHP seems to be a flexible decision making tool for multiple-criteria problems. It enables decomposition of a problem into hierarchy and ensures that both quantitative and qualitative aspects of a problem are included in evaluation process.

1.2 Statement of the problem

In developing countries like Ethiopia, there is a lack of funding for the construction of new roads and maintenance of existing roads. The fluctuation of funding leads to a shortage on the budget to be allocated for the maintenance activities of roads which should take into account all road links on the road network and had to be done on timely manner. But by not doing so, the responsible agencies are opted to spend more money that increased at a logarithmic scale from the initial case for the purpose of road maintenance. Due to these problems only limited number of road links was maintained for a long period of time while other links were given low attention which leads to a problem of failure of the road network to operate as its capacity (Road Fund, 2015)

'Which road link to be maintained first from the road network, for the road network to serve to its capacity' is decided by professionals, which they do decide based on their experience, and politicians who may not be technical and also might be biased while deciding. This kind of random decision making process, which is largely relied on assumptions rather than a systematic quantification, leads to a time taking process which directly end up on the necessary road sections which were supposed to be maintained but remain unmaintained causing lower road capacity and level of service throughout the road network resulting in budget fluctuation, most of the time.

Therefore to solve this problem, it is necessary to develop a model that considers the major decision making criteria and depending on their weights decide which road section from the road network should be maintained first. As a result, most of the road sections will be in good condition, the budget allocation will be fair; and financial fluctuations will be stabilized.

'What are the most significant factors that should be taken into account during prioritization decisions for pavement maintenance works by road authorities?' and 'what are the best way to deal with these criteria and ranking maintenance projects?' are the main questions this paper will try to answer in detail.

1.3 Research questions

- What are the most significant factors that have to be taken into account in the prioritization decisions for pavement maintenance works by road authorities?
- What is the significance level of each factor with respect to those that are accountable for the prioritization decisions for pavement maintenance works?
- On what basis do authorities decide which road sections should have the priority for maintenance? Is that trend scientific and acceptable?
- What is the best way to prioritize these criteria and ranking maintenance projects?

1.4 Objectives

1.4.1 General objective

The overall objective of this thesis is to develop a scientific decision making model that considers the major decision making criteria or factors and weights relative to one another in order to decide which road section should be maintained first to sustain the road network in good condition utilizing the available budget on hand and concurrently so that the budget allocation will be rational ultimately controlling and stabilizing the financial fluctuation.

1.4.2 Specific objective

The specific objectives of the research are to:

- Investigate the current pavement maintenance management practices, its principles and related challenges in the city of Addis Ababa;
- Transfer the random and limited maintenance project prioritization decision making approach to a more scientific approach by considering the essential factors to make a decision;
- Develop a method that can help select maintenance projects that should get priority by considering both technical and non-technical criteria;
- Determine the level of influence or weight of each factor or parameter on the final decision of selection of project where maintenance to be applied; and
- Simplify the decision making process by providing a simple framework.

1.5 Outline of the Research Methodology

The research flows is illustrated in Figure 1.1 below.

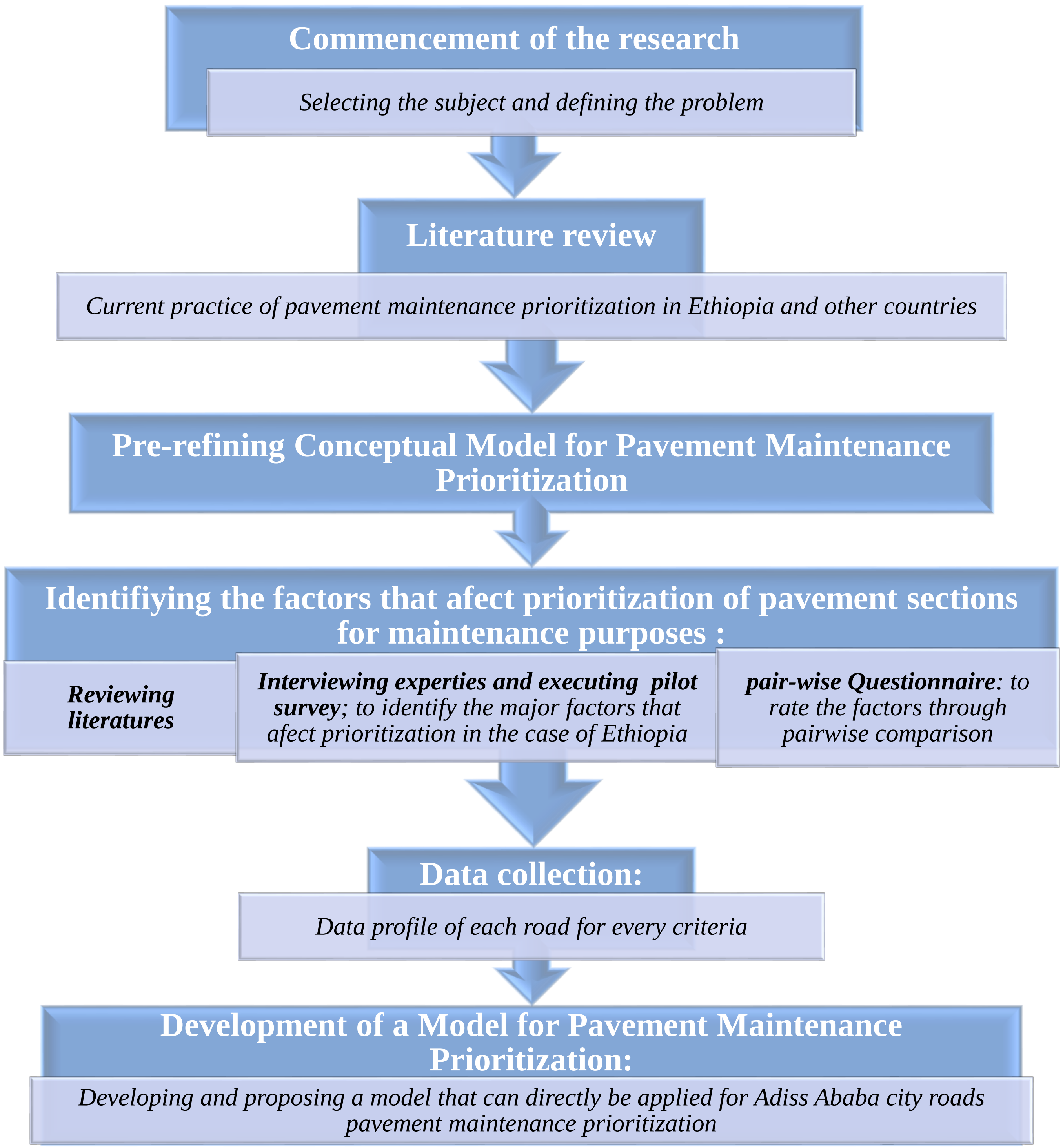

Figure 1.1: Research Design Model

1.6 Scope and limitation of the study

1.6.1 Scope of the study

The scope of this research focuses on first to assess the current periodic pavement maintenance management practices in AACRA and then to model a maintenance project prioritization technique for Primary Arterial Streets or PAS roads.

1.6.2 Limitation of the study

There is a limitation on the research since the assessed pavement maintenance management practices were for the most part only applicable if and only if the data for all proposed factors are available. It should also be noted that the quality of the decision on prioritization of maintenance of road sections is dependent on the quality of the collected data which in our country is very low.

The specific limitations that encountered while doing this research are:

- The AHP pairwise questionnaire survey was given to selected persons due to the reason that it needs long time from individual survey participants to fill the questionnaire and reach the acceptable consistency limit. Since the quality of the decision is highly dependent on the number and quality of survey participants, it would have been ideal if all the decision making bodies had participated on the questionnaire survey.
- Only quantifiable criteria were used but it would have been better if we were able to quantify Criteria like: road users comfort, political importance level of the road and air and noise pollution caused due to the road deterioration
- Inconsideration due to unavailability of data on criteria like: traffic delay due to pavement deterioration, accident rate related to surface condition, pavement deterioration rate, age of pavement and number of routine maintenance received by the pavement section in the past, makes the research limited;
- There is no any recorded data related to the average rate of deterioration which has significant role for modeling performance prediction of road segments and scheduling short term and long term pavement management plan

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

2.1.1 Pavement maintenance

Road maintenance has been defined by the Permanent International Association of Road Congresses (PIARC, 1982) as "Suitable routine, periodic and urgent activities to keep pavements, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as-constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts."

PIARC further defined periodic maintenance as "Operations that are occasionally required on a section of road after a period of a number of years. They are normally large scale and require specialist equipment and skilled resources to implement, and usually necessitate the temporary deployment of those resources on the road section. These operations are costly and require specific identification and planning for implementation, and often require design."

Periodic maintenance is akin to preventive maintenance defined by the American Association of State Highway and Transportation Officials (AASHTO) as follows (Galehouse, 2003): "…preventive maintenance is a planned strategy of cost-effective treatments that preserves and maintains or improves a roadway system and its appurtenances and retards deterioration, but without substantially increasing structural capacity." The U.S. Federal Highway Administration, (FHWA, 1999) defines pavement preservation as: "all activities undertaken to provide and maintain serviceable roadways; this includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects."

Periodic or preventive maintenance is non-structural and is applied to extend the life of the pavement, to enhance the performance and to reduce user delays (Galehouse, 2003). Examples of preventative (or periodic) maintenance are re-graveling of unpaved roads, resealing (with surface dressing, ultra-thin asphalt, etc.) of paved roads, and re-graveling of shoulders.

Routine maintenance is defined by PIARC (PIARC, 1982) as "Operations required to be carried out once or more/year on a section of road. These operations are typically small-scale or simple, but widely dispersed, and require skilled or unskilled manpower."

Non-preventive maintenance can also be described as routine, recurrent and urgent (FHWA, 1999), where routine refers to the "fixed-cost" activities such as grass cutting, drainage maintenance and road sign maintenance; recurrent to activities required throughout the year such as pothole patching, crack sealing, and grading, and urgent to the repair of defects caused by disasters (e.g., floods) or accidents.

The urgent maintenance is required to keep the highways open, protect property and road users. This has also been referred to as emergency maintenance (Galehouse, 2003) and includes repair of washouts, rigid pavement blow-ups, and earth slides.

AUSTROADS (1991), divides road maintenance into preventive and remedial maintenance, with preventative maintenance involving actions to prevent the roads from deteriorating and remedial maintenance involving the repair of defects.

2.1.2 Importance of on time maintenance

On time maintenance is extremely important. Studies have proven that it is more cost-effective to implement preventative maintenance actions on the pavement on a regular basis than neglecting the same and later trying to rehabilitate the pavement. Typically, premature periodic maintenance is 20 times costlier than proper routine and recurrent maintenance, while it is 3 times costlier to strengthen the pavement rather than properly maintain it (Robinson, 1988). Caltrans (Massey and Pool, 2003) found that for every US$1 spent on preventative maintenance, US$6 could be saved on rehabilitation and US$20 on reconstruction if applied timely. Timely maintenance can extend the pavement's service life by 5 to 10 years. Timely interventions are one-third to one-fifth the cost of a major repair (OECD, 1999). Similar principles are true for other elements such as bridges, culverts and road signs.

Maintenance produces very high benefit – cost ratios (Faiz and Horak, 1987). For the highway users, it is equally important to avoid accidents due to unsafe conditions rather than to rectify the defect after an accident has occurred. Poor maintenance (in terms of quality and timing) can increase the vehicle operating costs by 15% and no maintenance by 50% (Robinson, 1988).

A further consequence of poor maintenance is the possible lack of accessibility. Poor maintenance of bridges, culverts, drainage structures and the pavement can lead to closure of roads for periods of time with the related detrimental social and economic consequences.

Highway authorities normally budget for remedial maintenance based on historical trends and preventative maintenance based on the outputs from pavement management systems (PMS). The amounts vary depending on the age of the road, the importance, the traffic levels, the location, etc. Typical annual remedial costs/lane-kilometer is up to four to five times lesser than that of the preventative maintenance cost. The sum of the annual remedial and preventative cost is in the order of 1 to 4% of the initial construction costs of the highway (i.e. the asset value). Table 2.1 below shows typical comparative costs estimated by Robinson (1988) for highway maintenance.

Table 2.1: Pavement maintenance activities and their relative costs

Road Type	Activity	Cost Range (units)
Paved and unpaved	Routine and recurrent	1to 5
Paved and unpaved	Periodic	4 to 5
Paved	Strengthening overlay	25 to 40
Paved	Rehabilitation	60 to 100

Source (Robinson, 1988)

Generally highway maintenance has the following objectives:

- the repair of the functional pavement defects;
- prolonging the functional and structural life of the pavement;
- maintaining road safety and signage; and
- keeping the road reserve in an acceptable condition.

2.2 Pavement Management System (PMS)

2.2.1 Definition of PMS

The following definition of Pavement Management System (PMS) is provided by the FHWA and AASHTO (FHWA, 1989; AASHTO, 1990). “A set of tools or methods that (can) assist decision makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition.” In other words, a PMS is a systematic approach that provides quantifiable engineering information to help administrators and engineers manage highway pavements. The decision-making process is based on information from a working PMS and involves engineering experience, budget constraints, scheduling needs, management priorities, public input, and political considerations.

Highway maintenance must be planned, managed, designed and executed. Planning and management are done by means of maintenance management systems and procedures. These systems and procedures are normally different from a pavement and bridge management systems since the latter do not focus on long-term and strategic repair and upgrading issues. Relevant pavement and bridges can be identified for protective and preventative actions as part of a highway maintenance program (AUSTROADS, 1991).

Pavements are the important component of the inland transport system. It's a challenging job for engineers and scientists to enhance the performance of roads to meet the needs of growing urban communities. It is very important to maintain the existing pavement network in its serviceable condition within the available resources. And this can be achieved by adopting appropriate maintenance strategy for the road network under consideration. Managing the pavements is a systematic approach, which includes different activities like pavement performance evaluation, determination of maintenance and rehabilitation (M&R) requirements, optimization of resources and prioritization of pavement sections for timely maintenance using resources effectively. These activities collectively create the pavement management system (PMS) (Johnson A. &., 2017).

Priority ranking, as used in PMS, is a process used to rank the pavement sections in an order of urgency for maintenance and repair. The prioritization process is the main step of PMS, before the decision makers' takes final decision on execution of maintenance program (Sharaf, 1993).

The quality of priority-setting is directly influencing the effectiveness of available resources which are, in most cases, the primary judgment of the decision maker. The priority ranking process depends on various factors like pavement condition, traffic volume, environmental effects, desired performance standards, and budgetary constraints. Since maintenance actions affect the scheduling of work and allocation of resources, proper selection of such actions (priorities) is crucial to the most efficient use of limited resources. In the present study an effort has been made to broadly classify various approaches/methods for prioritization of pavement maintenance and the applications of these models made by different researchers at global level. A discussion on the limitations of the different models is also given in this study (Sharaf, 1993).

2.2.2 Development of PMS Concept

The PMS concept was first used in late 1960s to develop the systems approach for pavement design (Hudson et al., 1968), which integrated systems engineering, management principles, engineering analysis, and economic evaluation. It was followed by advances in related technologies in the 1970s (Terrel and LeClerc, 1978; Finn, 1994) and the knowledge was documented in a book on PMS (Haas and Hudson, 1978). In the late 1970s PMS evolved as a process to address the maintenance needs for the entire road network in the jurisdiction of an agency (Hudson et al., 1979). the modern PMS concept of pavement management has now progressed to a widely accepted approach worldwide for cost-effective planning of road investment and maintenance management of road and highway networks. The FHWA and AASHTO have encouraged states in the U.S. to implement PMS. Pavement management has also become a required component of international funding agencies, such as the World Bank, for most road and highway projects in developing countries for improved maintenance planning.

The highway network of a country forms the backbone of its economy and represents a huge investment in millions of dollars that allows for the safe and efficient movement of people and goods. Economically feasible and technically sound decisions on design, construction, maintenance, rehabilitation, and reconstruction of highway pavements are crucial for preserving the highway network in an acceptable condition. The economic prosperity of a country is strongly associated with the relative size and physical condition of its road network, which is the most important component of its transportation infrastructure (Hudson et al., 1997). High paved road density values in km per million inhabitants

(Queiroz et al., 1994; Mobility, 2001; Uddin, 2002a) are reported for industrialized countries (examples: 12,517 for the United States; 9,330 for the European Union of Western European countries; 9,200 for Japan; and 7,880 for Central and Eastern European countries). Comparatively, low values of this important economic development indicator are observed in developing countries (examples: 104 for Afghanistan; under 200 for China and India; 310 for Nigeria; and 763 for Brazil). These trends show that new construction and upgrade of road projects consume most road funds in many developing countries, and more funds are allocated in industrialized nations to maintenance, rehabilitation, and preservation of the existing pavement assets. As competition for funding among different sectors of the economy and society has grown, there is a critical need to implement modern management and systems engineering tools to assist decision makers for cost-effective and longer lasting pavement construction and effective use of funds for timely maintenance to preserve the condition and prolong the life of pavement assets.

2.3 Maintenance project prioritization techniques in pavement management system (PMS)

The primary purpose of a pavement management system (PMS) is to provide information so that roadway improvements can be priority-ranked. Ideally, prioritization is a consistent and justifiable process. It should involve minimizing life-cycle costs subject to minimum levels of serviceability and budget constraints. Prioritization is a complicated process that requires sound engineering judgment and a good understanding of local conditions. Current fiscal crises and rising roadway improvement costs have made prioritization decisions more important than ever. Priority analysis is a systematic process that determines the best ranking list of candidate sections for maintenance based on specific criteria such as pavement condition, traffic level, traffic characteristics, etc. Various methods are used for priority analysis ranging from simple listing based on engineering judgment to true optimization based on mathematical formulations.

The Simple Multi-attribute Rating Technique (SMART) is one of the methods utilized in dealing with the multi-objective problems. Its main strength is its relative simplicity; however, the cost of its simplicity is that the method may not capture all the detail and complexities of the real problem (Goodwin and Wright, 2004). Decision tree is a valuable tool for people to obtain a deeper understanding of complex problems, but it deals with decision problems that consist of multi-stages. In addition, it involves continuous probability distribution that makes it difficult to use in practice. ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality) (ELECTRE) is another way of evaluating decision options which are widely used and applied for many practical problems. However, since the method does not provide a way of obtaining weights and scores, the numbers are accepted unchallenged as inputs to a complicated algorithm. Moreover, it compares alternatives but does not produce a single index of performance (Watson and Buede, 1987).The major three techniques adopted throughout the world to deal with these issues are discussed below.

2.3.1 Priority numbers

Risk priority numbers have been used to quantify risks of different failure modes. For example, Zaifang Zhang et al. used this same methodology to quantify the different failure modes for a drilling machine. This methodology assessed the risk of each alternative in terms of severity, occurrence, and detection. Severity is a measure of the impact of failure. The more severe the impact, the higher the risk will be. Occurrence is a function of the frequency of failure or failure rate. Detection evaluates the likelihood a problem can be identified before the task is completed (Zhang, 2011).

This particular methodology has been widely implemented for its simplicity. Its downside, however, is that it only captures risk as a function of these three criteria, which may lead to underrepresented risk values (Zhang, Zaifang and Chu, Xuening, 2011).

2.3.2 HDM III and HDM-IV Programs

The World Bank's HDM program is the recommended choice of the World Bank and other international banks on the highway construction and maintenance management projects funded by these institutions. These programs perform a comprehensive life-cycle analysis of agency costs, user costs, and benefits using condition deterioration models for roughness, cracking, and rutting. The roughness and distress attributes are used for interventional levels. The M,R&R treatments (called maintenance standards in HDM) are arbitrary. The most economical M,R&R strategy is then selected for the project-level design (Watanatada et al., 1987). The HDM-IV version has extensive features for creating the network level database and M,R&R work programs (HDM, 2002). The HDM performance prediction models are empirical regression models and needs calibration (specially, the distress progression models), if used in different geographical areas. Therefore, it requires experienced HDM users to calibrate the models and establish rational M,R&R treatments and policies for a new geographical application region. These models were mostly developed using performance data on relatively thinner and inadequately maintained pavements in Brazil during the 1970s, which do not present the recent and current practice of thicker and high quality highway pavements. The HDM standard condition deterioration models predict a higher rate of deterioration for well-maintained asphalt highway pavements (Uddin, 2002a). The HDM methodology does not consider deflection and associated rational overlay design procedures in its maintenance standards (Yogesh U. Shah, 2014).

The following input parameters should be collected to feed into the software:

i. Road network data: Functional and structural condition, Drainage condition, Maintenance history and Geometric details of sections;
ii. Traffic volume data: Flow pattern and Traffic composition;
iii. Vehicle fleet details;
iv. Climatic details; and
v. Work costs.

It is important that prior to using HDM-IV, the system should be configured and calibrated for local use. Since HDM-IV has been designed to be used in a wide range of environments, calibration of HDM-IV provides the facility to customize system operation to reflect the norms that are customary in the environment under study (Chakrabarti and Rawat, 1995).

The need of excessive and appropriate data in the likes of maintenance history and IRI of the road sections for the decision making and it's inconsideration of factors like accident rate, land use and so on made the HDM-IV programs inflexible and difficult to use it in Ethiopia in the case of pavement maintenance project prioritization.

2.3.3 Multi – criteria decision analysis (MCDA)

There are many different MCDA methods found by researchers around the world. From these methods the following five are the most widely used (Triantaphyllou, 2000):

- Weighted sum model (WSM);
- Weighted product model (WPM);
- Analytic hierarchy process (AHP);
- Elimination and choice translating reality (ELECTRE); and
- Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS).

2.3.3.1 Weighted Sum Model (WSM) and Weighted Product Model (WPM)

In respect of WSM, if there are m alternatives and n criteria, the best alternative is the one that satisfies the expression. For i=1,2,3,...,m:

$$A\,wsm - score \quad = max \sum_{j=1}^{n} aij\ wij \tag{2.1}$$

Where

$A_{WSM - score}$ is the WSM score of the alternative;

n is the number of decision criteria;

a_{ij} is the actual value of the i-th alternative in terms of the j-th criteria; and

wj is the weight of importance of j-th criteria.

The 'additive utility assumption' governs this model and it can be used without any difficulty with singe-dimensional cases where all the units are the same. However, the difficulty emerges when it is wanted to multi-dimensional MCDM problems because of the reason that the assumption is violated when different units are combined (Ale).

To correct this issue Triantaphyllou (2000), established a weighted product model (WPM) with the fallowing equation:

$$\mathrm{R}\left(\frac{\mathrm{Ak}}{\mathrm{Ai}}\right) = \prod_{\mathrm{j=1}}^{\mathrm{n}} (\mathrm{akj/aij})^{\mathrm{w}} * \mathrm{j} \tag{2.2}$$

Where:

n is the number of criteria,

aij is the actual value of the i-th alternative in terms of the j-th criteria, and

wj is the weight of importance of j-th criteria.

According to Triantaphyllou WPM is similar to WSM except that WSM uses addition while WPM deals with multiplication. Hence, he stated that the structure of WPM eliminates any units, it can be used in single and multi-dimensional MCDM with the advantage of using relative values instead of WSM ones.

2.3.3.2 Elimination and Choice Translating Reality (ELECTRE) and Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS)

The ELECTRE method focuses on “outranking relation” with pair-wise comparisons using separate alternative criteria. For example, under two alternatives Ai and Aj, the outranking relationship between the two describes that even when the i-th alternative doesn’t dominate the j-th alternative quantitatively, the decision-maker may still take the risk of regarding ai as better than aj. This means that one alternative is dominated by another which makes it excel in one or more criteria while remaining equivalent in other criteria (Triantaphyllou, 2000). However, it is noted that since the method yields a system of binary outranking relations between alternatives where the system is not necessarily complete, the method is sometimes unable to identify the most preferred alternative, only producing a core of leading alternatives. Regarding of the above shortcomings, the method has a clear view of alternatives by eliminating less favorable ones which is convenient when there are decision problems that involve a few criteria with a large number of alternatives (Triantaphyllou, 2000).

According to Triantaphyllou, TOPSIS was developed as an alternative to the ELECTRE method. The basic concept of TOPSIS is that the selected alternative should have the shortest distance from the ideal solution in a geometric sense. The method assumes that each criteria has a tendency of monotonously increasing or decreasing utility with easy definition of ideal and non-ideal solutions. Under this method, a normalized decision matrix is constructed first (the same as under ELECTRE method) followed by a weighted normalized decision matrix then, ideal and negative-ideal solutions are determined fallowed by separation measures, the best alternative is the one that has the shortest distance to the ideal solution.

2.3.3.3 Analytical Hierarchy Process (AHP)

AHP has been successfully used in different fields and disciplines. Its ability to handle both qualitative and quantitative data makes AHP an ideal methodology for some prioritization problems. There has been extensive research on prioritization problems using the AHP method.

The fundamental logic of AHP is to decompose a large complex task into smaller, manageable subtasks. In essence, AHP enables users to create different levels or hierarchies depending on the complexity of the problem. Furthermore, the prioritization is based on pairwise comparison assessments. Each pairwise comparison assessment is obtained by comparing two alternatives at a time, and a relative value is assigned to each pair. Using AHP, a priority vector of the alternatives is developed from the synthesis of the pairwise comparisons.

There have been many variations of AHP since it was first used in prioritization. The AHP described earlier is the additive AHP (AAHP), which is the most commonly used. To address the lack of ability to deal with extreme cases, multiplicative AHP (MAHP) was proposed to give a more balanced result. Apart from the traditional 1–9 scale system proposed by Saaty (Saaty, 1980), many other scale systems have been developed, such as the inverse linear scale system proposed by Ma and Zheng to address more delicate differences between preferences (Ma, D., and X. Zheng, 1991), as well as the power scale system and logarithmic scale system to address non-linear cases. Because of the many successful applications and its simplicity, the additive AHP was selected as the methodology for this research

2.4 Major advantages of AHP over the other prioritization techniques for this research

Due to the multiple criteria inclusion of the project, in order to achieve the decision goal, the study requires embedding a multi-criteria decision method for conducting a multi – criteria decision analysis (MCDA).

MCDA aids decision makers in analyzing possible actions or alternatives based on multiple incommensurable factors/criteria. In other words, utilizing a decision system that deals with multiple criteria assists decision makers with rating or ranking the alternatives (Eastman, 2009). For mainstream practitioners of MCDA, it differs from quantitative optimization in a way that concerns of subjectivity is also taken into consideration in quantitative approaches that structure and formulate a decision making problem (Belton and Stewart, 2002; Roy, 2005).

MCDA methods are clustered as follows (Hobbs and Meier, 2000):

Value or Utility Function-Based Methods:

- Multi Attribute Utility Theory (MAUT);
- Simple Multi Attribute Rated Technique (SMART);
- Analytical Hierarchy Process (AHP); and
- Simple Additive Weighting (SAW).

Outranking Methods:

- ELECTRE family (ELECTRE 1-2-3);
- PROMETHEE family (1&2); and
- Regime Method Analysis.

Other Methods:

- Novel Approach to Imprecise Assessment and Decision Environment(NAIADE); and
- Stochastic Multi-objective Acceptability Analysis (SMAA).

From the Utility Function-Based Methods, the Simple Multi-attribute Rating Technique (SMART) has a main strength in its relative simplicity; however, the cost of its simplicity is that the method may not capture all the detail and complexities of the real problem (Goodwin and Wright, 2004). Decision tree is a valuable tool for people to obtain a deeper understanding of complex problems, but it deals with decision problems that consist of multi-stages. In addition, it involves continuous probability distribution that makes it difficult to use in practice. ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality) (ELECTRE) is another way of evaluating decision options from the Outranking Methods which is widely used and applied for many practical problems. However, since the method does not provide a way of obtaining weights and scores, the numbers are accepted unchallenged as inputs to a complicated algorithm. Moreover, it compares alternatives but does not produce a single index of performance (Watson and Buede, 1987)

To compare the usage of MCDA methods for specific purpose in every field, Toloie-Eshlaghy and Homayonfar (2011) conducted a comprehensive literature review, based on 20 scholarly journals published between 1999 and 2009 and classified MCDA methods in accordance with the application areas (See Table 2.2). MCDA methods and their implementation frequencies related to transportation studies are highlighted in the stated table. The numbers stated in the table represent the numbers of published papers for each field.

Table 2.2: Classification of MCDA Methods According to the Application Areas

Method / Application	AHP	ANP	SAW	TOPSIS	ELECTRE	LA	GP	MOP	VIKOR	DEMATEL	PROMETHEE	SMART	FMCDM	Group MCDM	Group Decision Making	multiple criteria analysis	MAUT/MAVT	Compromise Programming	SMAA	OWA	DSS	DEA	choquet integral	rough sets Theory	Fuzzy set theory	Heuristic Algorithms	Other Methods	Total (Fuzzy/Crisp)	Total
Environment Management	3 1				1			1			3		3	1	1	2	1	2	1		9 1						2	27 5	32
Water Management	5		1	1	2		1				3					3	2	3		1 1	2				1		3	28 1	29
Business and Financial Management	9 3	4 2	1	5 2	1		2	1	1	1	1		8	1	1	1	1				1 1	1		1	5		7 2	39 26	65
Transportation and Logistics	14 9	11		8 5	1		6 2	7 4	2 1	1	2	1 1	4	2	2	1			1		2	2	2		8	5	12 2	79 39	118
Manufacturing and Assembly	4 4	1		1 1			1 1	5	1		1		4	1	1		1	1			3	2			2	8	5	34 14	48
Energy Management	5				2			3			3		2		1	1					1				1		5	21 3	24
Agricultural and Forestry Management	1						2									1	3				2						3	12 0	12
Managerial and Strategic Planning	9 3	6		3 1	1	1	2 1	4		1	4		5		2	1	1				1 1	2				1	8	47 11	58
Project Management and Evaluation	11 6	4		4			3	1		1			1	1	2	1					2 3	1			1		9	40 11	51
Social Service	1	2		1 1			1	3																			3	11 1	12
Military Service	2			1				1			1	1			1						1 1				1		3	10 3	13
Other topics	7 3	3 1	1	4 1				4			1	1	2 4				1		1		1	1	2		2		8 2	39 11	50
Non application Papers	38 2	3	2	10 5	7		15	16 3	3	1	3	1	1 1	1	4		7	1 2	8	6	12	8	6	2	12	4	72 9	230 44	274
Total	142	37	5	54	15	1	37	53	8	5	22	5	4 4	7	15	11	1 7	9	11	8	44	17	10	3	33	18	155	786	786

Source: Toloie-Eshlaghy and Homayonfar, 2011.

When selecting a suitable MCDA method for this research, the following criteria are considered:

- Ease of use;
- Ability to support large number of decision makers; and
- Ability to handle data comprising different units (such as pavement condition data, traffic volume data, land use data and so on).

Overlapping these considerations with the classification supplied in Table 2.2, which has verified its popularity among decision-makers, Analytical Hierarchy Method (AHP) appears to be a frequently used method in transportation and pavement management field and arises as the suitable method for adoption in this evaluating framework so that it is proposed to utilize it for this research.

The relative strengths of AHP include:

- Formal structuring of problem;
- Simplicity of pair-wise comparisons;
- Redundancy allows consistency to be checked; and
- Having great diversity or variety.

AHP offers an alternative approach when a decision-maker is dealing with a problem that involving multiple criteria. The method that was originally developed by Thomas Saaty has been commonly used in decision problems in areas such as project selection, economics and planning, material purchasing and handling, and transportation. Saaty (1980) concluded that in order for a problem to be represented and priorities to be developed for alternatives based on the user's judgment, AHP as a multi-criteria decision method is useful, as the method uses hierarchical structures. Steps are followed in order in the AHP procedure (Ibraheem and Atia, 2012):

i. Defining the problem;
ii. Developing hierarchical structures;
iii. Pairwise comparison;
iv. Estimating relative weights; and
v. Testing consistency.

Identification of weighting factors for the criteria is to be carried out via an appropriate method. There are three steps in utilizing any decision-making technique involving numerical analysis of alternatives (Triantaphyllou et al., 1998):

- Determining the relevant criteria and alternatives;
- Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria; and
- Processing the numerical values to determine a ranking of each alternative.

2.5 Steps for Pair-wise Comparison of Criteria using AHP

2.5.1 Calculation of weights of factors

The next step after identification of important factors is to assign their weight relative to one another. Finding factor weights will be done through conducting pair-wise comparisons of rated factors with a view of establishing an Importance Matrix (IM) to get a more precise ranking of factors organized according to their significance. The normalization of the paired matrix provides the importance attached to each factor. The design of the Importance Matrix can be seen below (Ibraheem, 2012)

$$A = \begin{bmatrix} \frac{w1}{w1} & \frac{w1}{w2} \cdots & \frac{w1}{wn} \\ \frac{w2}{w1} & \frac{w2}{w2} & \vdots \\ \frac{wn}{w1} & \cdots & \frac{wn}{wn} \end{bmatrix} \quad (2.3)$$

Where,

w_1 = rating value for factor 1 (F_1):

w_2 = rating value for factor 2 (F_2) and

w_n = rating value for factor n (F_n).

To calculate the relative weights of factors in the pair-wise comparison matrix, eigenvalue method is used. The relative weights (*W*) of matrix *A* are obtained from the following equation (Ibraheem, 2012)

$$(A - \lambda max * I) * W = 0 \quad (2.4)$$

Where,

λmax = the biggest eigenvalue of matrix A; and

I = unit matrix.

Let *A* = [a_{jk}] for the n x n matrix and the following vector equation is considered:

$$Ax = \lambda x \quad (2.5)$$

Where,

X = unknown vector,

Λ = unknown scalar

"A value of λ for which (*Ax*=λ*x*) has a solution *x*≠ 0 is called eigenvalue or characteristic value of matrix *A*. The corresponding solutions *x*≠ 0 of (*Ax*=λ*x*) are called eigenvectors or characteristic vectors of matrix *A* corresponding to that eigenvalue λ" (Ibraheem, 2012).

The steps of determination of eigenvalues and eigenvectors are illustrated in terms of matrix (2.6):

$$A = \begin{bmatrix} a11 & a12 \cdots & a1n \\ \vdots & \ddots & \vdots \\ an1 & an2 \cdots & ann \end{bmatrix} \quad (2.6)$$

Eigenvalues are determined first as in equation (5.5).

$$A = \begin{bmatrix} a11 & a12\cdots & a1n \\ \vdots & \ddots & \vdots \\ an1 & an2\cdots & ann \end{bmatrix} \begin{bmatrix} x1 \\ : \\ xn \end{bmatrix} = \lambda \begin{bmatrix} x1 \\ : \\ xn \end{bmatrix} \quad (2.7)$$

Written out in components,

$a11x1 + a12x2 + \ldots\ldots + a1nxn = \lambda x1$

$a21x1 + a22x2 + \ldots\ldots + a2nxn = \lambda x2$

$an1x1 + an2x2 + \ldots\ldots + annxn = \lambda xn$

Transferring the terms from right to the left, the following are obtained:

$(a_{11} - \lambda)x_1 + a_{12}x_2 + \ldots\ldots + a_{1n}x_n = 0$

$a21x1 + (a22 - \lambda)x2 + \ldots\ldots + a2nxn = 0$

$an1x1 + an2x2 + \ldots\ldots + (ann - \lambda)xn = 0$

This can be written in matrix notation,

$$(A - \lambda I)\, x = 0 \quad (2.8)$$

“By Cramer’s Theorem, this homogeneous linear system of equations has a nontrivial solution if the corresponding determinant of the coefficients is zero” (Ibraheem, 2012):

$$D(\lambda) = \det(A - \lambda I) = \begin{bmatrix} a11 - \lambda & \cdots & a1n \\ \vdots & a22 - \lambda & \vdots \\ an1 & an2\cdots & ann - \lambda \end{bmatrix} \quad (2.9)$$

$D(\lambda)$ is called the characteristic determinant and equation (2.9) is called the characteristic equation of the matrix A. Iteration is necessary until the consecutive values of weights of factors become similar and the matrix became consistent.

2.5.2 Calculation of Consistency Ratio

According to Saaty (2001), the consistency ratio (CR) demonstrates the degree of compatibility of data analyzed through the AHP method. By definition, the consistency ratio reveals any potential incompatibility in subjective matrix scores. The relative scoring of factors will result in a matrix of scores, say a(i, j). The matrix holds the expert judgment of the pair-wise comparisons. Nevertheless, the judgment should be consistent. Therefore, inconsistency test is necessary to validate it. The inconsistency measure is useful for identifying possible errors in judgments data entry of a survey participant as well as actual inconsistencies in the judgments of participants themselves. Inconsistency measures the logical inconsistency of the judgments. For instance, if we say that "A" is more important than "B" and "B" is more important than "C" and then say that "C' is more important than "A", we are not being consistent. A somewhat less inconsistent situation would occur if we would say that "A" is 4 times more important than "B", "B" is 3 times more important than "C" and that "A" is 2 times more important than "C" but it is still inconsistent. In broad-spectrum, the inconsistency ratio of less than 0.1 be considered as reasonably consistent. Particularly, a matrix a(i, j) is said to be consistent if all its elements follow the transitivity and reciprocity rules below (Saaty T. L., 2001). The consistency ratio formula is:

$$CR = CI / RI \tag{2.10}$$

Where,

CI = consistency index, and

RI = random index:

$$CI = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2.11}$$

Where,

λmax = the biggest eigenvalue of matrix A; and

n = number of variables or factors considered.

Geometric consistency index (GCI) for a combined priority matrix of every participant's judgment is calculated using:

$$GCI = \frac{2\sum_{i<j}^{j} \ln a_{ij} - \ln\frac{p_i}{p_j}}{(n-1)(n-2)} \tag{2.12}$$

Where,

p_i and p_j = participant i^{th} and j^{th} judgment respectively; and

n = number of variables or factors considered.

The formulas above demonstrate calculating consistency with regard to the largest eigenvalue. The largest eigenvalue λmax (allowing for deviations owing to the large numbers) is obtained through excel template as "9.15", and when it is applied within the equation given above, where n is the size of the matrix, it gives a GCI value of "0.05".

Saaty (2001) and many researchers have conducted simulations with different numbers of matrices to find the average random Consistency Index. The random index table produced by Tummala (1994) and Alonso (2006) is used in this research. Though they used different number of matrices to demonstrate the random index, their indices became similar to Saaty's. In random matrices, the RI is the mean value of CI. RI values for the matrices comprising n elements (for different matrix orders) are shown in Table 2.4.

Table 2.0.3: Random index (RI) for the factors used in the decision making process

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Source: Tummala, 1994; Alonso, 2006.

2.6 Current practices of pavement maintenance project prioritization techniques around the world

After conducting an exhaustive literature review on different state, national, and international highway agency procedures, it was discovered that limited funding and budget fluctuations for maintenance of roads are not unique to Ethiopia. However, the methods to address them are quite varied. Many highway agencies allocate the vast majority of their budgets to pavement preservation and many have adopted asset management principles and techniques to assist with their maintenance operations. Therefore, a thorough review of current practices of pavement maintenance prioritization techniques around the world is done and summarized as follows.

2.6.1 Zambia (Africa)

There is currently no formal rational system for the prioritization of urban roads for maintenance in Zambia. There are no decision support systems to support how funds had been distributed for maintenance of the urban roads. However, under the Road Maintenance Strategy, a multi criteria approach for prioritization of maintenance activities on the urban roads network is used based on the following criteria: (RDA, 2013):

i. Road Condition;

ii. Ranking of Town/City:

- Cities,
- Provincial headquarters,
- Municipalities,
- Districts,

iii. Traffic volumes;

iv. Access to social amenities;

v. Economic activities/potential;

vi. Resource envelopes; and

vii. Political input.

Through the Road Maintenance Strategy, Routine Maintenance activities on the Core Road Network (CRN) are given the first priority in the Road Sector Annual Work Plan (RSAWP), followed by periodic maintenance and then finally rehabilitation and upgrading works. The reason for this prioritization is to ensure preservation of the existing road asset which is in a maintainable condition. All roads in good and fair condition will be placed on routine maintenance. The timely application of the maintenance activities will be guided by the use of a Road Asset Management System (RAM). The RAM will draw input from annual road condition surveys. The prioritization of road maintenance will be based on the following (RDA, 2013):

- Road classification;
- Traffic volumes; and
- Social economic factors – access to schools, hospitals and public facilities etc

The priority ranking for maintenance on the CRN is as shown in Table 2.4.:

Table 2.4: The proposed annual allocation of the Road Fund for road maintenance in Zambia

Road Classification	Rank	Resource allocation Ratio
Trunk, Main and District (TMD)	1	60%
Primary Feeder Roads	2	25%
Urban Roads	3	15%

Source: RDA, 2013

2.6.2 Washington State Department of Transportation (WSDOT) (North America)

The Washington State Department of Transportation (WSDOT) implemented a system called Maintenance Accountability Process (MAP). This process is aligned with the department's strategic planning, budget and maintenance service delivery. In essence, MAP provides the necessary tools to evaluate the effectiveness and accountability of the state's maintenance program. The program basically relies on random evaluations of selected sample locations, where field surveys results are compared against established benchmarks and a level of service is determined. This level of service is then plotted and a historic performance trend is obtained (WSDOT, 2008).

MAP's most important and significant tool is its Priority Matrix. This Priority Matrix ranks the maintenance activities according to their contribution towards the maintenance program objectives. These objectives include the following:

- Safety of traveling public and employees;
- Operation of the highway system (Highway System, keeping the road open);
- Meeting environmental responsibilities;
- Maintaining the infrastructure;
- Addressing legal mandates other than environmental (including torts); and
- Contributing to comfort, aesthetics, and or convenience.

Each maintenance activity is then assigned a value between 0 and 9 (9 being the highest impact) in terms of its impact on the maintenance objectives identified earlier. A cumulative score is then obtained that essentially becomes the priority value or rank. The maintenance activities are then ranked in the order of descending priority values. The MAP also serves as a communication tool among all the stakeholders. The Washington State Government, Transportation Commission, and taxpaying public are kept informed of the impact of policy and budget decisions on the program service delivery (WSDOT, 2008).

2.6.3 Highway Agency (UK, Europe)

The United Kingdom's (UK) Highway Agency (HA) conducts a research in three methodologies that include (UK Roads Board, 2011):

- Value Management Process (VM);
- Effective Asset Management; and
- Risk Assessment Methodologies.

The Value Management (VM) process aims at establishing a risk approach to prioritizing highway maintenance. Some of its anticipated benefits include the greater transparency and understanding of risks in the prioritization of maintenance schemes. It will assist decision makers in understanding the consequences of funding or not funding certain maintenance works, and it will also allow the HA to assess the value of the benefits obtained by funding specific maintenance programs. Finally, this methodology will unify assessment across diverse asset types (UK Roads Board, 2011).

The Effective Asset Management methodology will implement a whole life costing (WLC) approach to obtain the risk of delayed or deferred maintenance. On the other hand, the Risk Assessment methodology proposes a framework for operational decision making and will establish possible ways of addressing inconsistency in decision making by implementing monetary based multi-criteria analysis (MCA) (UK Roads Board, 2011).

2.6.4 VICROADS (Australia)

VICROADS is responsible for the development, construction, and maintenance of highways for the State of Victoria in Australia. The agency conducts road condition surveys to identify their pavement and resurfacing projects. In addition to the data collection, the agency implements a structural maintenance project that identifies risk as the product of the probability of failure and the consequence of failure. This approach takes into account the importance of the highway in the maintenance strategy decision making process (VicRoads, 2005).

In terms of its roadside maintenance strategy, the agency has identified the following three objectives or goals:

- Safety;
- Environmental and Cultural Heritage Values; and
- Amenity and Access.

These three goals represent the agency’s top priorities for their roadside maintenance strategy (VicRoads, 2005).

2.6.5 PMPS in Gaza City (Asia)

In Pavement Maintenance Management Systems (PMMS) or Gaza city maintenance projects are prioritized after the overall condition of network sections is defined, and each segment treatment is determined with its equivalent cost (Jendia, 2005). In choosing, a logical order is established by the ranking index formula that is a combination of section condition, traffic exposure and functional classification (Ali, 1995). Equation 2.13 is the basis for the prioritization on PMMS for road pavements in Gaza.

$$PI = \frac{1}{PCI} * TF * FC * MF * SR \qquad (2.13)$$

Where:

PI = Priority Index.

TF = Traffic Exposure Factor.

FC = Road Classification Factor.

MF = Maintenance History Factor.

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

The application requires an orderly process which begins with a proper inventory of the Gaza road network comprising management segments. Each pavement segment condition is examined and a valuation of the condition is performed using a specific criterion. The treatment strategy and cost implications are then defined on each pavement section. Prioritization is done and is concluded by documenting report results (Jendia, 2005).

2.7 Current practices of pavement maintenance prioritization technique in Ethiopia

Back in the years, Ministry of Finance of Ethiopia used to finance road maintenance works. However, this funding arrangement has been transferred to Office of the Road Fund (ORF) and the Office has become the chief financer of maintenance works since then (ORF, 2015)

Accordingly, in the early years of the establishment of ORF , the budget allocation has been in the proportion of 70% for Federal roads, 20% for Regional roads and 10% for Municipal roads. However, currently 65% of the regular Road Fund budget for the purpose of maintenance is allocated to the Ethiopian Roads Authority towards the maintenance of the federal road network; 25% is allocated to the Regional Road Authorities for rural roads and 10% to the Municipalities for the maintenance of city roads. This implies that the budget allocation isn't based on road condition maintenance need (ORF, 2015).

The total road network of the country at the beginning of RSDP was about 15,870 km. Due to the construction of new gravel and asphalt roads during RSDP; the total road network has increased to 20,080 km in the year 2007 and 27,606 km in the year 2015. Overall, the road network in Ethiopia has been increasing on the average by 3.2% between 1997 and 2015 (ORF, 2015).

It is inevitable that as the road network increases, the maintenance need increases accordingly, thereby increasing the required budget. However, due to the insufficiency of the yearly allocated maintenance budget, it is difficult to provide adequate and timely maintenance to the entire road network. This will have associated impact on the road users, such as increase in vehicle operating costs, and hence reluctance to use the road in addition to increasing the maintenance cost. Figure 2.1 below presents the requested versus the allocated funds between 2010/11 and 2015/16.

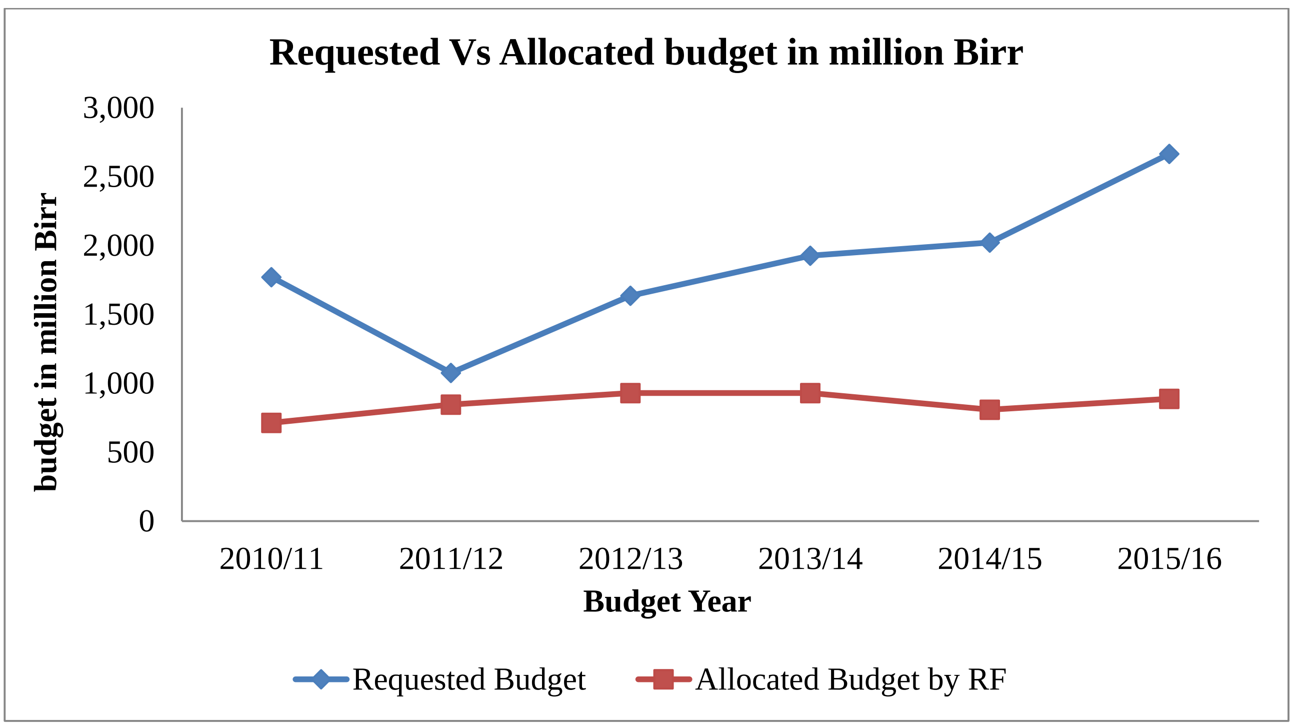

Figure 1.2: The requested Vs allocated budget by the Road Fund in Ethiopia (Source: Office of Road Fund, 2015)

As indicated in the above chart, the yearly allocated budget for maintenance works was much less than the requested budget. It is indicated that the allocated maintenance budgets do not show constant rate of increase or decrease in proportion to the increasing road network. This is due to the limited amount of income that ORF collects from fuel levy, axle weight through vehicle license renewal fee, overloading fines, Government budget and any other road tariff as may be fixed and approved by the necessity to finance the road maintenance work.

AACRA gets its maintenance budgets from two offices; from ORF and from the Municipality Office of Addis Ababa. Road fund allocates funds proportionally for the entire countries projects; therefore, it has a trend of allocating fixed fund which is most of the time not sufficient that AACRA needs for its maintenance operation. However, the Municipality Office allocates budget for emergency maintenance, only for road links that are thought to be important for a short period of time due to special occasions that will be held around that particular place. Most of the time, the budget from ORF is allocated for projects which are contributory to communities' activities and are with low cost. On the other hand, the Municipality Office influences AACRA to concentrate on emergency projects.

Many times, AACRA receives only about 20% of the fund that it requires s for achieving its annual road maintenance program. But unlike other years, in the fiscal 2016/17 the Municipality Office released to AACRA nearly five times of the fund compared to the previous years and AACRA did massive maintenance undertakings throughout the city.

According to interviews with higher officials in AACRA road asset management department , before 2002 maintenance scheduling were done traditionally by selecting road links that are politically important (for example the Sidistkilo, - Aratkilo - Betemengist -Bole routes), which should be kept in good serviceability condition at all time. But other road links are not given the required attention. Generally, the city roads are maintained on random basis. Other road links that may be given due attention for maintenance are those subjected to public complaint. Normally, it can be concluded that there is no as such system that considers any scientific approach for pavement maintenance prioritization of road links.

In 2002, the Road Asset Management Department at AACRA, which is responsible for the management of pavements, started working with a foreign company named SMEC which provided them a consulting service on their pavement management system (PMS), bridge management system (BMS) and traffic management system (TMS). They also developed a system that was integrated with HDM IV for the PMS. They also came up with an IRI establishment machine and many new technologies for Ethiopia. The Department used PMS software in 2005. in cooperation SMEC. The

SMEC system was developed first to model the pavement performance and then generate an optimized work programs. Before modeling the performance of road pavement, it needs recorded profile for particular pavement. These records are the following: (SMEC, 2002)

i. Pavement surface condition;
   - Condition of distress,
   - Roughness of pavement, and
   - Rutting of the pavement.
ii. Pavement structural number (which is also used in HDM 4;
   - Pavement structural number,
   - Information on pavement layers, and
   - Surface treatment history.
iii. Pavement traffic data determined in terms of;
   - Annual Average Daily Traffic (AADT),
   - Classification of traffic spectrum, and
   - Growth rate.

However, the cooperation was terminated in 2005 due to undisclosed reason before it came into realization and so the system collapsed before thorough utilization by the Authority.

After that time In AACRA, pavement evaluation is done on yearly bases using visual condition survey method using spread sheet comprising: Street number, street name, total length, road type, defect type and defected area detail (specific area, length, width, area and condition). A sample spread sheet is shown in Appendix V. After visual condition survey, the pavement conditions are summarized and reported as: very good, good, fair, poor, and very poor and also by types of distress according to ASTM D66-33 manual. The Road Asset Management Department defines and report maintenance type, unit rate and maintenance priority schedule to the maintenance department which is responsible for performing routine and periodic maintenance works of the city (see Appendix I).

In 2015 Addis Ababa City Roads Authority (AACRA) started to work in cooperation with a company from japan named Japan International Cooperation Agency (JICA) to develop its road maintenance system and capacity (JICA, 2017).

The JICA drafted a project named 'Project for Development of Road Maintenance Capacity of Addis Ababa City'. It has been implemented to ensure that the roads in Addis Ababa would be maintained in a sustainable manner. In order to do that it is essential that the management capacity of AACRA with regards to road maintenance be enhanced. The JICA expert team assigned to AACRA has been reviewing the road maintenance implementation structure of the organization with various counterparts through discussions, interviews, surveys and site visits. Training sessions for AACRA staff have also been held in Japan and Addis Ababa with regards to: road maintenance, road inspections, maintenance planning and developing maintenance management systems (JICA, 2017).

The desired outputs at the completion of the project in 2018 are: improved road maintenance implementation structures within AACRA; the establishment of processes for formulating road maintenance plans and improved maintenance skills and knowledge of AACRA technical staff (JICA, 2017).

Until the JICA's project comes to realization, the AACRA Road Asset Management Department is responsible for registering all road assets and defining the necessary maintenance activity with the respective maintenance cost to be done for city roads based on the summarized condition survey data. The limitation of budget for the maintenance and rehabilitation work of pavements necessitates the prioritization of pavement maintenance projects. There is no developed method to predict the future condition of the road segment to estimate the average rate of deterioration which might have played a significant role for scheduling in short-term and long-term plan. Moreover, there is no system for prioritization and selection of the appropriate treatments for the roadway network. With the exception of emergency works, the department has a trend of prioritizing projects and rank them depending only on the severity grade and extent of the road damage which in other words mean: the more the road is damaged, the more chance it will have the priority to be maintained.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Introduction

This research starts with reviewing of pertinent literatures, identification of factors affecting pavement maintenance prioritization, where factors are to be rated in terms of importance by professionals at road authorities. Furthermore, interviews were conducted with experts in the field to justify the rated factors. However, the main aim of this research is to develop a model that is applicable for AACRA, road maintenance prioritization with the expectations its applicability at the Authority.

3.2 Selection of Methodological Choice

The adopted methodological choice for this research is using interviews and questionnaire techniques to obtain both qualitative and quantitative data. When using a mixed methodology for doing a research, the main research activities will be centered on the following three strategies:

i Surveys based on the two elements of a interviews and questionnaire, to obtain both qualitative and quantitative data;

ii Pavement maintenance prioritization modeling to develop decision support aid; and

iii A Case Study on Addis Ababa city roads to test the model.

3.3 Data Collection

The detailed data collection methods for this research are as follows:

- Preliminary questionnaire surveys to establish relevant factors affecting pavement maintenance management decisions and interviews with experts to justify the quality of the rated factors that should be taken into account;
- Pair-wise questionnaire surveys to establish the significance level of factors; and
- a secondary data, which is going to be used to score factors for each sampled road, was collected from AACRA to test the model.

3.3.1 Questionnaires

A two stage questionnaire survey was made in this research that are a preliminary questionnaire survey, which was used to identify the major factors from those that were found through reviewing of relevant literatures which have a high impact on the decision of pavement maintenance prioritization, and a pairwise questionnaire survey, which was developed and used to calculate and rate the significance level of each factors by relating one to the other.

The questionnaire surveys were directed at practicing professionals from AACRA Road Asset Management Office, practicing engineers from AACRA Road Maintenance Office, site engineers who have an experience on road maintenance projects, and expertise on road and transportation engineering. For the purposes of obtaining a reliable consensus on the most significant factors currently influencing pavement maintenance management decisions; and establishing the relative weight assigned to such factors by different experts. These factors were eventually justified and used in the development of a model with the aid of the multi-criteria decision making process in pavement maintenance management. The questionnaires were given to the target survey participants in person and an AHP pairwise comparison excel template was used to calculate the weight of every factor and the consistency of decision of every participant while filling the survey in computer. Appendix II contains details of the preliminary questionnaire survey questions adopted during the process and Appendix III shows a sniped picture of the excel survey questions employed in the pavement maintenance prioritization survey questionnaire.

3.3.2 Interviews

Interviews were conducted to justify the relevance of the factors that were identified as the major factors which have a high impact on the decision making of pavement maintenance prioritization affecting pavement maintenance prioritization, that were found through preliminary questionnaire survey. Many interviews were conducted with pertinent experts.

3.4 Study Area

The case study approach was considered as one of the research strategy components for this research. Specific roads within AACRA were used to test the proposed frame work. The roads were selected from the same road hierarchy according to AACRA for the purpose of comparison. This is due to the relatively higher availability of data on those roads which are selected for the case study and this will also help to compare the final decision of the model with the AACRAs' maintenance project prioritization decision and concurrently to check if the model can be used and applied for the entire road network within the city.

In total, 43 road sections from different sub cities were selected for the purpose of testing the model. The road sections were selected from similar road classes, according to data found from AACRA, to make the comparison between them to be consistent. the selection was made depending the reasons as shown on the figure 3.1 below.

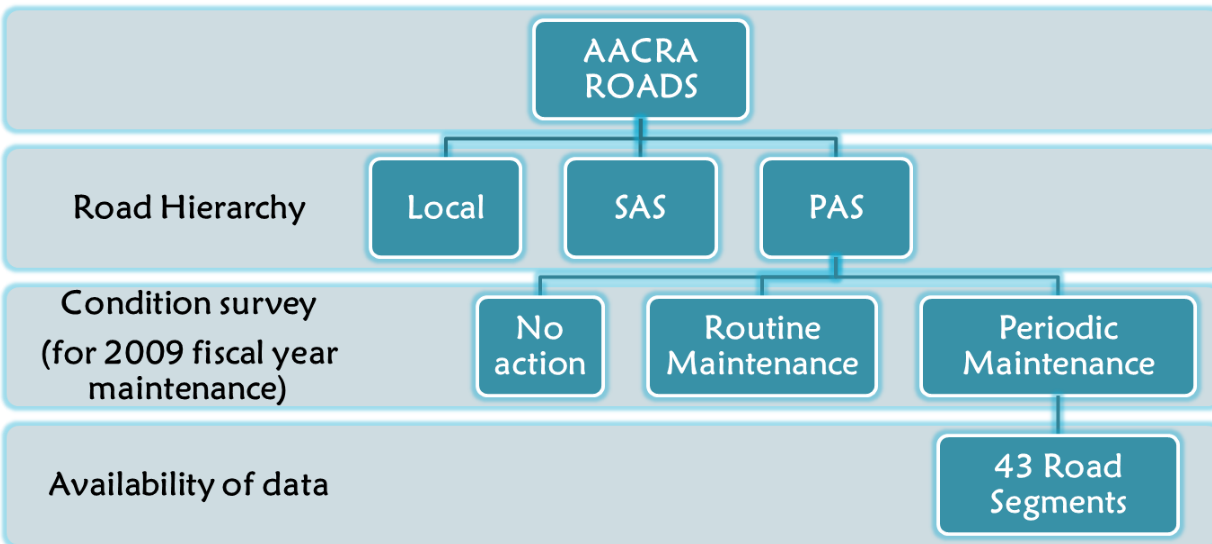

Figure 3.1: Selection of road segments to test the framework.

The selected forty three road segments are depicted in Table 3.1 below.

Table 3.1 Selected road sections or links number and name (origin – destination)

Road no	Road Origin - Destination
R1	Addisu Gebeya - 70 kuter Semen Mazegaja
R2	Alert Roundabout - FM Radio Station
R3	Ambesa Garage Police - Shegole
R4	AMCE - Egziyabher Ab Church
R5	Art Design universty - Genfle Bridge
R6	Atlas Hotel -Ras Desta Hospital
R7	Belay zeleke - Rufail
R8	Berbere Tera -Mola Maru (Kebele Meznagna)
R9	Betel Roundabout - Augusta Ring Road
R10	Betemengist - Gibi Gebrial
R11	Bis Mebrat - Old Post House
R12	Bole Medanialem Church – Haya hulet Menged
R13	Brass hotel - Gumruk Air Lines
R14	Debesko - 5 kuter Mazoria(G/Markos)
R15	Ethiopian comercial Bank - Emigration
R16	Filwuha Hotel - Zewditu Hospital
R17	From Ararat hotel - Kara
R18	From Bancko Diroma Junction – Statistics Birou
R19	From Bole Homes - Koria Hospital
R20	Gibi gabrial - Ginfle Bridge
R21	Gofa mebrat Hail - Lafto Dildiy
R22	Gojam Ber - Total
R23	Hulegeb Yaynesiwran Mahber - Ring road
R24	Kasanchis Total - Gedera Hotel
R25	Kolfe Dildiy - 18 Mazoria
R26	Lideta - Carl Roundabout
R27	Lideta - Emu Pension

R28	Megenagna - Woreda 24 (64 bus station)
R29	Mesalemia - Samba Nekersa
R30	Nigid Matemia bet - Stastics
R31	Nigid Matemia bet - Orma Garaje
R32	Ras Desta Hospital - Kechene
R33	Rufail Enkulal fabrica dildiy - Semen Mazegaja
R34	Samba Nekersa – Medhanialem
R35	Sebategna - Amanual Church
R36	Sefere selam - Efoyta (kolfe Dildiy)
R37	Shewa supermarket - Bis Mebrat
R38	Shewa supermarket - Bancko Diroma Turn
R39	Shiro meda - Sidist Kilo
R40	Tikur Ambesa Hospital - Post Office
R41	Tile Factory- Getahun Besha Bldg
R42	Traffic Police - England Embassy
R43	Yerer Ber - Urael Church

3.5 Data Analysis Techniques Adopted

As established previously in this section, this research is based on a mixed methods approach, which involves on both qualitative and quantitative methodologies. Therefore, the approach to be adopted for analyzing the data must also comprise a combination of appropriate methods to suite each type of data.

Data from the preliminary questionnaire survey was subjected to interviews, which generated qualitative data as they justify and describe the factors. In order to maintain external validity, experts in pavement maintenance are selected from the city road authority to interview. Then the justified factors were weighted through questionnaire to get their overall weight. Data from the questionnaires regarding pavement maintenance management factors were rated by the respondents according to their significances and these data were quantitative in that they have a numerical aspect in terms of ranks or weights. The assessment for determining road priority is a complex process. Many aspects should be taken into consideration. Therefore, basic statistics was used for data analysis, and the Analytical Hierarchy Process (AHP) was used for specific calculations.

The AHP methodology was utilized in the evaluation framework. This is because it offers a number of strengths over other methods in capturing the details and complexities of the real problem (Goodwin and Wright, 2004). AHP's widespread use has verified its popularity among decision-makers. The relative strengths of AHP include:

a) Formal structuring of problem;
b) Simplicity of pair-wise comparisons;
c) Redundancy allows consistency to be checked; and
d) Having great diversity or variety to be utilized in different fields.

CHAPTR FOUR

FACTORS AFFECTING PAVEMENT MAINTENANCE PRIORITIZATION

4.1 Introduction

According to Fwa (2006), the maintenance project selection and prioritization depends on the following criteria and information:

- Pavement condition parameters for the network level analysis (type, severity and extent of distresses, rutting, roughness, structural condition, loss in skid resistance or friction, noise, geometric deficiencies, etc.);
- Minimum acceptable condition for selected attributes (may vary with functional class, traffic level, vehicle composition, etc.);
- Capital improvement needs (more lanes, upgrade to a higher functional class, etc.);
- Other executive priority criteria (urgency, safety, emergency based on accidental or natural disasters, overall M, R & R budget constraints, etc.)

As the pavement condition deteriorates, user costs and frequency of public complaints increase; therefore, the identification of a highway section for timely maintenance is a great benefit of PMS to the agency, as well as the public. Decision criteria and M, R & R policies should be established as soon as possible as a part of the overall PMS development with the assistance of peoples involved in planning, design, construction, research and pavement evaluation, and maintenance. Finally, these critical decisions should be approved by the agency executive management' because any major change in the criteria may have drastic effects on the maintenance reports and agency resources (Fwa, 1993).

A thorough review of literature is performed in order to identify and account for the factors influencing pavement maintenance prioritization decisions, a questionnaire survey was conducted to identify the major factors and a well-grounded justification for the questionnaire is provided. The pair-wise questionnaire survey, which is one of the main data collection methods adopted in this research, and its analysis is performed employing the AHP method and it is done after interviewing expertise who have experience in the field. Finally, considerations such as consistency of the survey and sensitivity of the result were also dealt with.

The aim of the survey was to establish a general consensus among practicing professional road engineers and managers who have a role of deciding which road project should have the priority to be maintained, as to the most significant factors affecting pavement maintenance management prioritization decisions. The preliminary questionnaire was designed after identifying many significant factors affecting prioritization decisions by reviewing many literatures, and was subsequently modified and refined to consider a shortlisted number of factors based on the outcome of the interviews, before being delivered to the finally selected target participants for the proposed main survey. The preliminary and the pair-wise survey questionnaires are included in Appendix II and III respectively.

4.2 Preliminary questionnaire survey

An important preparation step before disseminating the main questionnaire surveys is to carry out a preliminary questionnaire survey and an interview with professional experts to select the most important factors affecting decision on pavement maintenance prioritization in the case of selected roads in Addis Ababa City and therefore maintain the quality.

Major factors that are responsible for prioritization decisions in road maintenance schemes were included by the researcher based on detail literature reviews. Then, a preliminary questionnaire survey was held with the professionals to extract from the list of factors and also gave their opinions on other factors to be included that are very influential in the case of Ethiopia. The objective was for the respondents to rate these factors according to the degree of importance based on the Likert Scale of the following well-defined, evenly spaced rating range:

1 = Not Important
2 = Less Important
3 = Important
4 = Very Important
5 = Extremely Important

The factors that were subjected for the preliminary questionnaire survey to be prioritized by the professionals were: Remaining service life of the road, Annual Average Daily Traffic (AADT), Vehicle composition, Functional class of the road, Observed deterioration rate, Type of distress, Severity of distress, Extent (percentage of damaged area), Project cost, Accident rate, Drainage condition, Importance of Road/Classification and Land use. The draft version of the adopted survey questionnaire that is going to be refined during interviews is included in Appendix II.

From 70 questionnaire surveys disseminated among practicing professionals from AACRA Asset Management Office, practicing engineers from AACRA Road Maintenance Office, site engineers who have an experience on road maintenance projects and expertise on road and transportation engineering 40 questionnaires were filled and returned in hand.

4.3 Interview

4.3.1 Why interview?

. In this research, interview was used to seek feedback from professionals, from road authorities, many of whom have extensive experience related to pavement maintenance. The target interview participants were selected based on their experiences, availability and readiness to take part in the survey. Table 4.1 below shows the educational level and work experience of interviewees.

Table 4.1 : List of interviewees

Full Name of interviewee	Company	Position	Area of expertise
Meseret Abera	AACRA	Road asset department head	Structural engineer
Melkte Abiy	AACRA	Road asset department, office engineer	Civil engineer
Asres simeneh	AAiT	Lecturer	Road & transport engineer
Kaleab W/yohanis	AAiT	Lecturer	Road & transport engineer

The primary aims of the interviews were to test the effectiveness of the questionnaire design and detect any flaws in the questionnaire details, in order to modify the survey design, based on the feedback, prior to the main survey. The principal objective of this exercise was also to ultimately maximize the quality of the questionnaire, examine the adequacy of the questions in covering the intended topic, to increase, reduce the risk of inaccuracies in the answers given, to test the efficiency of the technique and contents of the survey and check question clarity. The interview enabled the questions to be refined before the main survey. Practicing professionals from AACRA Pavement Maintenance Road Asset Management offices and Postgraduate researchers from the Addis Ababa Institute of Technology (AAiT) were interviewed to get a comprehensive and good quality result.

4.3.2 Interview results

Summaries of the interview scripts reveal slight divergence in personal views. The subjective observation is justified given the interviewees' different background and experience in pavement maintenance management. There is reasonable consistency in interviewees' opinions within contextual specifics, which leads to establishing a trend that enables to extract the major 9 factors that were commonly accepted as very influential in making a decision by the interviewees.

Therefore after thorough interviews, the commonly agreed on major factors affecting pavement maintenance prioritization between the interviewees were:

- F1: Average Annual Daily Traffic (AADT);
- F2: Vehicle composition;
- F3: Type of distress;
- F4: Severity;
- F5: Extent (percentage of damaged area);
- F6: Project cost;
- F7: Accident rate;
- F8: Drainage condition; and
- F9: Land use

4.4 Pair-wise questionnaire survey (main questionnaire survey)

4.4.1 The questionnaire survey

After selecting the major factors that influence the decision making process through an interview, the next step was to prepare a questionnaire survey that encompasses pair-wise comparison between every criteria. Therefore, an AHP pair-wise comparison questionnaire was disseminated to target recipients. The final version of the adopted AHP pair-wise comparison survey questionnaire is included in Appendix III.

4.4.2 Selection of target recipients of the main survey

According to Bell (1999), depending on the size of the survey and the target population, the researcher may need to employ sampling techniques to be able to produce a sample, which should be representative of the population as a whole, and be able to draw generalizations from the findings (Bell, 1999). The task regarding the questionnaire survey was therefore decided based on the survey participants' sample from amongst the numerous practicing professionals and the AACRA road managers. Therefore, in order for the target interviewees to be professionals who have a good exposure to the subject, engineers and managers from the AACRA road maintenance and road asset management offices, lecturers from the AAiT, Road and Transport Department, postgraduate researchers from AAiT, engineers, formen and surveyors who work on pavement maintenance on sites were selected to be the target interviewees of the main survey.

4.4.3 Method of distribution of the questionnaire

The questionnaire format was adopted from Geopels' AHP pair-wise comparison template which was developed on Microsoft Excel. Then, after a brief explanation until it comes clear for participants to fill the questionnaire accurately, and the AHP pairwise comparison template was given to them in a laptop computer and/or in a softcopy format to finish and return the softcopy of their final result to the researcher.

An Excel-based survey tool was adopted with the objective of providing a relatively easy visual interface to the survey participants. The survey tool was modified for evaluating weights of all nine criteria goals. The survey tool records the survey taker's preference and strength of preference for each pair-wise comparison and provides guidance for improving consistency (see appendix III). The tool also calculates the weight and rank of each criteria based on an overall average weight using the AHP algorism (Goepel K. D., 2013).

Five of the questionnaires were filled and returned to the researcher, which was satisfactory to proceed to the next step of the research.

4.5 Definitions of the most important factors employed in the Model

The processes of identification of the most important factors affecting the decision of pavement maintenance project prioritization had been already discussed. So the next step before employing the model should be defining these factors in detail.

4.5.1 Traffic characteristics

4.5.1.1 Average Annual Daily Traffic (AADT)

Traffic volume over each section of the roads affects the pavement maintenance priority. The greater the traffic volume on a section is, the higher the priority will be. Indeed, for a highly crowded road, on-time maintenance and rehabilitation would cause considerable reduction in the operational costs of a great number of vehicles. Consequently, when two roads are in similar in all other parameters except their traffic volume, the one with greater traffic volume should be given higher priority.

4.5.1.2 Vehicle composition

Relative to cars and buses, trucks carry loads much in excess of legal limits and are largely responsible for poor road conditions, in addition to the diminishing allocation of funds year after year for maintenance and rehabilitation. Very huge capital investments are now needed to upgrade and rehabilitate the existing road network to make it capable of withstanding high stresses and tyre pressures that are caused by heavy wheel loads. In view of experiencing of such small magnitude of funds becoming available in the near past, one of the best course to remedy the situation would be to consider the number of trucks passing through the roads while deciding which road should be maintained first (B.M. Sharma et al, 1995).

4.5.2 Pavement condition

One of the key components of an effective pavement management system is an accurate assessment of the condition of the existing pavement network. This assessment has historically been accomplished by an annual visual pavement condition survey. The surface cracking of a pavement is represented by a Surface Rating and Dominant Distress for each segment of the pavement network (ASTM, 2007).

A visual inspection of the pavement surface can provide valuable information. Visual inspection data can be used to evaluate current pavement condition, predict future pavement performance, determine and prioritize pavement maintenance and rehabilitation needs, estimate repair quantities, and evaluate the performance of different maintenance and rehabilitation techniques and materials. Most roads rely on a visual inspection as the network level condition assessment used within their Pavement Management System (Broten et al. 2001).

The inspector checks the sample unit and records the type, severity and amount that must correspond to those defined in the Distress Identification Manual. The quantities and severities should normally be estimated using measuring techniques as accurate as possible (ASTM, 2007).

Type of deterioration informs of the nature of repair treatment and intervention point. Knowing the reasons for deterioration is fundamental information in the process of major maintenance intervention and repair.

The condition survey will be measured in terms of the type, severity and extent of the distress or defect. 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. The Ethiopian Road Authority – Paved Road Condition survey Form is included in Appendix V.

4.5.2.1 Types of distresses

Distresses in flexible pavements can be grouped into four broad categories:

- Deformation;
- Cracking;
- Surface Defects; and
- Edge Defects.

- Deformation

Deformation in pavement is defined as the change in the pavement surface profile and it can affect roughness condition and skid resistance when water ponding occurs (Austroads, 1987). Deformations may also accelerate crack initiation. The common pavement deformations are corrugations, depressions, rutting, and shoving, as shown in Figure 4.1.

i. Corrugations

Corrugations in flexible pavements are identified as closely and regularly spaced transverse waves, as shown in Figure 4.1. Corrugations are plastic movements of the pavement surface and usually occur where acceleration and deceleration take place such as, bus stop, bends, and intersections. Lack of stability in the surface or base course is the possible cause for corrugations.

ii. Depressions

Depressions are localized bowl shaped settlement in the pavement (see Figure 4.1) caused by one or combination of the following:

- settlement of service trenches;
- consolidation in the poorly compacted subgrade; and
- change of moisture in the subgrade.

Water ponding in the depressions causes cracking and other pavement damages such as roughness and skidding problem.

iii. Rutting

Rutting is the longitudinal depression (see Figure 4.1) that occurs in the wheel path due to inadequate surface thickness, and lack of compaction or stability in the surface or base course. Rutting in early pavement life may be due to poor compaction, high moisture content, or lack of lateral resistant. On the other hand, under-strength material and over loading are among the causes for rutting in the later part of pavement life. Untreated significant rutting may lead to further damage such as cracking and hydroplaning especially when water ponding occurs.

iv. Shoving

Shoving or creep is the horizontal displacement of surfacing materials occurring mainly in the direction of traffic where braking or acceleration actions take place, as shown in Figure 4.1. Permanent displacements can cause single ridges or depressions similar to corrugations. Possible causes for shoving are weak bond between pavement layers, lack of edge support, and insufficient pavement thickness or stability.

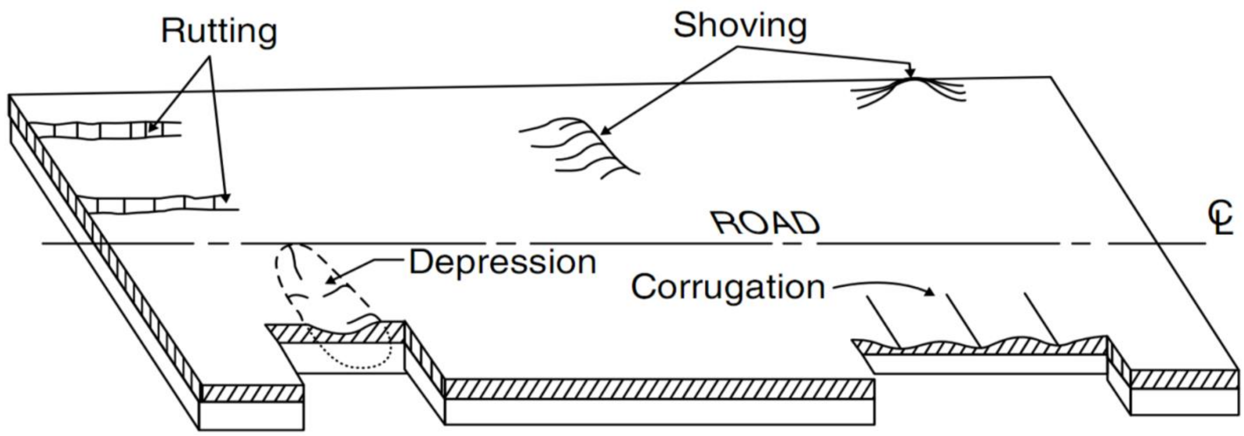

Figure 4.1: Sketch of deformations in flexible pavements (Source: Austroads, 1991).

- Cracks

Cracks are fractured pavement condition resulting from a number of causes and are found in a variety of patterns ranging from single to an interconnected pattern. Possible causes of cracks are deformations, fatigue life exceeded, reflection of cracks from underlying layers, shrinkage, and poor construction joints (Austroads, 1987). Presence of cracks causes numerous problems in the pavement including limiting load spreading capability through loss of structural strength, loss of water proofing, and loss of roughness level. As seen in Figure 4.2, the following types of cracks are commonly found in the flexible pavements:

- Crocodile cracks;
- Longitudinal cracks;
- Transverse cracks;
- Block cracks;
- Diagonal cracks;
- Meandering cracks; and
- Crescent shaped cracks.

Some of the major types of cracks that occur more often on site are discussed below

i. Crocodile Cracks

As the term implies, crocodile cracks are interconnected cracks forming a series of small polygons resembling a crocodile skin (see Figure 4.2). Crocodile cracks are usually fatigue cracks and are the early signs of pavement distress. They indicate a pavement condition where excessive movements occur in or more underlying layers. These cracks are caused due to inadequate pavement thickness, low modulus base course and aged wearing course, shrinkage of aged bitumen, very low temperature and over-loaded vehicles. Crocodile cracks usually appear only in the traffic loading areas and allow water entering in the pavement.

ii. Longitudinal Cracks

Single or a number of parallel cracks appear longitudinally along the pavement (see Figure 4.2) due to reflection of a shrinkage crack or joint in the underlying layer, weak bond between pavement lanes, asphalt hardening, volume change in the subgrade, and differential settlement between cut and fill. Poorly constructed lane joint may also cause longitudinal cracks. These cracks do not usually result from load but wide cracks will permit water to enter the pavement structure.

iii. Transverse Cracks

Transverse cracks run transversely across the pavement (see Figure 4.2) and are common in aged asphalt surfaces. These cracks are caused due to primarily reflection of a shrinkage crack or joint in the underlying layer, construction joint, and structural failure in the cement base. Similar to longitudinal cracks, wide cracks permits water in the pavement.

iv. Block Cracks

Interconnected cracks that form a series of rectangular blocks over the entire pavement are known as block cracks (see Figure 4.2). Block cracks are generally non-load assisted, but repeated loads increase severity. These cracks indicate that the asphalt has hardened significantly and the possible causes are:

- shrinkage and fatigue cracking in the underlying cemented materials;
- joints in the underlying layer; and
- fatigue and shrinkage cracking in the asphalt surfacing layers.

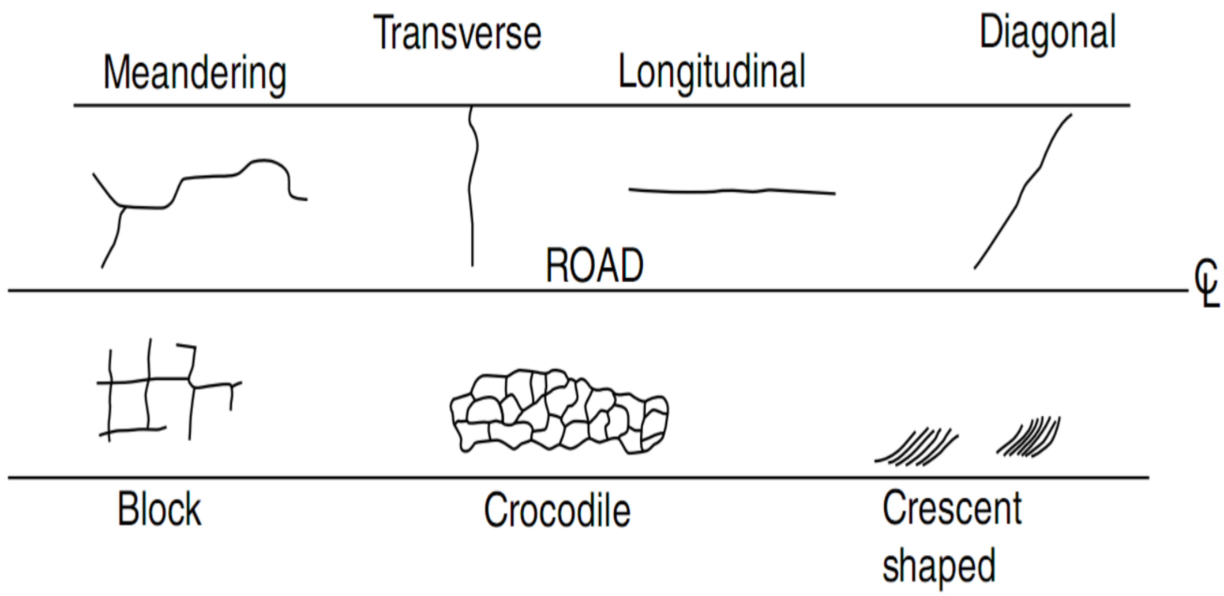

Figure 4.2: Sketch of common types of cracks in flexible pavements (Source: Austroads, 1991).

- Surface Defects

As the term implies, surface distresses are associated with the pavement surface and usually do not indicate structural problem in the pavement layers, as shown in figure 4.3 (Austroads, 1987). However, they cause significant effect on pavement serviceability and skid resistance, and, if not treated, may lead to structural problems. Common types of surface defects are:

- Delamination;
- Flushing;
- Polishing;
- Raveling;
- Stripping;
- Pothole; and
- Patching.

Some of the major types of surface defects that occur more often on site are discussed below.

i. Raveling

Raveling is used to define a distress condition where both aggregate and binder are progressively lost from pavement surface, as shown in Figure 4.3. Raveling is caused due to inadequate binder, deterioration of binder condition, or inferior asphalt mix design. Inadequate compaction or construction in the wet or cold periods may also cause raveling. Delamination and raveling in sprayed seal pavements may not be easily differentiated.

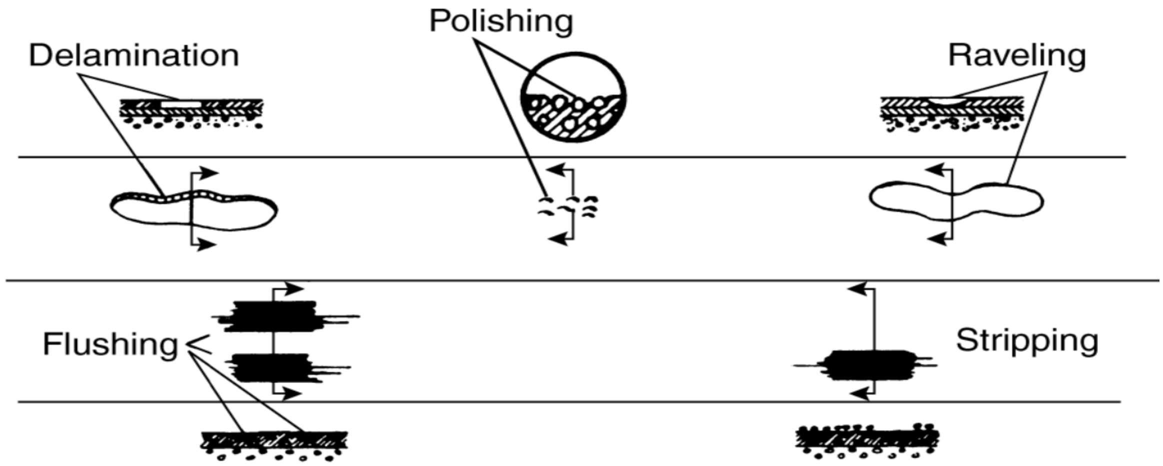

Figure 4.3: Sketch of surface defects in flexible pavements, Surface texture deficiencies (Source: Austroads, 1991).

ii. Pothole

Potholes, bowl-shaped cavity in the pavements (see Figure 4.4), are developed due to the loss of surface and base course material that become weak and loose when water enters into the pavement though cracking. Localized disintegration and freeze–thaw cycles also cause potholes in the pavement. Traffic and water in the cavity accelerate the development of pothole.

iii. Patches

Pavement sections repaired to fix loss of serviceability or structural capacity are termed as patches (see Figure 4.4). Patches are considered as the distress when it is raised or depressed below the surface level. Other distresses may also occur in the patches. Patches include surface repair without digging out pavement layers, reconstruction of surface or other layers, and excavation for services.

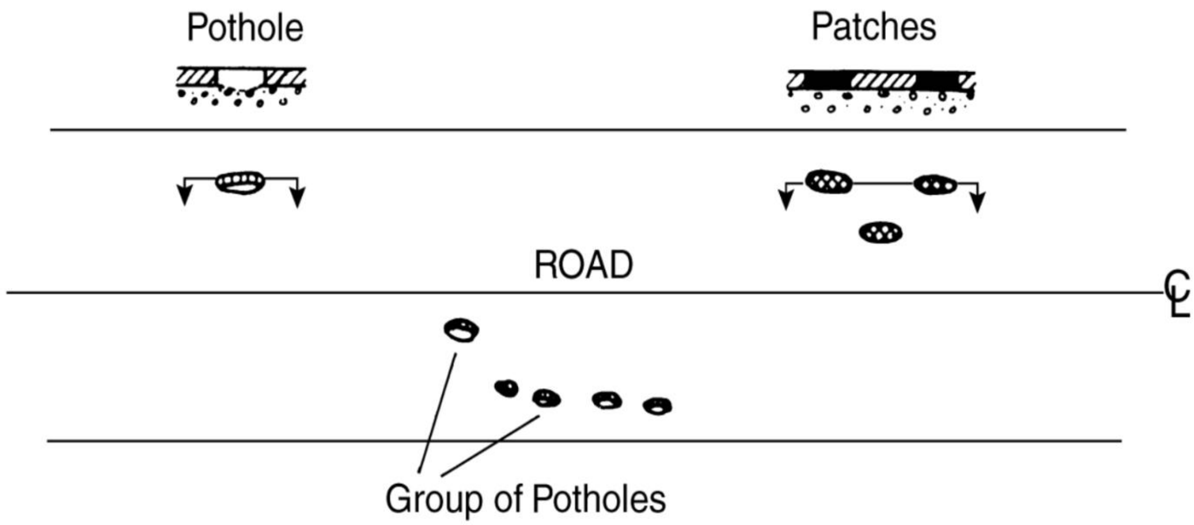

Figure 4.4: Sketch of surface defects in flexible pavements, Pothole and patches (Source: Austroads, 1991).

- Edge Defects

Defects that occur along the joint of the pavement edge and shoulder are known as edge defects (Austroads, 1987). These defects may appear in isolated areas or continuously along the joint and they are particularly significant for unsealed shoulders. Edge defects reduce pavement width and affect ride quality. They also allow water entry into the pavement. Two types of edge defects, such as, edge break and edge drop-off, as shown in Figure 4.5 are common in flexible pavements.

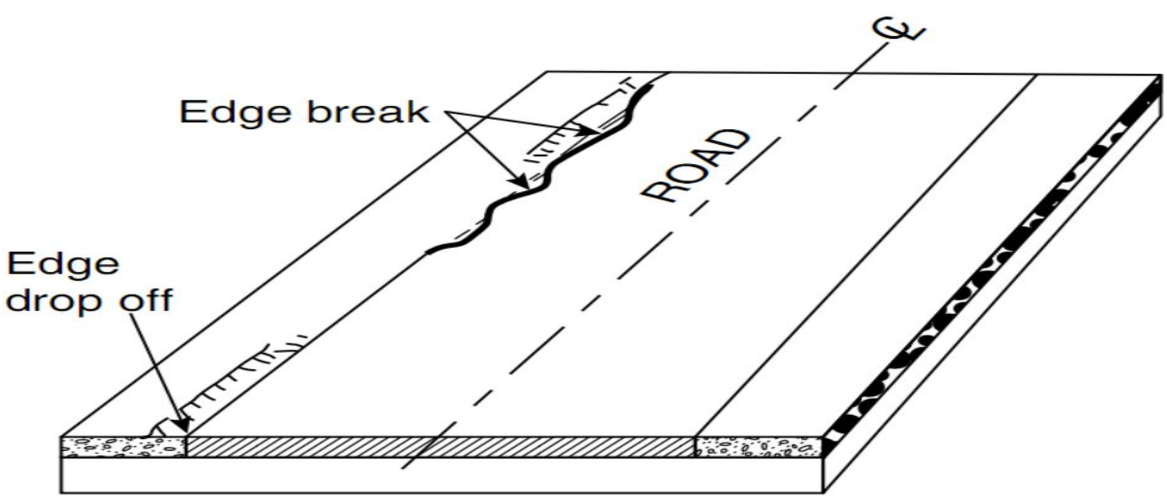

Figure 4.5: Sketch of edge defects in flexible pavements (Source: Austroads, 1991).

4.5.2.2 Severity

The definition of severity for a given defect varies with each distress and is generally a measure of how badly or to what intensity a given defect has deteriorated. Examples are; crack widths, crack deterioration or spalling, and loss of materials. The severity levels of major types of distresses according to ERA (2005) are discussed below:

i. Alligator Cracking (Fatigue):

Severity Levels: (measured by its length of running meter)

- L - Fine, longitudinal hairline cracks running parallel to each other with no, or only a few interconnecting cracks. The cracks are not spalled.
- M - Further development of light alligator cracks into a pattern or network of cracks that may be lightly spalled.
- H - Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic. (FHWA, 1998).

ii. Block Cracking:

Severity Levels: (measured by its length of running meter)

- L - Blocks are defined by low-severity cracks.
- M - Blocks are defined by medium-severity cracks.
- H - Blocks are defined by high-severity cracks.

iii. Patching and Utility Cut Patching:

Severity Levels: (measured in square meter)

- L - Patch is in good condition and satisfactory. Ride quality is rated as low severity or better.
- M - Patch is moderately deteriorated, or ride quality is rated as medium severity, or both.
- H - Patch is badly deteriorated, or ride quality is rated as high severity, or both; needs replacement soon (FHWA, 1998).

iv. Longitudinal and Transverse Cracking:

Severity Levels: (measured by its length of running meter)

- L - One of the following conditions exists: non filled crack width is less than 10 mm, or filled crack of any width (filler in satisfactory condition).
- M - One of the following conditions exists: non filled crack width is greater than or equal to 10 mm and less than 75 mm: non filled crack is less than or equal to 75 mm surrounded by light and random cracking; or, filled crack is of any width surrounded by light random cracking.
- H - One of the following conditions exists: any crack filled or non-filled surrounded by medium- or high-severity random cracking; non-filled crack greater than 75 m or a crack of any width where approximately 100 mm of pavement around the crack is severely broken (FHWA, 1998).

v. Rutting

Severity Levels: (mean rut depth)

- L - 6 to 13 mm.
- M - 13 to 25.
- H - 25 mm (FHWA, 1998).

4.5.2.3 Extent (percentage of damaged area)

Extent is the measure of area, length, or count associated with a given distress. It is how much and how far a given defect has progressed form the total pavement stretch area. A road section that has a high extent of damage will have a low riding quality and hence should be given a priority to be maintained.

4.5.3 Project cost

The availability of the required amount of fund for the maintenance of pavements is very low not only in developing countries like Ethiopia, but also in developed countries. Hence, to preserve most of the road network from deterioration it is advisable to focus on road sections with low Maintenance cost than those with higher maintenance cost, while other factors being similar in these road sections.

The maintenance cost of a road section is a function of the maintenance activity that particular road section needs, which in this case is represented by the maintenance unit rate, and the stretch area of the road section. It can be found by multiplying the maintenance unit rate with the stretch area of the road section.

4.5.4 Accident rate

As a road become damaged, drivers will be obligated to get away from the road surfaces with a pothole or any damaged pavement in front and use the one that doesn't have any damage. This sudden maneuvering action of the vehicle will cause collision with pedestrians, a vehicle adjacent to it or other stopping body and might end up in a severer traffic accident. Because of this reason, accident rate factor can receive a high priority to avoid future litigation if accidents that are attributable to a road surface issue. Therefore, it is clear that on those roads that exhibit a high traffic accident rate, the pavement should be preserved on timely manner and the roads shall have the priority to be maintained first relative to those that have a low accident rate.

Maintenance produces very high benefit – cost ratios (Faiz and Horak, 1987). For the highway users, it is equally important to avoid accidents due to unsafe conditions rather than to rectify the defect after an accident has occurred. Poor maintenance (in terms of quality and timing) can increase the vehicle operating costs by 15% and no maintenance by 50% (Robinson, 1988).

4.5.5 Drainage condition

The condition of drainage is very important because bad drainage has been found to be the most damaging factor for flexible pavements and is considered as one of the major problems in urban areas. Hence, the effect of drainage condition is also considered in prioritizing process by taking it as a factor on the maintenance project prioritization decision making. As a result the more the drainage condition affected the higher priority the road will have to be maintained.

4.5.6 Land use

While doing maintenance of road sections, land zones with high economic activities, high percentage of commercial area and high economic importance of the areas adjacent to the road should be given a priority than those with lower activities. This is due to the significant impact of every activity at commercial areas on the overall economy of a country. The economic significance level of a road section can be estimated by the percentage of commercial land from the total land that is found adjacent to the road.

4.6 Summary

In this chapter the most significant pavement maintenance prioritization factors has been identified. These factors have been derived based on shortlisting the major factors through reviewing literatures and subjecting these factors to a preliminary questionnaire survey. The pilot questionnaire survey was filled by 40 persons who are: practicing engineers from AACRA and different bodies who has experience related to pavement maintenance to come to a consensus and nine (9) major factors were identified. Subsequently interviews were made with responsible bodies on maintenance prioritization decision making to justify the significance of the factors.

CHAPTER FIVE

ESTABLISHING A FRAMEWORK OF PAVEMENT MAINTENANCE PROJECT PRIORITIZATION TECHNIQUE

5.1 Introduction

Based on the findings from the literature reviews, interviews and questionnaire surveys, it is essential to develop a Pavement Maintenance Management Model (PM^3) to manage pavement maintenance effectively. This chapter deals with the structure and details of the proposed model.

The structure and functionality of the model under consideration, the evaluation methods and the foreseen output of the model under consideration will be discussed in this chapter.

In carrying out pavement maintenance work, many factors, including the observed pavement condition, have to be considered for the purpose of prioritization. However, because of the inadequate funding that is available for pavement maintenance and management each year, decisions have to be made to implement work that provide the highest value of return to the road network in general.

Models like this facilitate data integration which could be traffic, maintenance and rehabilitation (M&R) history or inventory, data collection which includes the processing of gap detection among others, and output presentation such as the average pavement condition. Their functions are extensive so that even information in drainage condition and accident rate could be used to develop pavement performance models, or apply land use policy into regional development models (Flintsch, 2004)

5.2 Functionality and structure of the proposed framework

5.2.1 Functionality of the proposed framework

In this study, data processing and analysis are based on the Analytic Hierarchy Process (AHP). Ibraheem and Atia (2012) concluded that Multiple Criteria Decision Making (MCDM) methods are convenient for solving practical complex problems, such as the prioritization of maintenance works for overall road network. AHP is adopted in this study for estimating the relative weights of different factors that are considered for prioritizing pavement maintenance.

The mechanism of determining factor weights using AHP will be discussed in detail later but first it is only schematically presented here as step two in utilizing the AHP method. The next stage of the process before the evaluation of individual roads on the basis of each factor is collecting data to get the profile of each competitive road. Figure 5.1 illustrates the association of factors against alternative roads.

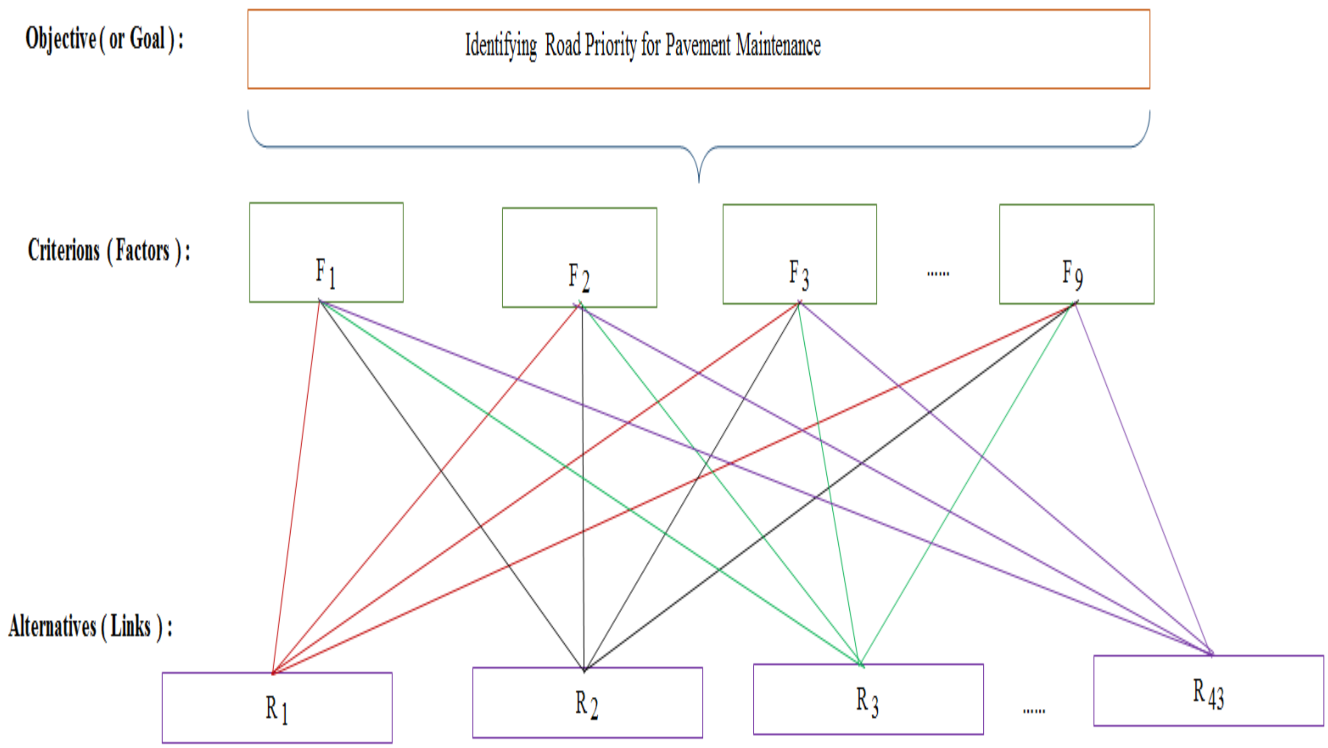

Figure 5.1: Mechanism of maintenance prioritization of alternative roads (Source: Saaty, T. L, 2001.

5.2.2 Structure of proposed framework

Four phases are included in the proposed model, representing the main components. Figure 5.2 illustrates the components of the proposed model for pavement maintenance management.

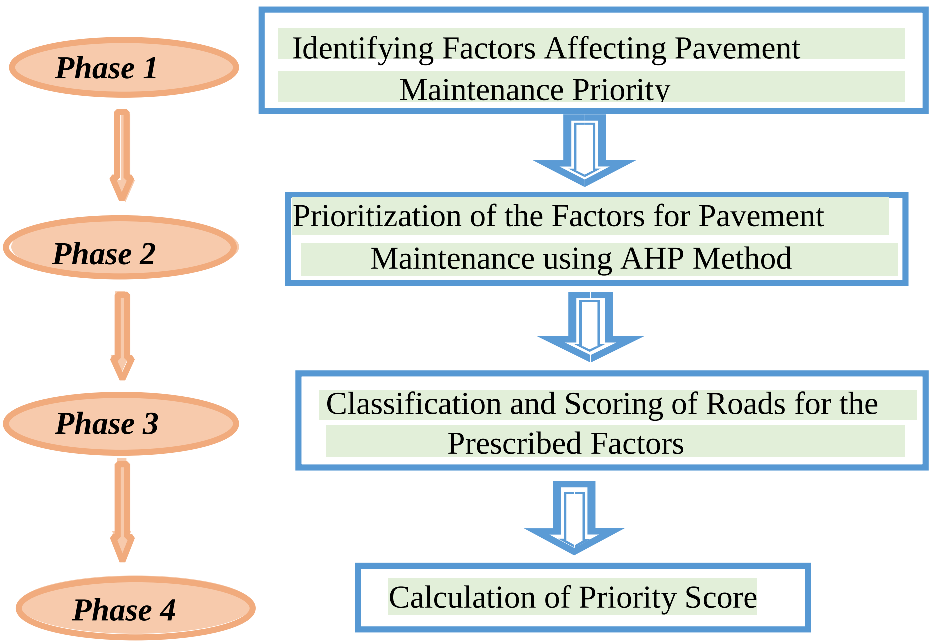

Figure 5.2: Components of the Proposed Model for Pavement Maintenance

Phase 1: Identifying Factors Affecting Pavement Maintenance Management

Before examining other components of the proposed model, it is essential to identify the factors that influence the prioritization process of pavement maintenance. These factors can influence the performance and efficiency of the model.

In this research, many important factors were dealt with under literature review, and nine (9) significantly important factors have been identified through preliminary questionnaire surveys and interviews, which should be taken into account for the proposed model of pavement maintenance management. The nine factors affecting pavement maintenance management were defined and discussed in Chapter Four.

Phase 2: Prioritization of the Factors Affecting Ranking of Pavement Maintenance Program using AHP Method

The Analytic Hierarchy Process (AHP) method will be adopted in this study for estimating the relative weights of different factors that are considered to the case of prioritizing pavement maintenance and determining the relative ranking of alternatives through pair-wise comparison between factors.

Calculation of weights of factors will be done in this phase of the stated AHP algorithm. Then, in order to determine the relative ranking of alternatives, a priority matrix should be determined through assigning scores for factors according to their classification, which will be achieved in the next phase.

Phase 3: Classification and Assigning Scale of the Framework's Parameters

In this phase, the 9 factors affecting pavement maintenance priority will be used to compute the output priority scores for the proposed model. Therefore, it is necessary to classify, describe and assign classification scale for every factor. The tasks of classifying factors will mainly follow the recommendation of the "ERA Condition Survey Manual, 2002", "Code of Practice for Highway Maintenance Management – Well-maintained Highways in UK", Planning and Transport (ADEPT) and Road Surface Treatments Association (RSTA) report, Adlinge & Gupta (2008) and various related reports. However, some factors will also be classified and scored based on rational judgment.

As mentioned above, a Likert scale, a scale of 1 to 5, will be used for the assigned data in the priority matrix, where 1 represents least attention for pavement to be maintained, 3 represents intermediate attention for pavement to be maintained, and 5 represents immediate attention for pavement to be maintained. Classification scales for the 9 factors will be discussed in detail later.

Phase 4: Calculation of Pavement Maintenance Priority Score (PMPS)

The next step will be to calculate PMPS, which indicates the ranking of alternatives. This is done by multiplication of the priority matrix and the vector of factors' weights. The output of this calculation is the vector that indicates ranking of alternatives. The AHP algorithm used to calculate the Priority Score is presented as follows:

$$PMPS = [(F1 * W1) + (F2 * W2) + (F3 * W3) + (F4 * W4) + (F5 * W5) + (F6 * W6) + (F7 * W7) + (F8 * W8) + (F9 * W9)$$

Where,

F = Score of Factor (1 to 5) and

W = Weight of Factor

The last step of the AHP algorithm yields the vector of the alternative ranking, expressed as the product of the priority matrix and the factor weight vector.

5.3 Identifying Factors Affecting Pavement Maintenance Management

In this research, significant factors were considered from reviewed literatures and accordingly nine (9) factors have been accounted for use in the proposed model of pavement maintenance management that have been identified through preliminary questionnaire surveys and interviews. These factors had been already discussed in the previous chapter.

5.4 Weighting of the Criteria for Pavement Maintenance projects prioritization using AHP Method

Saaty (1980) concluded that, in order for a problem to be represented and priorities to be developed for alternatives based on the user's judgment, AHP as a multi-criteria decision method is useful, as the method uses hierarchical structures. Steps orderly followed under the AHP procedure are the following (Ibraheem, 2012):

i. Defining the problem;
ii. Developing hierarchical structures;
iii. Pair-wise comparison;
iv. Estimating relative weights; and
v. Testing consistency.

The steps of defining the problem and developing hierarchical structures is already discussed. The next step is developing a pair-wise comparison survey. In this regard, an Excel-based survey tool was adopted with the objective of providing a relatively easy visual interface to the survey participants. The survey tool was modified for evaluating weights of all nine criteria goals. The survey tool records the survey taker's preference and strength of preference for each pair-wise comparison and provides guidance for improving consistency (see appendix III). The tool also calculates the weight and rank of each criteria based on an overall average weight using the AHP algorism (Goepel K. D., 2013).

A pair-wise comparison was done between all the nine criteria that had a total of thirty six (36) pair-wise comparisons. The questionnaire survey participants first filled their preferences and the strength of the preference of every criteria over the other and then they were allowed to see the consistency of the decision they made so that they can correct their preferences until their decisions became consistent enough to develop the model.

Saaty's 9-point scale was identified as the most appropriate scale to rank the relative importance of factors that could contribute to selecting and ranking a pavement project for treatment. As shown in Table 5.1 below, the scale ranges from one to nine, and one refers to factors with equal importance, while nine refers to the extreme importance of one factor over the other. Additionally, the consistency ratio and the Alonso and Lamata (2006) consistency approach were utilized to check for consistency.

Table 5.1: AHP importance scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

5.4.1 Calculation of weights of factors

Factor weights were yielded through conducting pair-wise comparisons of rated factors with a view of establishing an Importance Matrix (IM) to get a more precise ranking of factors organized according to their significance. The normalization of the paired matrix provides the importance attached to each factor (Ibraheem, 2012). The design of the Importance Matrix can be seen below in equation 5.1.

$$A = \begin{bmatrix} \frac{w1}{w1} & \frac{w1}{w2} \cdots & \frac{w1}{wn} \\ \frac{w2}{w1} & \frac{w2}{w2} & \vdots \\ \frac{wn}{w1} & \cdots & \frac{wn}{wn} \end{bmatrix} \tag{5.1}$$

Where,

w_1 = rating value for factor 1 (F_1):

w_2 = rating value for factor 2 (F_2) and

w_n = rating value for factor n (F_n).

The priority vector (eigenvector) of the matrix is the relative weights for maintenance objectives. The priority vector can be calculated by the process which is described as follows:

- The first step is to normalize the matrix. To do this, first obtain the column totals for the original matrix [A].
- The second step is to divide each entry in the matrix by its corresponding column total.
- After the matrix has been normalized, the third step is to sum the total for each row.
- The last step is to divide the row totals by n which corresponds to the size of the square matrix [A]. In this particular case, n = 9 for the 9×9 matrix.

To calculate the relative weights of factors in the pair-wise comparison matrix, eigenvalue method is used. Iteration was necessary until the consecutive values of weights of factors became similar and the matrix became consistent. The method of calculation of weights was already dealt in the literature review.

The adopted excel template performs an iteration in every step when a questionnaire survey participant enters his/her preference of one factor over the other. Every questionnaire survey participant's judgmental values of Eigenvalue (λ_{max}) and the eigenvector (Weights of Factors) are calculated through Excel template which comprises all the above calculations (see Appendix III).

After each individual evaluator has specified his or her preferences for each pair-wise comparison, it must then be combined with the other group members' preferences. This will incorporate all the individual's unique judgments into a single representative value for each combination of different criteria and alternatives and a new matrix incorporating all the individual's pairwise comparisons is created. Equation 5.2 demonstrates the algorithm of how each individual evaluator's pair-wise comparisons are combined into a single value using the geometric mean (Goepel K. D., 2013).

$$a_{ij} = \left(\prod_{k=1}^{N} a_{ij}^{k}\right)^{\frac{1}{N}} \qquad (5.2)$$

Where,

i, j = Alternatives in pair-wise comparison;

a_{ij} = Combined judgment for alternative i over alternative j;

a_{ij}^{k} = Evaluator k's judgment for alternative i over alternative j;

N = Number of evaluators participated.

Using this algorithm the individual judgments of maintenance objectives were combined and a combined matrix for maintenance objectives was found. And then, by following the same procedure, the compound judgment of survey participants or consolidated result of weights of criteria were found.

Therefore after these calculations it is found that the final results of λmax of the compound judgment of survey participants is 9.15 and the developed weights of criteria, F1 to F9, are shown in figure 5.3 below:

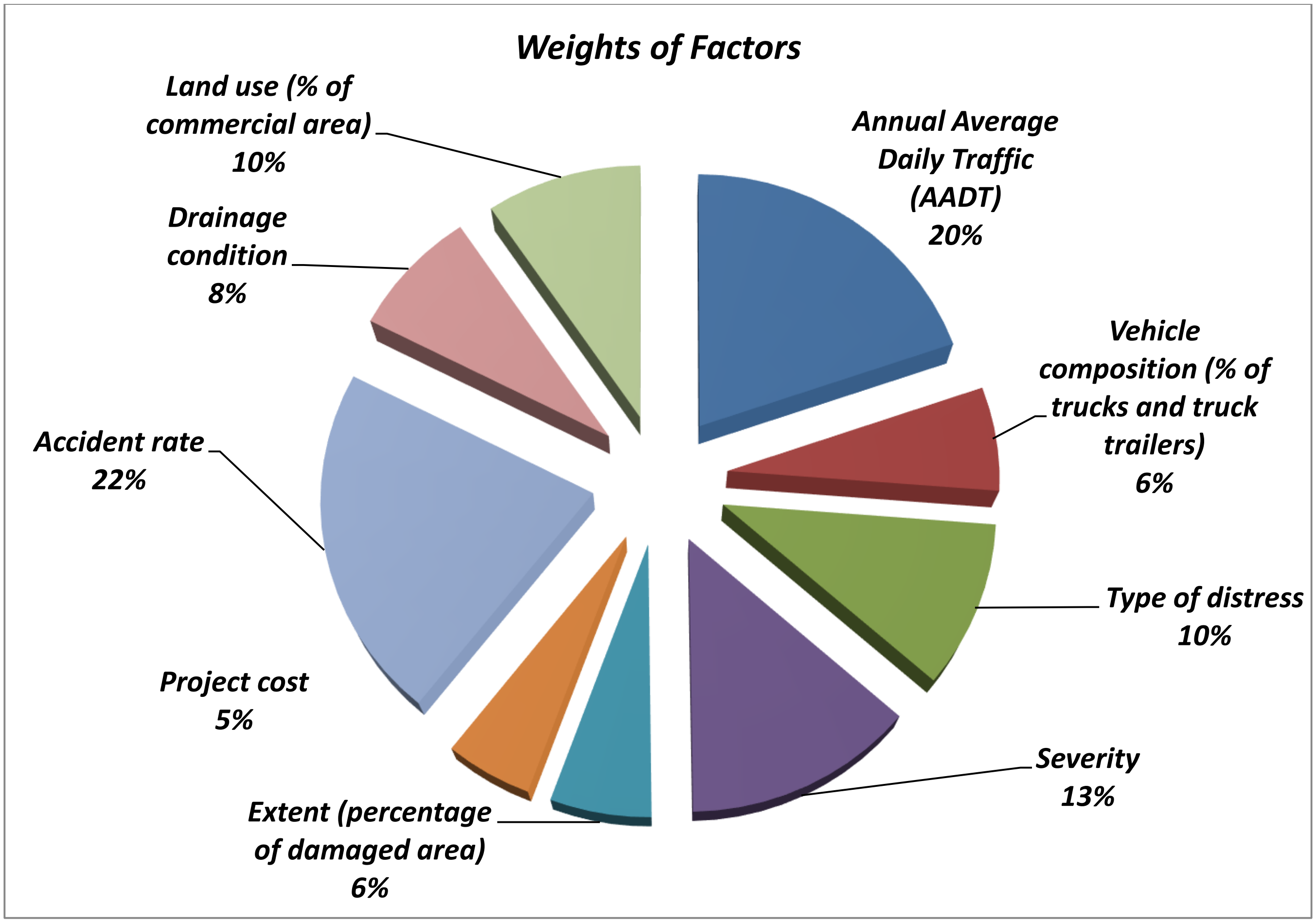

Figure 5.3: Weights of Factors

5.4.2 Checking consistency

According to Saaty (2001), the consistency ratio (CR) demonstrates the degree of compatibility of data analyzed through the AHP method. By definition, the consistency ratio reveals any potential incompatibility in subjective matrix scores. The relative scoring of factors will result in a matrix of scores, say a(i, j). The matrix holds the expert judgment of the pair-wise comparisons. Nevertheless, the judgment should be consistent. Therefore, inconsistency test is necessary to validate it. The inconsistency measure is useful for identifying possible errors in judgments data entry of a survey participant as well as actual inconsistencies in the judgments of participants themselves. Inconsistency measures the logical inconsistency of the judgments. For instance, if we say that "A" is more important than "B" and "B" is more important than "C" and then say that "C' is more important than "A", we are not being consistent. A somewhat less inconsistent situation would occur if we would say that "A" is 4 times more important than "B", "B" is 3 times more important than "C" and that “A” is 2 times more important than “C” but it is still inconsistent. In broad-spectrum, the inconsistency ratio of less than 0.1 or 10% be considered as reasonably consistent. Particularly, a matrix a(i, j) is said to be consistent if all its elements follow the transitivity and reciprocity rules below (Saaty T. L., 2001)

The consistency ratio formula is shown in equation 5.3 below:

$$CR = CI / RI \tag{5.3}$$

Where,

CI = consistency index, and

RI = random index:

$$CI = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1} \tag{5.4}$$

Where,

λmax = the biggest eigenvalue of matrix A; and

n = number of variables or factors considered.

Geometric consistency index (GCI) for a combined priority matrix of every participant’s judgment is calculated using:

$$GCI = \frac{2\sum_{i<j}^{j} \ln a_{ij} - \ln\frac{p_i}{p_j}}{(n-1)(n-2)} \tag{5.5}$$

Where,

pi and pj = participant ith and jth judgment respectively; and

n = number of variables or factors considered.

The formulas above demonstrate calculating consistency with regard to the largest eigenvalue. The largest eigenvalue λmax (allowing for deviations owing to the large numbers) is obtained through iteration using an excel template as “9.15”, and when it is applied within the equation given above, where n is the size of the matrix, it gives a GCI value of “0.05”.

Saaty (2001) and many researchers have conducted simulations with different numbers of matrices to find the average random Consistency Index. The random index table produced by Tummala (1994) and Alonso (2006) is used in this research. Though they used different number of matrices to demonstrate the random index, their indices became similar to Saaty's. In random matrices, the RI is the mean value of CI. RI values for the matrices comprising n elements (for different matrix orders) are shown in Table 5.2.

Table 5.2: Random index (RI) for the factors used in the decision making process

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Source: Tummala, 1994; Alonso, 2006.

This thesis employs an order of magnitude of pair-wise comparison matrix equal to 9, which yields an RI value of 1.45. The consistency ratio of the comparison process is then calculated by means of the CI and RI values of the consolidated matrix obtained above. The CR value being lower than 0.1 means that consistency is validated in the comparison process. For the consistency of pair-wise of factors to become in the acceptable range an AHP pair-wise comparison template was used for the questionnaire survey.

The survey participants were given the pair-wise comparison template that has a tool checking the consistency by utilizing the above calculations. Therefore, they got the opportunity to update their judgments until their consistency came to be in the acceptable range. In broad-spectrum, the inconsistency ratio of less than 0.1 be considered as reasonably consistent. Finally, the CR value of the combined priority matrix of every participant's judgment was found to be 0.013 or 1.3% which is strongly acceptable.

5.5 Describing Factors and assigning Classification Scale

The 9 factors affecting pavement maintenance priority of a project were used to compute the priority scores for the proposed model. The raw data of each factor is presented in table 5.3 below.

Table 5.3: Collected raw data for the nine factors

Road Origen - Destination	(AADT)	% of truck	type of distress	Severity	% of Dam aged Area	project cost	Total accidents / 6 month	drainage maintenance type	% of commercial area
Addisu Gebeya - 70 kuter Semen Mazegaja	14,455	8%	Low Surface Defects	Slight	5%	3,823	102	only cleaning	64%
Alert Roundabout - FM Radio Station	8,425	10%	medium Surface Defects	Slight	3%	7,424	112	simple maintenance	21%
Ambesa Garage Police - Shegole	7,344	14%	Cracking, corrugation, bleeding	Moderate	10%	53,278	7	only cleaning	32%
AMCE - Egziyabher Ab Church	6,897	17%	Cracking, corrugation, bleeding	Moderate	15%	321,581	7	only cleaning	17%
Art Design universty - Genfle Bridge	13,716	6%	Low Surface Defects	Very slight	22%	100,224	2	only cleaning	23%
Atlas Hotel -Ras Desta Hospital	11,456	4%	Low Surface Defects	Severe	5%	36,028	6	only cleaning	34%
Belay zeleke - Rufail	8,820	11%	Cracking, corrugation, bleeding	Slight	5%	78,593	2	only cleaning	37%
Berbere Tera -Mola Maru (Kebele Meznagna)	15,764	14%	Cracking, corrugation, bleeding	Slight	20%	111,222	33	high maintenance	92%
Betel Roundabout - Augusta Ring Road	8,251	5%	Low Surface Defects	Slight	19%	522,113	86	simple maintenance	24%

Betemengist - Gibi Gebrial	12,007	7%	medium Surface Defects	Very slight	45%	5,884	8	high maintenance	3%
Bis Mebrat - Old Post House	7,842	8%	medium Surface Defects	Very severe	18%	135,379	17	medium maintenance	64%
Bole Medanialem Church – Hayahulet Menged	6,481	3%	Low Surface Defects	Moderate	9%	84,433	11	simple maintenance	61%
Brass hotel - Gumruk Airlines	10,455	9%	medium Surface Defects	Slight	9%	137,644	58	medium maintenance	43%
Debesko - 5 kuter Mazoria (G/Markos)	7,249	6%	Low Surface Defects	Moderate	5%	137,682	10	simple maintenance	26%
Ethiopian comercial Bank - Emigration	11,852	8%	medium Surface Defects	Slight	17%	313,581	33	cleaning / maintenance	54%
Filwuha Hotel - Zewditu Hospital	5,412	6%	Low Surface Defects	Severe	20%	100,874	10	simple maintenance	24%
From Ararat hotel - Kara	4,658	7%	medium Surface Defects	Slight	20%	2,296,746	3	medium maintenance	23%
From Bancko Diroma Junction – Statistics Birou	6,008	6%	Low Surface Defects	Slight	3%	97,793	22	cleaning / maintenance	45%
From Bole Homes - Koria Hospital	11,546	5%	Low Surface Defects	Moderate	5%	147,840	66	cleaning / maintenance	14%
Gibi gabrial - Ginfle Bridge	11,463	8%	medium Surface Defects	Slight	13%	193,975	18	simple maintenance	7%
Gofa mebrat Hail - Lafto Dildiy	7,348	9%	medium Surface Defects	Slight	20%	220,119	33	cleaning / maintenance	48%

Gojam Ber - Total	11,438	12%	Cracking, corrugation, bleeding	Slight	13%	880,411	21	simple maintenance	71%
Hulegeb Yaynesiwran Mahber - Ringroad	10,884	9%	medium Surface Defects	Slight	28%	87,560	6	cleaning / maintenance	16%
Kasanchis Total - Gedera Hotel	13,425	7%	medium Surface Defects	Slight	15%	85,390	12	medium maintenance	68%
Kolfe Dildiy - 18 Mazoria	11,464	9%	medium Surface Defects	Severe	10%	83,723	3	simple maintenance	72%
Lideta - Carl Roundabout	10,381	5%	Low Surface Defects	Slight	19%	209,865	4	only cleaning	61%
Lideta - Emu Pension	6,237	6%	Low Surface Defects	Moderate	1%	5,134	7	only cleaning	54%
Megenagna - Woreda 24 (64 bus station)	8,102	7%	medium Surface Defects	Moderate	4%	68,610	4	simple maintenance	29%
Mesalemia - Samba Nekersa	12,972	8%	medium Surface Defects	Very severe	11%	114,417	1	simple maintenance	45%
Nigid Matemia bet - Stastics	7,031	8%	medium Surface Defects	Slight	14%	44,844	3	cleaning / maintenance	37%
Nigid Matemia bet - Orma Garaje	6,125	10%	medium Surface Defects	Slight	16%	37,385	9	cleaning / maintenance	28%
Ras Desta Hospital - Kechene	7,864	6%	Low Surface Defects	Slight	17%	194,146	12	medium maintenance	42%
Rufail Enkulal fabrica dildiy - Semen Mazegaja	3,121	7%	medium Surface Defects	Slight	4%	77,743	4	cleaning / maintenance	57%

Samba Nekersa – Medhanialem	8,472	4%	Low Surface Defects	Very severe	7%	61,669	15	only cleaning	39%
Sebategna - Amanual Church	11,901	11%	Cracking, corrugation, bleeding	Slight	7%	90,749	5	cleaning / maintenance	84%
Sefere selam - Efoyta (kolfe Dildiy)	10,358	8%	medium Surface Defects	Very severe	12%	137,126	13	high maintenance	43%
Shewa supermarket - Bis Mebrat	7,124	6%	Low Surface Defects	Severe	18%	48,005	3	cleaning / maintenance	55%
Shewa supermarket - Bancko Diroma Turn	7,309	4%	Low Surface Defects	Severe	10%	7,222	9	medium maintenance	71%
Shiro meda - Sidist Kilo	5,473	9%	medium Surface Defects	Very severe	2%	104,810	59	simple maintenance	36%
Tikur Ambesa Hospital - Post Office	4,155	8%	medium Surface Defects	Very severe	15%	68,397	7	high maintenance	6%
Tile Factory- Getahun Besha Bldg	7,980	12%	Cracking, corrugation, bleeding	Very severe	5%	211,803	23	medium maintenance	48%
Traffic Police - England Embassy	11,364	5%	Low Surface Defects	Slight	8%	72,057	42	simple maintenance	56%
Yerer Ber - Urael Church	13,848	7%	medium Surface Defects	Very slight	5%	24,428	12	cleaning / maintenance	79%

After collection of raw data for every factor, describing and assigning classification scales of every factor is necessary due to their difference in SI unit. The tasks of classifying factors will mainly follow the recommendation of the ASTM D6433, the "ERA Condition Survey Manual, 2002", the "Code of Practice for Highway Maintenance Management – Well-maintained Highways in UK", Planning and Transport (ADEPT) and Road Surface Treatments Association (RSTA) report, (Adlinge, 2008) and various related reports. However, some factors were also classified and scored based on rational judgment by relating the actual or real situation between the sample roads.

As stated above, a scale of 1 to 5 was used for the factors according to their classification, and then the score of each factor is assigned to each road to form the priority matrix. As no real data is available in some cases and due to difficulties accessing some data, assumptions are made in order to assign a score for each factor, where 1 represents least attention on pavement to be maintained, 3 represents intermediate attention for pavement to be maintained, 5 represents immediate attention for pavement to be maintained and 2 and 4 represent intermediate values above 1 and 3 respectively. Classification scales for the 9 factors are discussed below:

(i) Traffic characteristics

- Average Annual Daily Traffic (AADT)

Table 5.4: Classification and Scale for AADT Factor

Average Annual Daily Traffic (AADT)	Scale
< 2,000	1
2,000 to 5,000	2
5,000 to 8,000	3
8,000 to 11,000	4
> 11,000	5

Source: (Danial Moazami, 2011)

- Vehicle composition

From the composition of vehicles utilizing the road section as the proportion of trucks that use a road section increase the more the pavement becomes susceptible to damage (Yong Bai, 2009). And scaling was made depending on the relative percentage of tracks on the selected road segments. Table 5.5 below shows classification and Scale for vehicle composition Factor.

Table 5.5: Classification and Scale for vehicle composition Factor

total percentage of Trucks & Truck Trailers	Scale
< 5%	1
5% to 7%	2
7% to 9%	3
9% to 11%	4
> 11%	5

Source: Author

(ii) Pavement condition

The classification and scaling of type, severity and extent of distress is adopted from ASTM D 6433-07 (2007) and FHWA (1998) where the ERA Condition Survey Manual (2002) was adopted from. For the purpose of simplification on site investigation it was set in a simplified table format as follows. The overall classification table is shown in Appendix VI.

- Type of distress

Table 5.6 below presents selected classification and scale for type of distress factor.

Table 5.6: Classification and Scale for type of distress Factor

Type of distress (Deterioration Type)	Scale
Low Surface Defects	1
medium Surface Defects	2
Cracking, corrugation, bleeding	3
High cracking, corrugation, bleeding	4
Potholes, rutting, wheel track cracking and block and transverse cracking	5

Source: (ASTM, 2007)

- Severity

Scaling of distress severity was made depending on data found from AACRA as it is presented on Table 5.7 below.

Table 5.7: Classification and Scale for distress severity Factor

Distress severity	Scale
Very slight (low) damage	1
Slight (low) damage	2
Moderate (medium) damage	3
Severe damage	4
Very severe (high) damage	5

Source: (AACRA, 2015)

- Extent (percentage of damaged area)

Table 5.8 below presents Classification and Scale for Extent (percentage of damaged area) Factor.

Table 5.8: Classification and Scale for Extent (percentage of damaged area) Factor

Extent (percentage of damaged area)	**Scale**
Less than 5% of area affected (Occasional)	1
5% to 10% of area affected (less Frequent)	2
10% to 15% of area affected (Frequent)	3
15% to 20% of area affected (very Frequent)	4
Greater than 20% of area affected (Extensive)	5

Source: (ASTM, 2007)

(iii) Project cost

The project cost varies depending on the type of treatment needed and the length of the link. The maintenance unit cost also differs for every type of treatment. The type of treatment needed might vary from repairing of the defect with a wearing course and patching to an overlay for extensive potholes or resurfacing the whole link. Table 5.9 below shows the relative maintenance project costs and their scaling.

According to the project cost that is budgeted to these maintenance projects by AACRA scaling was made which is depending on the relative cost of the selected forty three roads.

Table 5.9: Classification and Scale for project Cost Factor

maintenance project cost	**Scale**
Very low	1
Low	2
Medium	3
High	4
Very high	5

Source: Author

(iv) Accident rate

Scaling is made depending on the relative accident rates of the selected road segments and table 5.10 below presents Classification and Scale for accident rate Factor.

Table 5.10: Classification and Scale for accident rate Factor

Relative number of accident per day (Accident Rate)	Scale
Very Low accident rate	1
Low accident rate	2
Medium accident rate	3
High accident rate	4
Very High accident rate	5

Source: Author

(v) Drainage condition

The drainage condition is evaluated by visual inspection, interviewing local residences the scale is developed depending on AACRAs' drainage maintenance treatment technique. Table 5.11 below presents classification and Scale for drainage condition Factor.

Table 5.11: Classification and Scale for drainage condition Factor

Drainage condition	Scale
only cleaning of drainage utilities	1
cleaning / maintenance of drainage utilities	2
simple maintenance of drainage utilities	3
medium maintenance of drainage utilities	4
high maintenance / new fixtures of drainage utilities	5

Source: Author

(vi) Land use (percentage of commercial area)

Depending on site visits, percentage of commercial areas on the selected road section was recorded and scaling was made depending on the relative percentage of commercial areas on the selected road segments. Table 5.12 presents classification and Scale for land use (land zone characteristics) Factor.

Table 5.12: Classification and Scale for land use (land zone characteristics) Factor

Commercial area ratio	Scale
Very Low: Less than 10%	1
Low: 10 - 25%	2
Medium: 25 - 40%	3
high: 40 - 60%	4
Very high: More than 60%	5

Source: Author

5.6 Calculation of Pavement Maintenance Priority Score (PMPS)

5.6.1 Data Profiles of Alternative Roads

After scaling the factors affecting pavement maintenance according to the classification of each factor, scores of 1 to 5 were assigned to each road representing the 9 factors, in order to form the priority matrix. Most of the data were collected from the AACRA Road Asset Department Office, Traffic Police Management Office (TPMO) and other remaining data was collected through preparing a checklist which was used to assess the real data on site. However, in some cases, due to difficulties to access real data for the case study, some assumptions were made regarding the scores to illustrate the calculations of the priority score. Table 5.13 below shows the compiled data of scaled profiles of alternative roads.

Table 5.13: Scaled profile of alternative roads

Road no	Road Origen - Destination	SCALE								
		F1	F2	F3	F4	F5	F6	F7	F8	F9
R1	Addisu Gebeya - 70 kuter Semen Mazegaja	3	4	2	2	1	1	5	3	2
R2	Alert Roundabout - FM Radio Station	3	5	3	3	3	2	2	1	3
R3	Ambesa Garage Police - Shegole	3	5	4	3	4	5	2	1	2
R4	AMCE - Egziyabher Ab Church	5	2	5	1	5	3	1	1	2
R5	Art Design universty - Genfle Bridge	4	1	2	4	2	1	2	1	3
R6	Atlas Hotel -Ras Desta Hospital	3	5	1	2	1	2	1	1	3
R7	Belay zeleke - Rufail	5	5	5	2	4	3	4	5	5
R8	Berbere Tera -Mola Maru (Kebele Meznagna)	3	2	2	2	4	5	5	3	2
R9	Betel Roundabout - Augusta Ring Road	5	3	4	1	5	1	2	5	1
R10	Betemengist - Gibi Gebrial	3	3	5	5	4	3	3	4	5
R11	Bis Mebrat - Old Post House	3	1	3	3	2	2	3	3	5
R12	Bole Medanialem Church – Hayahulet Menged	4	4	3	2	2	3	5	4	4
R13	Brass hotel - Gumruk Airlines	3	2	2	3	1	3	2	3	3
R14	Debesko - 5 kuter Mazoria (G/Markos)	4	3	5	2	4	5	4	2	4
R15	Ethiopian comercial Bank - Emigration	2	2	5	4	5	3	3	3	2
R16	Filwuha Hotel - Zewditu Hospital	2	3	5	2	4	5	1	4	2
R17	From Ararat hotel - Kara	3	2	1	2	1	2	4	2	4
R18	From Bancko Diroma Junction – Statistics Birou	4	2	1	3	1	3	5	2	2
R19	From Bole Homes - Koria Hospital	4	3	3	2	3	4	3	3	1
R20	Gibi gabrial - Ginfle Bridge	3	4	5	2	4	4	4	2	4

R21	Gofa mebrat Hail - Lafto Dildiy	4	5	4	2	3	5	4	3	5
R22	Gojam Ber - Total	4	4	5	2	5	2	2	2	2
R23	Hulegeb Yaynesiwran Mahber - Ringroad	5	3	2	2	3	2	3	4	5
R24	Kasanchis Total - Gedera Hotel	4	4	3	4	3	2	1	3	5
R25	Kolfe Dildiy - 18 Mazoria	4	2	2	2	4	4	1	1	5
R26	Lideta - Carl Roundabout	3	2	1	3	1	1	2	1	4
R27	Lideta - Emu Pension	3	3	1	3	1	2	1	3	3
R28	Megenagna - Woreda 24 (64 bus station)	5	3	4	5	3	3	1	3	4
R29	Mesalemia - Samba Nekersa	3	3	4	2	3	1	1	2	3
R30	Nigid Matemia bet - Stastics	3	4	2	2	4	1	2	2	3
R31	Nigid Matemia bet - Orma Garaje	3	2	4	2	4	4	3	4	4
R32	Ras Desta Hospital - Kechene	2	3	1	2	1	2	1	2	4
R33	Rufail Enkulal fabrica dildiy - Semen Mazegaja	3	1	3	5	2	2	3	1	3
R34	Samba Nekersa – Medhanialem	4	5	2	2	2	2	1	2	5
R35	Sebategna - Amanual Church	4	3	4	5	3	3	3	5	4
R36	Sefere selam - Efoyta (kolfe Dildiy)	3	2	2	4	4	1	1	2	4
R37	Shewa supermarket - Bis Mebrat	3	1	1	4	2	1	2	4	5
R38	Shewa supermarket - Bancko Diroma Turn	2	4	1	5	1	3	5	3	3
R39	Shiro meda - Sidist Kilo	2	3	2	5	4	2	2	5	1
R40	Tikur Ambesa Hospital - Post Office	3	5	3	5	1	4	4	4	4
R41	Tile Factory- Getahun Besha Bldg	4	2	3	2	2	2	4	3	4
R42	Traffic Police - England Embassy	5	3	1	1	2	1	3	2	5
R43	Yerer Ber - Urael Church	0	0	0	0	0	0	0	0	0

5.6.2 Solving Pavement Maintenance Priority Score (PMPS) Equation and ranking of alternative roads

The above mentioned figures illustrate individual component scores. In order to achieve the overall Pavement Maintenance Priority Score (PMPS), the PMPS equation should be solved. The PMPS equation can be represented as follows:

$$PMPS = [(F1 * W1) + (F2 * W2) + (F3 * W3) + (F4 * W4) + (F5 * W5) + (F6 * W6) + (F7 * W7) + (F8 * W8) + (F9 * W9)] \quad (5.11)$$

Where,

F = Score of Factor and

W = Weight of Factor

PMPS equation 5.11 was calculated using the Excel Software. Table 5.14 below illustrate the calculation of overall PMPS with rank of alternatives.

Table 5.14: Calculation of Overall PMPS and Rank of Alternatives

Link No.	Street name	F_1*W_1	F_2*W_2	F_3*W_3	F4* W4	F5* W5	F6* W6	F7* W7	F8* W8	F9* W9	PMPS	Rank
R8	Berbere Tera -Mola Maru (Kebele Meznagna)	0.99	0.32	0.51	0.27	0.23	0.15	0.87	0.40	0.48	**4.22**	**1**
R36	Sefere selam efoyta (kolfe Dildiy)	0.79	0.19	0.41	0.67	0.18	0.15	0.65	0.40	0.38	**3.82**	**2**
R22	Gogam Ber total	0.79	0.32	0.41	0.27	0.18	0.25	0.87	0.24	0.48	**3.80**	**3**
R11	Bis Mebrat- old Post House	0.59	0.19	0.51	0.67	0.23	0.15	0.65	0.32	0.48	**3.80**	**4**
R41	Tile factory to Getahun Besha bldg	0.59	0.32	0.31	0.67	0.06	0.20	0.87	0.32	0.38	**3.72**	**5**
R13	Brass hotel -Gumruk air lines	0.79	0.26	0.31	0.27	0.12	0.15	1.09	0.32	0.38	**3.68**	**6**
R15	Ethiopian comercial bank to Emigration	0.79	0.19	0.51	0.27	0.23	0.25	0.87	0.16	0.38	**3.66**	**7**
R21	Gofa mebrat Hail -Lafto Dildiy	0.59	0.26	0.51	0.27	0.23	0.20	0.87	0.16	0.38	**3.48**	**8**
R29	Mesalemia to samba nekersa	0.99	0.19	0.41	0.67	0.18	0.15	0.22	0.24	0.38	**3.43**	**9**
R24	Kasanchis Total ot Gedera Hotel	0.99	0.19	0.20	0.27	0.18	0.10	0.65	0.32	0.48	**3.38**	**10**
R1	Addisu Gebeya-70 kuter Semen Mazegaja	0.99	0.19	0.10	0.27	0.06	0.05	1.09	0.08	0.48	**3.31**	**11**
R39	Shiro meda to Sidist Kilo	0.40	0.26	0.10	0.67	0.06	0.15	1.09	0.24	0.29	**3.25**	**12**
R42	traffic police to england embassy	0.79	0.13	0.31	0.27	0.12	0.10	0.87	0.24	0.38	**3.20**	**13**
R9	Betel round about Augusta Ring road	0.59	0.13	0.20	0.27	0.23	0.25	1.09	0.24	0.19	**3.20**	**14**
R32	Ras desta hospital to kechene	0.59	0.13	0.41	0.27	0.23	0.20	0.65	0.32	0.38	**3.19**	**15**
R25	Kolfe Dildiy 18 Mazoria	0.79	0.26	0.31	0.54	0.18	0.10	0.22	0.24	0.48	**3.10**	**16**

R16	Filwuha Hotel Zewditu Hospital	0.40	0.13	0.51	0.54	0.29	0.15	0.65	0.24	0.19	**3.10**	**17**
R19	From Bole homes to koria hospital	0.79	0.13	0.10	0.40	0.06	0.15	1.09	0.16	0.19	**3.07**	**18**
R23	Hulegeb Yayne siwran Mahber -Ring road	0.79	0.26	0.51	0.27	0.29	0.10	0.43	0.16	0.19	**3.01**	**19**
R10	Betemengist To Gibi Gebrial	0.99	0.19	0.41	0.13	0.29	0.05	0.43	0.40	0.10	**3.00**	**20**
R12	Bole Medanialem Church -	0.59	0.06	0.31	0.40	0.12	0.10	0.65	0.24	0.48	**2.95**	**21**
R2	Alert Round about -FM radio station	0.59	0.26	0.20	0.27	0.06	0.05	1.09	0.24	0.19	**2.95**	**22**
R20	Gibi gabrial to Ginfle bridge	0.79	0.19	0.31	0.27	0.18	0.20	0.65	0.24	0.10	**2.92**	**23**
R4	AMCE to Egziyabher Ab Church	0.59	0.32	0.41	0.40	0.23	0.25	0.43	0.08	0.19	**2.92**	**24**
R43	Yerer Ber -Urael Church	0.99	0.19	0.10	0.13	0.12	0.05	0.65	0.16	0.48	**2.88**	**25**
R34	Samba nekersa	0.59	0.06	0.31	0.67	0.12	0.10	0.65	0.08	0.29	**2.87**	**26**
R40	Tikur Ambesa Hospital -Post office	0.40	0.19	0.20	0.67	0.23	0.10	0.43	0.40	0.10	**2.73**	**27**
R3	Ambesa Garage police shegole	0.59	0.32	0.31	0.40	0.18	0.10	0.43	0.08	0.29	**2.70**	**28**
R38	Shewa supermarket Bancko Diroma Turn	0.59	0.06	0.10	0.54	0.12	0.05	0.43	0.32	0.48	**2.70**	**29**
R5	art design universty to gnfle bridge	0.99	0.13	0.51	0.13	0.29	0.15	0.22	0.08	0.19	**2.69**	**30**
R18	From Bancko Diroma Junction	0.59	0.13	0.10	0.27	0.06	0.10	0.87	0.16	0.38	**2.66**	**31**
R35	Sebategna Amanual Church	0.79	0.32	0.20	0.27	0.12	0.10	0.22	0.16	0.48	**2.66**	**32**
R26	Lideta To Carl Round about	0.79	0.13	0.20	0.27	0.23	0.20	0.22	0.08	0.48	**2.60**	**33**
R17	From Ararat hotel to Kara	0.40	0.19	0.51	0.27	0.23	0.25	0.22	0.32	0.19	**2.58**	**34**
R6	Atlas Hotel -Ras Desta Hospital	0.79	0.06	0.20	0.54	0.12	0.05	0.43	0.08	0.29	**2.56**	**35**
R37	Shewa supermarket Bis Mebrat	0.59	0.13	0.20	0.54	0.23	0.05	0.22	0.16	0.38	**2.51**	**36**

R14	Debesko 5 kuter mazoria(G/Markos)	0.59	0.13	0.20	0.40	0.06	0.15	0.43	0.24	0.29	**2.50**	**37**
R31	Nigid Matemia bet to orma Garaje	0.59	0.26	0.20	0.27	0.23	0.05	0.43	0.16	0.29	**2.49**	**38**
R30	Nigid Matemia bet stastics	0.59	0.19	0.41	0.27	0.18	0.05	0.22	0.16	0.29	**2.35**	**39**
R27	Lideta To Emu Pension	0.59	0.13	0.10	0.40	0.06	0.05	0.43	0.08	0.38	**2.23**	**40**
R28	Megenagna Woreda 24 (64 bus station)	0.59	0.19	0.10	0.40	0.06	0.10	0.22	0.24	0.29	**2.19**	**41**
R7	Belay zeleke toRufail	0.59	0.32	0.10	0.27	0.06	0.10	0.22	0.08	0.29	**2.03**	**42**
R33	Rufail Enkulal fabrica dildiy -Semen mazegaja	0.40	0.19	0.10	0.27	0.06	0.10	0.22	0.16	0.38	**1.88**	**43**

The given PMPS equation is a representation of the priority of roads regarding pavement maintenance. Higher scores indicate higher needs for pavement maintenances. Therefore, from the roads that were considered for the case study in this research, Link No R8, which is a road from Berbere Tera to Mola Maru (Kebele Meznagna), gets the highest priority to be maintained with PMP Score of 4.22 and Link No R33, which is a road from Rufail Enkulal fabrica dildiy to Semen Mazegaja, gets the minimum priority to be maintained with PMP Score of 1.88.

5.7 Sensitivity Analysis

Sensitivity analysis is determining the sensitivity of any change on the most influential parameters on the overall result of the model. When developing decision support systems using multiple criteria decision making methods, it is important to perform sensitivity analysis. There is a simple method developed by Johnson (2004) to use for determining the sensitivity of results to different parameters of the model by calculating the output percentage difference by varying one input parameter from its minimum value to its maximum value (Johnson R. a., 2004).

It is used to investigate the sensitivity of the alternatives to changes in the priorities of the objectives. What-if analysis can be performed with the sensitivity analyses graphs to determine how the overall result would change if the priorities of the objectives were changed. Now that the optimum option has been identified, how the model would respond to any changes in the weights of the listed Criteria.

First, consider the AADT factor, by increasing the share of this criterion to an extreme of 50% of the main goal, leaving 50% for the other factors while keeping the proportionality between each. By performing a sensitivity analysis on the change of the PMPS for a variation of AADT factor weight, it has been noticed that the model is still in favor of LINK R8 with a PMPS of 4.51 as shown in Figure 5.5. The sensitivity analysis of the rest of the factors was done one by one using the same procedure and the results are included in Appendix VII. Figure below illustrates the results of the sensitivity analyses.

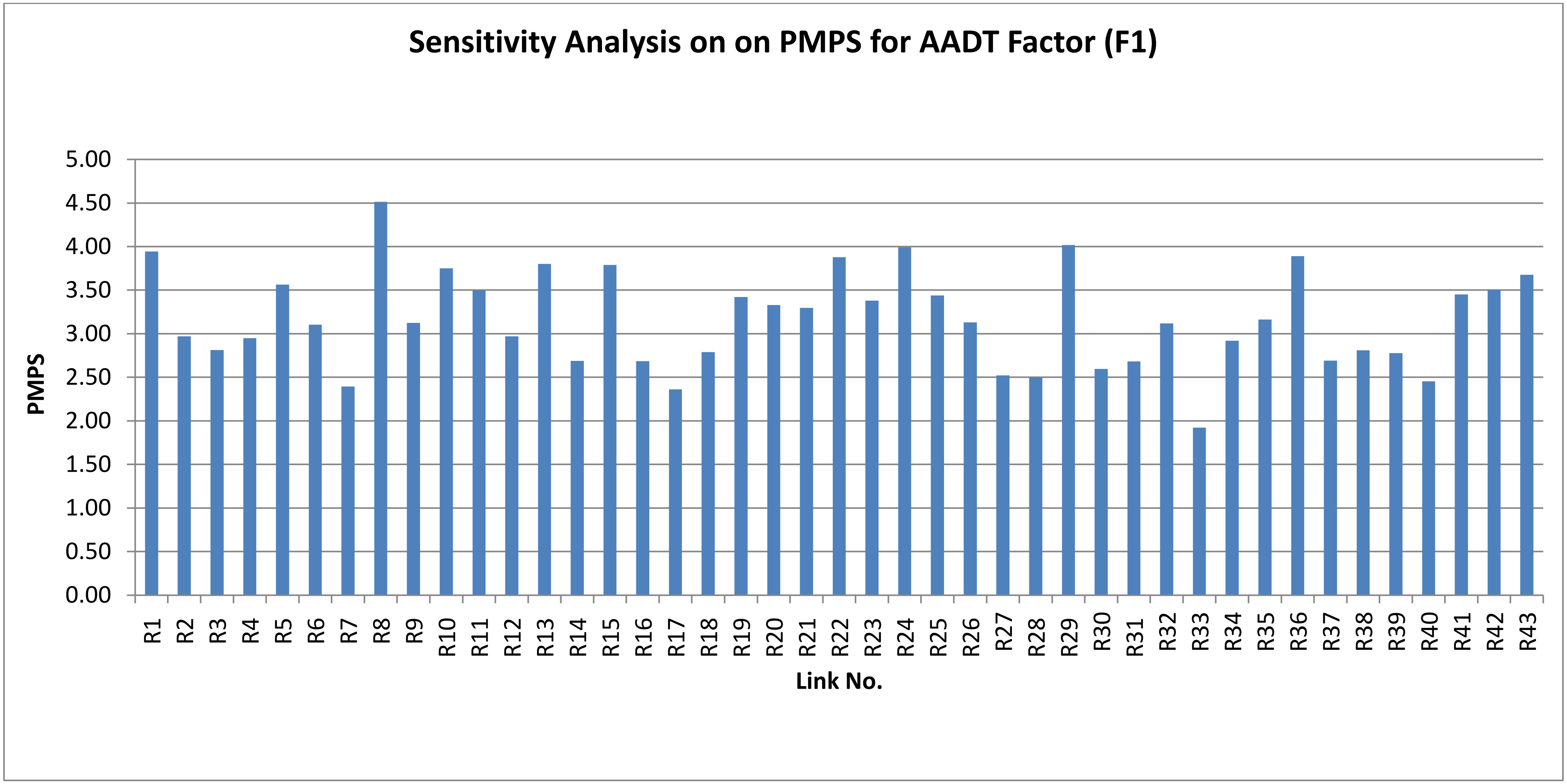

Figure 5.4: Sensitivity analysis of AADT Factor

Sensitivity of change in weight of the factors on overall PMPS and on ranks of alternatives was also conducted. The calculation was done through calculating the average change of PMPSs and ranks of alternatives when increasing the share of each criterion one by one to a maximum of 50% of the total weight, leaving the balance of 50% for the remaining factors while keeping the proportionality between each and then averaging the change in the PMPS and the rank. From Figure 5.6 below, it can be seen that the extreme pavement damage factor (F5) shows a maximum PMPS change of 0.54 while the AADT factor (F1) shows a minimum PMPS change of 0.30. The change of average ranks of alternatives is also shown in Figure 5.6, as the land use factor (F9) and the Accident rate factor (F7) exhibit the maximum and minimum changes of percentage rank of 0.49 and 0.23 respectively. Overall, as seen from the figure, it can be concluded that the highest sensitivity is observed in the case of Land Use (F9). Correspondingly, the lowest value for the sensitivity was found in the case of the Annual Average Daily Traffic (F1).

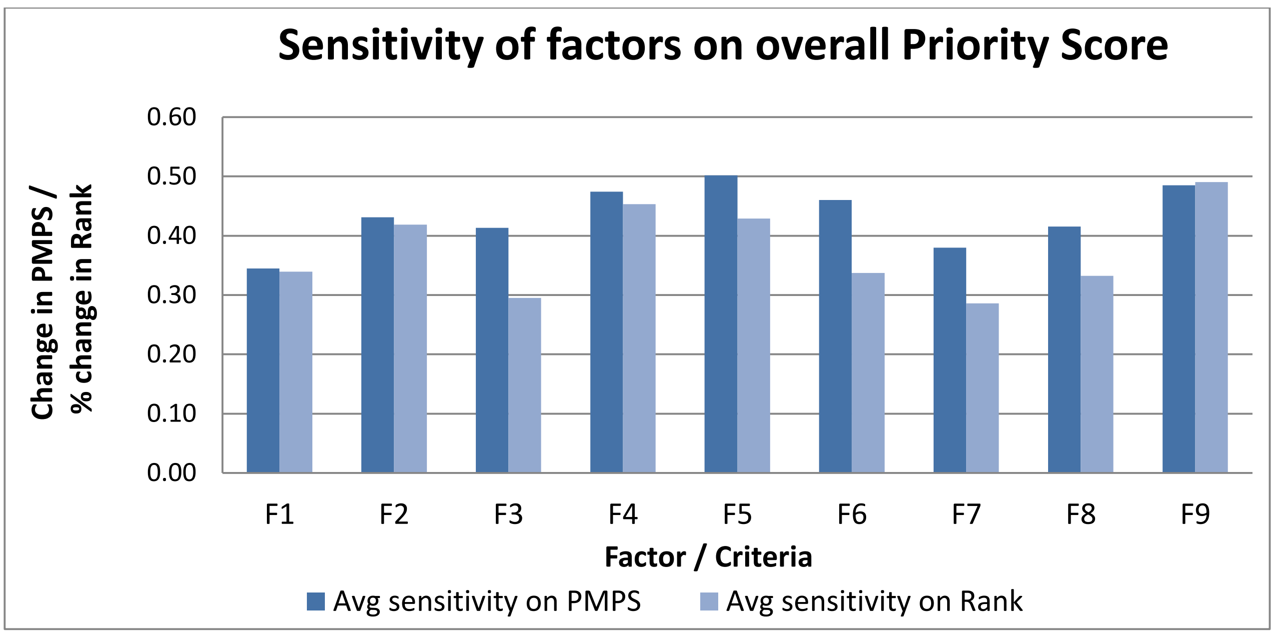

Figure 5.5: Sensitivity of factors on overall Priority Score

Sensitivity analysis was also performed on the alternative links for the change of weight factors by calculating the average percentages of PMPS from their original values due to changes in weight of every factor. As presented in Figure 5.7, Link R17 is the most sensitive one for a variation of factor weight showing a pick of 10.5% change and Link R10 is the least.

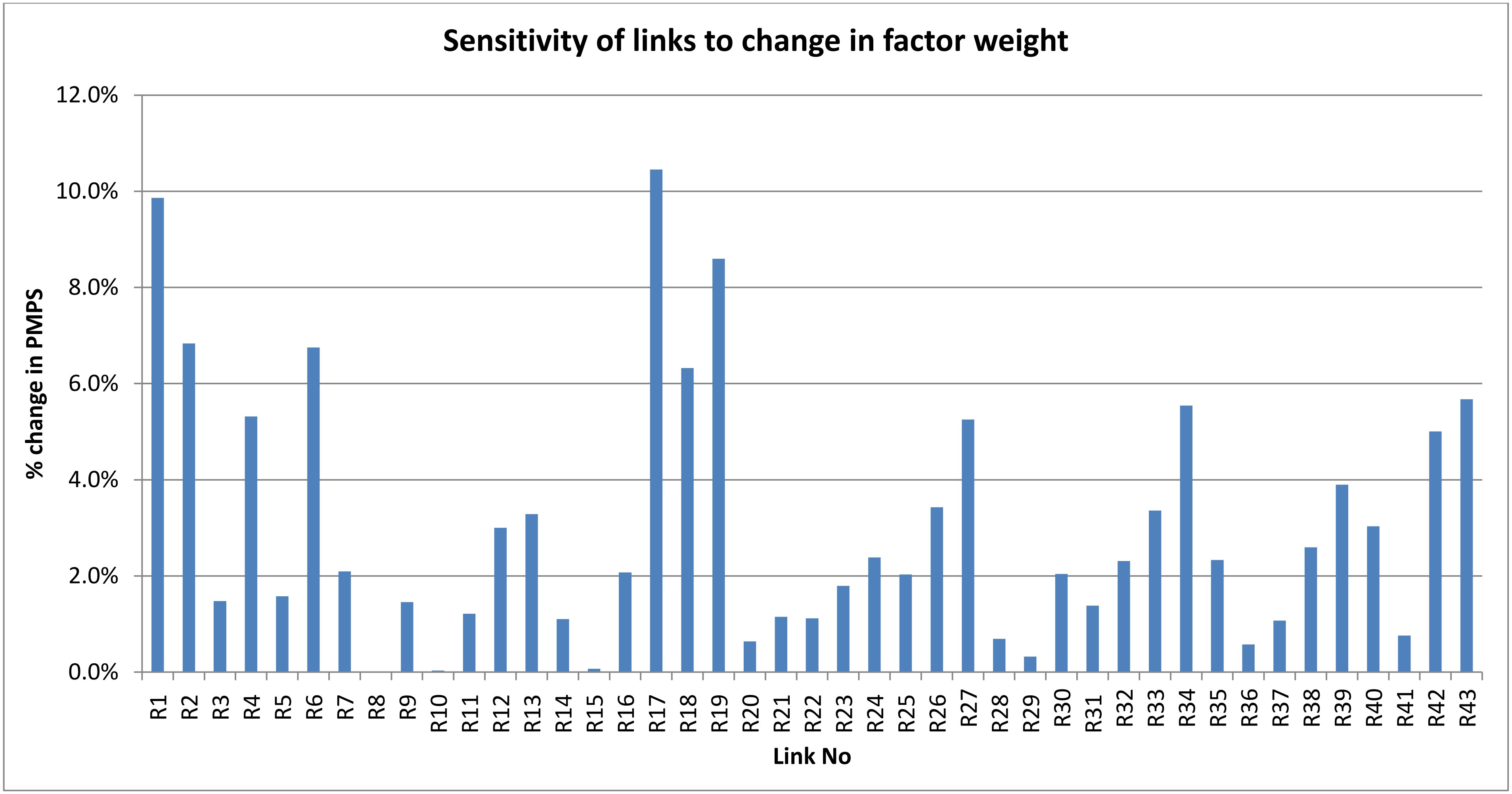

Figure 5.6: Sensitivity of links for a change in factor weight

5.8 Comparison between AACRAs' maintenance decision and the decision by the proposed framework

AACRA make a maintenance project prioritization decision by categorizing projects into a maintenance priority of 1 to 10. This means, projects with a maintenance priority of one will be maintained first and projects with a maintenance priority of 10 will be maintained last. The maintenance prioritization decision is done depending mainly on one criteria which is the pavement condition of the road. Appendix I shows a sample of road maintenance priority decision making table AACRAs' road asset management office.

A comparison was made on priority ranks of the selected sample of 43 alternative roads between the AACRAs' maintenance project priority rank which takes into account only the pavement condition factor for ranking alternatives, and the priority rank decision that was made using the model in this research which considered nine factors for prioritization purposes. Figure 5.8 below illustrates a comparison between AACRAs' decision approach and this research's decision model.

Another ranking was also made by performing analysis to check the outcome if only AACRA's prioritization criteria was used as criteria for pavement maintenance project prioritization on this researches decision model and then compared with the AACRAs' decision method. Figure 5.9 below illustrates a comparison between AACRAs' rankings and the rankings based on this research model, if only pavement condition was considered.

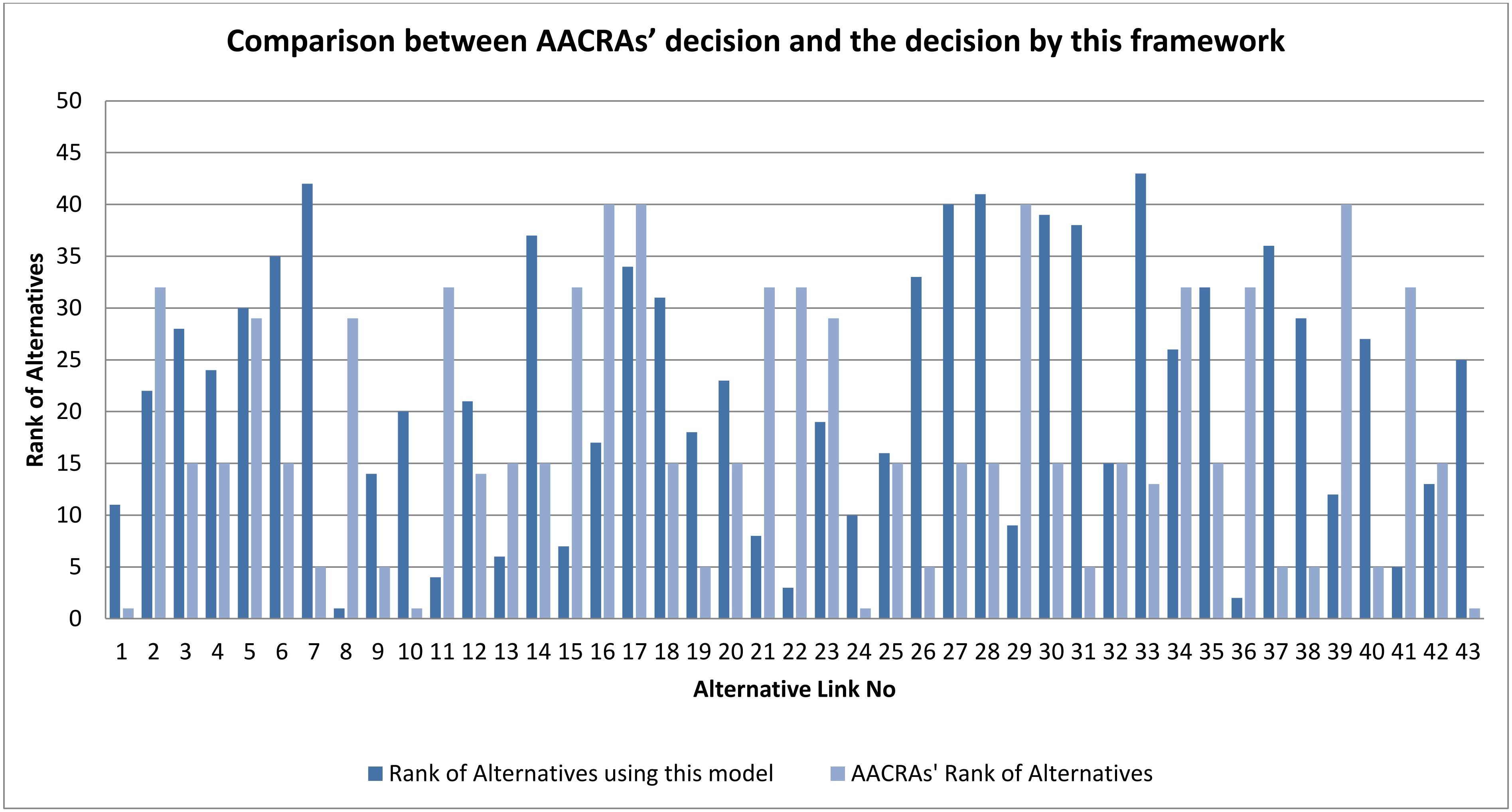

Figure 5.7: Comparison between AACRAs' decision and the decision by this model

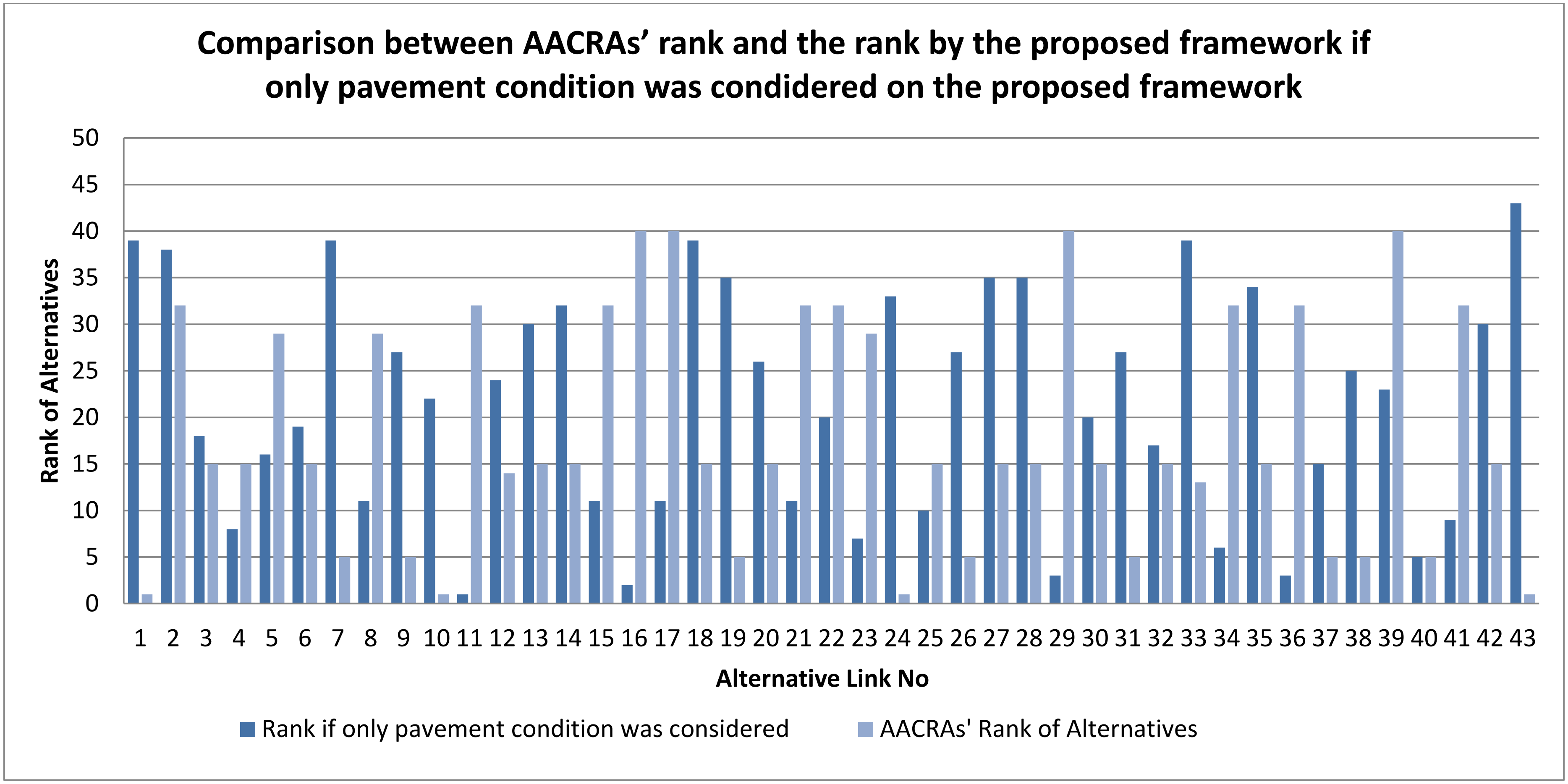

Figure 5.8: Comparison between the models' rank if only pavement condition was considered and AACRAs' rank

5.9 Summary

In this chapter, factors that affect pavement maintenance projects prioritization were established, followed by determining their significance level for maintenance project prioritization using the AHP pair-wise comparison methodology which was based on the responses of the survey questionnaire. The weights were then used as an input to the process of ranking of alternative roads.

Most of the factors that were used as criteria are correlated, but rather than focusing on the common characteristics between criteria, general conclusions are made by assuming that individual criteria has its own unique impact on the decision making process.as indicated in figure 5.3 It was found that from the factors that affect the maintenance decision prioritization factors, accident rate and AADT of a road link play the most significant role by taking the highest share of 21.7% and 19.8% respectively. Therefore from the observation it can generally be concluded that road links with a higher accident rate and AADT should get the priority to be maintained. Next to these factors, severity and type of distress on the link play a weighty role on the decision making of maintenance project prioritization by having a weight of 13.4 and 10.2% respectively. On the contrary, from the nine factors considered, the project cost and extent of damaged area have a relatively lower weight of 5 and 6% respectively.

The consistency of the response of every questionnaire survey participants and the judgment amongst the respondents was also achieved through calculating the consistency index and checking if it was kept within the acceptable limit while computing the weights of factors. According to Satty (1980), a consistency which is greater than 90% is acceptable for weighting factors and the consistency in this research was calculated at 98.7% which is significantly acceptable.

Subsequently describing and assigning classification scale for every factor was made based on credible manuals and in some cases based on rational judgments. Scaling was made because of the reason that the factors cannot be compared directly due to their different SI unit. A 1 to 5 scaling system was used where, 1 represents least attention for pavement to be maintained, 3 represents intermediate attention for pavement to be maintained, and 5 represents immediate attention for pavement to be maintained.

Initially, roads that were in AACRAs' list of maintenance were chosen as the case study in order to test the model and compare with their prioritization decision. Subsequently, a Pavement Maintenance

Priority Score (PMPS) equation was identified. The PMPS is a structured roads prioritization mechanism elaborated in this chapter. Forty-three (43) Primary Arterial Roads, according to AACRAs road hierarchical classification, were selected in order to run the model. The next step was joining the selected roads profile, which is depicted in Table 5.13, to the PMPS equation including the scale scores of roads in terms of identified factors, which was also depicted in Table 5.14. A PMPS Graph of the selected alternative maintenance projects were illustrated in figure 5.4 to give the decision makers flexibility in making decisions of choosing the maintenance project. Ranking of the priority scores for pavement maintenance was obtained for the case study. The result showed that from the selected roads for the case study, link R8 (which is the road from Berbere Tera to Mola Maru) had the highest priority, hence it is the first road to be maintained, whilst link R33 (which is the road from Rufael Enkulal Fabrica Dildiy to Semen Mazegaja) had the lowest priority, hence it is the last to be maintained, which can be clearly seen from Figure 5.4.

A sensitivity analysis on each parameter was carried out so that decision makers would be aware of the impact of any change of weight of each parameter on the output of the model results. From the sensitivity analysis results of the factors on the overall PMPS and on ranks of alternatives, (as depicted in Figure 5.6), it is found that the overall Pavement Maintenance Priority Score is very sensitive to the change of AADT factor (F1) and least sensitive to the Land use (F9) and Accident rate (F7) factors.

A comparison on priority ranks of the selected 43 sample alternative roads is made between AACRAs' maintenance project priority rank, which takes into account only the pavement condition factor for ranking alternatives, and the priority rank decision that was made using the model in this thesis, which takes nine (9) factors into account for prioritization purposes. From Figure 5.8, it can be seen that there is a huge difference in the order of maintenance prioritization decision. A comparison was also made by using only AACRAs' prioritization criteria on the proposed model, to simulate AACRAS' prioritization method as illustrated in Figure 5.9. Though the difference in decision or ranks of alternatives is abridged compared to the first case, there is still variation in priority. It can be concluded that AACRAs' decision making approach of maintenance project prioritization is inconsistent compared to the proposed model in this research.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

It was observed that the developed maintenance project prioritization Model, which uses the analytic hierarchy process (AHP) as a decision making tool, works sufficiently and yields rationale and adequate results as well as providing accurate decisions. Among the major criteria that guide decision makers during the evaluation process are: pavement condition, traffic characteristics and accident rate. The application of this framework which is based on the AHP method and a survey among government officials and transportation experts with a case study data obtained from AACRA in 2016 reveals that the link number R8 (which is the road from Berbere Tera to Mola Maru) has significant value; therefore, it is considered as the highest priority for maintenance.

Regarding achievements of the initial objectives of the research, the following conclusions can be made:

(i) **Achievement of objective i:** *"investigate the current pavement maintenance management practices, its principles and related challenges in Ethiopia, specifically in the city of Addis Ababa".*

In considering the existing pavement maintenance management practices as verified through reviewing literatures, it has been established that in Ethiopia, until recently it have been given a little attention to carry out pavement maintenance management duties. Instead, the road authorities considered pavement condition as the only factor when planning the prioritization of projects and selecting treatments. In addition, due to inadequate funding, the principle of "worst is first" has been applied in carrying out pavement maintenance.

The historical problem of inadequate funding of pavement maintenance and management functions was highlighted within Addis Ababa Road Authority. The Authority performs its road maintenance activity through funding by the national Road Fund Office and from the municipality office. However, as shown in figure 2.1, the budget is most of the time inadequate resulting in a huge built-up of maintenance backlog. In addition to the problem in amount of fund, political influence played a huge role in determining the maintenance project prioritization that end up in road sections that didn't get attention by decision makers to be unmaintained for a while and vice versa which results a maintenance backlog on the road network.

(ii) **Achievement of objective ii:** *"transfer the random maintenance project prioritization decision making approach to a more scientific approach by considering the essential factors to make a decision".*

The existing pavement management practices regarding prioritization of maintenance projects within the road authorities were investigated in the literature review to assess any evident inadequacies and gaps in the current practices. Based on the research, it is clear that road authorities need to adopt a more scientific decision making approach that considers the most important factors rather than following an inconsistent decision making procedure that takes into account the pavement condition as the only factor. For developing countries, such approaches are likely to be very useful since resource requirement to implement this approach is minimal. At the same time, they can guide maintenance planners to consider cost-effective strategies to efficiently maintain urban road networks.

Establishing the most significant factors affecting pavement maintenance prioritization was achieved initially through the literature review and then refined through the preliminary questionnaire survey which was undertaken with the aim of establishing a general consensus amongst road authorities' practicing road engineers and managers as to the most significant factors affecting pavement maintenance management prioritization decision which was later justified and validated through interviews with decision making bodies. A total of thirteen (13) factors were initially identified by the researcher, based on the literature review but finally adjusted to nine (9) factors based on interviews with professionals and during pilot survey.

(iii) **Achievement of objective iii:** *"develop a method that can help select the urgent maintenance projects by considering both technical and non-technical criteria"***.**

During conducting this research, it was observed that the AHP method is the widely applied method from the multi-criteria decision making approaches in making decision related to transport infrastructure because of its simplicity and flexibility. It has been well observed that the AHP model works sufficiently and yields adequate results in providing accurate decisions. Among the major criteria that guide decision makers during evaluation are: traffic characteristic, pavement condition and traffic safety.

It can also be concluded that the AHP, particularly in the framework of decision support systems, can significantly contribute to the improvement of the quality of decision making in the field of pavement maintenance management system development in urban areas like Addis Ababa. The preconditions that have to be met are well defined problems (objectives, criteria, and measures), criteria weights, properly developed alternatives and appropriate data of every factor for their evaluation with regard to selected criteria. In such conditions, the AHP can contribute to the quality of the decision making process for transport infrastructure in Addis Ababa by ensuring a high level of objectivity, transparency, and accountability of the decision making process.

(iv) Achievement of objective iv: *"determine the level of influence or weight of each factor or parameter on the final decision of selection of project where maintenance to be applied"*.

The most significant factors affecting pavement maintenance management prioritization decisions were weighted through an AHP pair-wise questionnaire survey. The AHP method was used because of the reason that it allows implementation of the analysis and selection of solutions based on pair-wise comparison of one criteria weight to another and individuals' judgment criteria weight to another individual criteria weight according to the goals that have been set and also it allows individuals to check the consistency of their decision. The AHP pair-wise questionnaire was given to selected individuals and a consolidated or combined result of participants weight of factors were calculated through pair-wise analysis of individual judgments by utilizing the AHP method, which were then used to calculate the pavement maintenance priority score (PMPS) of links.

(v) Achievement of objective v: *"simplify the decision making process by providing a simple framework"*.

An AHP pair-wise decision making analyses were carried out using an excel template first in questionnaire survey to get a consistent decision which is within the acceptable consistency ratio range and find the weights of factors. After weights were assigned to each respective factor, a model was developed using an excel sheet that integrates the scores that were given to sample road links with respect to each of these factors to weights of the factors. Then, pavement maintenance priority scores were calculated and links were given priorities to be maintained according to their score. Sensitivity analysis was also conducted using the model to check the sensitivity of PMPS and priority rank of alternatives to any change in the weight of each factor.

6.2 Recommendations

Based on the results of the research the following recommendations are forwarded:

i. AACRA may have to consider expanding the questionnaire survey to obtain a larger sample size or alternatively, hosting a brainstorming session for decision makers to discuss the factors, and the weights to be assigned to them.

ii. The Model in this research could be adopted by other road agencies including the Ethiopian Road Authority, while maintaining the same objectives and research theme. This would be of great benefit as a good scientific approach to assist the pavement maintenance management.

iii. The road authorities should give the required attention for maintenance of existing roads as they give for the construction of new roads and they shall influence for sufficient budget to be allocated for the purpose of maintenance according to the amount of maintenance work load and the increment of road network.

iv. Due to the reason that paved roads are crucial parts of the transportation networks and because of the costly and highly disruptive consequences of their poor condition on road users, pavement inspection is a vital part of the overall maintenance and management of pavement. It must be done through the whole road network at least once or twice a year in a timely manner by trained and competent pavement inspectors.

v. Agencies are encouraged to develop and use common location referencing system for all databases to facilitate easy searching and matching of pavement and other maintenance related information so that it will be easier to get a complete real time data that is needed to model the maintenance project prioritization.

vi. Regarding the accident data recording, availability of additional information related to how much the road was damaged when the accident happens will be helpful to assess the accident rate related to pavement surface condition.

vii. <u>A comprehensive framework, which takes a number of major technical and non-technical factors into consideration, in determining urban road priority for maintenance program need to be considered.</u>

6.3 Proposed future research area

i. Priority scores assigned to each factor as a scale according to the description and classification of the factors is a unique methodology. However, improvement of the classification to make scores consistently interpreted by the road authority could be considered for future research.

ii. A research on applications of GIS for storage of real time data to facilitate data integration which could be data on pavement condition and other maintenance related factors can be used as a decision support tool in Ethiopia as it had shown a great impact on the maintenance management of some road authorities in developed countries.

iii. Other potential factors that affect the decision making, if any, may be explored for consideration in the pavement maintenance project prioritization.

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APPENDIX

APPENDIX I

Addis Ababa City Road Authority Road Maintenance and Management priority matrix

Addis Ababa City Road Authority Road Maintenance And Management

Road no	Road Hierarchy	stretch length	Type of Distress	Damage area	Severity	Maintenance categor	Maintenan	ance unit rate	Amount	Remark	Total area	Extent	Condition Matrix
Road no	Equivalent length		Road Name Origen-Destn		Width	Total Area	Total Damege Area	% of Dammeged Area	Traffic Volume Priority	Road condition	Record No		Mentainance priority
nl1544	569	664	Dama Hotel -Meskel Square		6	3984	395	10%	1	Very poor	1		1
	Locale		crocodile Cracking	38	3	patching	M2	218	8297	Overlay	3984	1	5
	Locale		Shoving asphalt	357	3	Rehabilitation1	M2	298	106458		3984	1	5
174	617	720	Lafto dildey-Lafto Daget		6	4320	1226.5	28%	3	Fair	2		9
	SAS		Potholes	29.5	2	patching	M2	212	6266		4320	1	3
	SAS		crocodile Cracking	200	2	patching	M2	212	42483		4320	1	3
	SAS		Rutting	48	2	patching	M2	212	10196		4320	1	3
	SAS		Subsidence	17.5	2	patching	M2	212	3717		4320	1	3
	SAS		Corrugation	84	1	patching	M2	206	17344		4320	1	1
	SAS		Raveling	115	1	patching	M2	206	23745		4320	1	1
	SAS		Shoving asphalt	728	2	Rehabilitation1	M2	298	217090		4320	1	3
	SAS		Lacy Edge	4.5	2	patching	M2	212	956		4320	1	3
NL405	564	564	Eyob Engineering Bihere Tsege		7	3948	528.5	13%	3	Very poor	3		3
	Locale		crocodile Cracking	185	3	patching	M2	218	40395		3948	1	5
	Locale		Rutting	20	2	patching	M2	212	4248		3948	1	3
	Locale		Subsidence	199.5	2	patching	M2	212	42377		3948	1	3
	Locale		Shoving asphalt	110	3	Rehabilitation1	M2	298	32802		3948	1	5
	Locale		Lacy Edge	14	2	patching	M2	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]

APPENDIX II

Preliminary Questionnaire Survey

1. Personal information

1.1 What is your educational level

Other		BSC		MSC and above	

1.2 Do you have occupational experience

Experience (year)	

1.3 What is your occupational experience related to pavement maintenance

____

1. Pavement Maintenance Priority Factors

Please put 'x' in the appropriate box to **indicate the degree of importance of the following factors in the prioritization decisions for selection of road maintenance projects**. Please mark your answers according to the following scale:

1 = Not important
2 = Less important
3 = Important
4 = Very important
5 = Extremely important

No.	**Factors (Criteria)**	Importance level				
		1	2	3	4	5
1	Average Annual Daily Traffic (AADT)					
2	Remaining service life of the road					
3	Vehicle composition					
4	Functional class of the road					
5	Previous maintenances on the road					
6	Type of distress (damage)					
7	Severity of the damage					
8	Extent (percentage of damaged area)					
9	Observed deterioration rate					
10	Project cost					
11	Accident rate					
12	Drainage condition					
13	Land use (Land zone characteristics)					

Thank you!

APPENDIX III

Questionnaire for Pair-wise comparison of factors affecting pavement maintenance project prioritization decision

AHP Analytic Hierarchy Process

n= 9 Input

Objective: Calculate weights of factors affecting pavement maintenance project prioritization decision

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, **A or B**, and **how much** more on a scale 1-9 as given below. **Once completed, you might adjust highlighted comparisons 1 to 3 to improve consistency.**

	Criteria	Comment
1	F1	Annual Average Daily Traffic (AADT)
2	F2	Vehicle composition (% of trucks and truck trailers)
3	F3	Type of distress
4	F4	Severity
5	F5	Extent (percentage of damaged area)
6	F6	Project cost
7	F7	Accident rate
8	F8	Drainage condition
9	F9	Land use (% of commercial area)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

Participant 1	1	8/29/2017	α:	0.05	CR:	9%
Name	Weight	Date			Consistency Ratio	

i	j	Criteria A	B	more important? A or B	Scale (1-9)	
1	2	F1	F2	A	7	
1	3		F3	A	3	
1	4		F4	A	5	
1	5		F5	A	7	
1	6		F6	A	7	
1	7		F7	A	3	
1	8		F8	A	7	
2	3	F2	F3	B	5	
2	4		F4	B	1	
2	5		F5	A	5	
2	6		F6	A	3	
2	7		F7	B	3	
2	8		F8	A	3	
3	4	F3	F4	A	5	3
3	5		F5	A	7	
3	6		F6	A	5	
3	7		F7	B	3	
3	8		F8	A	5	
4	5	F4	F5	A	7	2
4	6		F6	A	5	
4	7		F7	B	3	
4	8		F8	A	3	
5	6	F5	F6	A	1	
5	7		F7	B	7	
5	8		F8	A	2	
6	7	F6	F7	B	5	
6	8		F8	B	1	
7	8	F7	F8	A	9	
1	9	F1	F9	A	5	
1	10					
2	9	F2	F9	B	3	
2	10					
3	9	F3	F9	A	1	
3	10					
4	9	F4	F9	B	3	
4	10					
5	9	F5	F9	B	5	
5	10					
6	9	F6	F9	B	3	
6	10					
7	9	F7	F9	A	5	1
7	10					
8	9	F8	F9	B	4	
8	10					
9	10					

Participant 2	1	8/29/2017	α:	0.05	CR:	8%
Name	Weight	Date			Consistency Ratio	

i	j	Criteria A	B	more important ? A or B	Scale (1-9)	
1	2	F1	F2	A	5	
1	3		F3	B	3	
1	4		F4	B	3	
1	5		F5	A	3	
1	6		F6	A	5	
1	7		F7	B	9	
1	8		F8	A	5	
2	3	F2	F3	B	5	
2	4		F4	B	5	
2	5		F5	A	1	
2	6		F6	B	1	
2	7		F7	B	9	
2	8		F8	B	1	
3	4	F3	F4	A	1	
3	5		F5	A	5	
3	6		F6	A	5	
3	7		F7	B	5	
3	8		F8	A	3	
4	5	F4	F5	A	7	
4	6		F6	A	5	
4	7		F7	B	5	2
4	8		F8	A	5	
5	6	F5	F6	A	1	
5	7		F7	B	9	
5	8		F8	A	1	
6	7	F6	F7	B	7	1
6	8		F8	A	1	
7	8	F7	F8	A	9	
1	9	F1	F9	B	1	
1	10					
2	9	F2	F9	B	5	
2	10					
3	9	F3	F9	A	3	3
3	10					
4	9	F4	F9	A	3	
4	10					
5	9	F5	F9	B	5	
5	10					
6	9	F6	F9	B	5	
6	10					
7	9	F7	F9	A	7	
7	10					
8	9	F8	F9	B	5	
8	10					
9	10					

PARTICIPANT 3	2		α:	0.05	CR:	5%
Name	Weight	Date			Consistency Ratio	

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	F1	F2	A	7
1	3		F3	A	7
1	4		F4	A	3
1	5		F5	A	5
1	6		F6	A	9
1	7		F7	A	1
1	8		F8	A	3
2	3	F2	F3	B	3
2	4		F4	B	5
2	5		F5	A	1
2	6		F6	A	3
2	7		F7	B	5
2	8		F8	B	3
3	4	F3	F4	B	5
3	5		F5	B	3
3	6		F6	A	3
3	7		F7	B	5
3	8		F8	B	5
4	5	F4	F5	A	3
4	6		F6	A	3
4	7		F7	A	1
4	8		F8	A	1
5	6	F5	F6	A	1
5	7		F7	B	3
5	8		F8	B	3
6	7	F6	F7	B	5
6	8		F8	B	3
7	8	F7	F8	A	3
1	9	F1	F9	A	7
1	10				
2	9	F2	F9	B	1
2	10				
3	9	F3	F9	A	1
3	10				
4	9	F4	F9	A	3
4	10				
5	9	F5	F9	B	3
5	10				
6	9	F6	F9	B	3
6	10				
7	9	F7	F9	A	5
7	10				
8	9	F8	F9	A	3
8	10				
9	10				

Name	Weight	Date	α:	CR:
Participant 4	1		0.05	9%

Consistency Ratio

		Criteria		more important ?	Scale	
i	j	A	B	A or B	(1-9)	
1	2	F1	F2	A	4	
1	3		F3	B	5	2
1	4		F4	B	2	
1	5		F5	A	3	
1	6		F6	A	7	
1	7		F7	B	7	
1	8		F8	A	3	
2	3	F2	F3	B	5	
2	4		F4	B	5	
2	5		F5	A	3	1
2	6		F6	B	3	3
2	7		F7	B	7	
2	8		F8	B	2	
3	4	F3	F4	A	1	
3	5		F5	A	3	
3	6		F6	A	5	
3	7		F7	B	3	
3	8		F8	A	3	
4	5	F4	F5	A	7	
4	6		F6	A	5	
4	7		F7	B	5	
4	8		F8	A	5	
5	6	F5	F6	A	1	
5	7		F7	B	7	
5	8		F8	A	1	
6	7	F6	F7	B	7	
6	8		F8	A	1	
7	8	F7	F8	A	7	

Participant 5	1		α:	0.05	CR:	8%
Name	Weight	Date				Consistency Ratio

i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)	
1	2	F1	F2	A	5	
1	3		F3	B	3	
1	4		F4	B	3	
1	5		F5	A	3	
1	6		F6	A	5	
1	7		F7	B	9	
1	8		F8	A	5	
2	3	F2	F3	B	5	
2	4		F4	B	5	
2	5		F5	A	1	
2	6		F6	B	1	
2	7		F7	B	9	
2	8		F8	B	1	
3	4	F3	F4	A	1	
3	5		F5	A	5	
3	6		F6	A	5	
3	7		F7	B	5	
3	8		F8	A	3	
4	5	F4	F5	A	7	
4	6		F6	A	5	
4	7		F7	B	5	2
4	8		F8	A	5	
5	6	F5	F6	A	1	
5	7		F7	B	9	
5	8		F8	A	1	
6	7	F6	F7	B	7	1
6	8		F8	A	1	
7	8	F7	F8	A	9	
1	9	F1	F9	B	1	
2	9	F2	F9	B	5	
3	9	F3	F9	A	3	3
4	9	F4	F9	A	3	
5	9	F5	F9	B	5	
6	9	F6	F9	B	5	
7	9	F7	F9	A	7	
8	9	F8	F9	B	5	

APPENDIX IV

Priority matrix of the model

AHP Analytic Hierarchy Process (EVM multiple inputs)

n= 9 Number of criteria (2 to 10) Scale: 1 AHP 1-9

p= 0 selected Participant (0=consol.) 2 7 Consolidated

Objective Calculate weights of factors affecting pavement maintenance project prioritization decision

Author Solomon.B

Date 24-Aug-17 Thresh: 1E-07 Iterations: 3 EVM check: 3.5E-08

Table	Criterion	Comment	Weights	Rk
1	F1	Annual Average Daily Traffic (AADT)	19.8%	2
2	F2	Vehicle composition (% of trucks and truck trailers)	6.4%	7
3	F3	Type of distress	10.2%	4
4	F4	Severity	13.4%	3
5	F5	Extent (percentage of damaged area)	5.8%	8
6	F6	Project cost	5.1%	9
7	F7	Accident rate	21.7%	1
8	F8	Drainage condition	8.0%	6
9	F9	Land use (% of commercial area)	9.5%	5
#			0.0%	

Result

Eigenvalue lambda: 9.149

Consistency Ratio 0.1 GCI: 0.05 CR: 1.3%

Matrix

		F1	F2	F3	F4	F5	F6	F7	F8	F9	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
F1	1	-	3 1/2	2	1 4/7	2 5/6	3 3/4	5/6	2 3/5	2 1/2	-	19.79%
F2	2	2/7	-	2/5	4/9	1 1/3	1 3/4	1/3	5/6	2/3	-	6.42%
F3	3	1/2	2 1/2	-	3/4	1 1/4	2 1/2	3/8	1	1 1/5	-	10.20%
F4	4	2/3	2 1/4	1 1/3	-	2 3/4	2 1/2	2/3	1 4/7	1 4/9	-	13.39%
F5	5	1/3	3/4	4/5	1/3	-	1	1/3	7/9	2/5	-	5.84%
F6	6	1/4	4/7	2/5	2/5	1	-	1/3	2/3	4/9	-	5.05%
F7	7	1 1/5	3	2 2/3	1 4/7	2 7/8	3	-	3	3	-	21.75%
F8	8	3/8	1 1/5	1	2/3	1 2/7	1 4/9	1/3	-	7/8	-	8.02%
F9	9	2/5	1 4/7	5/6	2/3	2 1/2	2 1/4	1/3	1 1/7	-	-	9.55%
0	10	-	-	-	-	-	-	-	-	-	-	0.00%

APPENDIX V

Addis Ababa City Road Authority – Paved Road Condition Form

Ethiopian Roads Authority - Paved Road Condition Form

Paved Road Condition Survey	Date		Inspector		District		Section		Page of	
Road No		Start Km		Segment No		Start Km		Direction		Calibration Factor

Kilometre			Km				Km				Km				Km				Km				Action Required
			0-500		500-1000		0-500		500-1000		0-500		500-1000		0-500		500-1000		0-500		500-1000		
			Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	
Left	Side drain /turnout	Silt																					
		Scour																					
	Shoulder	Deform																					
		Scour																					
		Vegetation																					
	Edge Step																						
	Edge Damage																						
Carriageway	Rutting																						
	Corrugations																						
	Cracking	Wheel Track																					
		Other																					
	Stripping/Fretting																						
	Potholes																						
	Bleeding																						
	Failures																						
	Safety																						
	Lane marking																						
Right	Edge Damage																						
	Edge Step																						
	Shoulder	Vegetation																					
		Scour																					
		Deform																					
	Side drain /turnout	Scour																					
		Silt																					
Notes																							

APPENDIX VI

Flexible pavement condition rating form (FHWA, 1998)

Section: ________________ Date: ________________

Log mile: ______ to________ Rated by: ______________

Sta: _________ to________ ______________________

FLEXIBLE

PAVEMENT CONDITION RATING FORM

DISTRESS	DISTRESS WEIGHT	SEVERITY WT.*			EXTENT WT.**			DEDUCT POINTS***
		L	M	H	O	F	E	
RAVELING	10	0.3	0.6	1	0.5	0.8	1	
BLEEDING	5	0.8	0.8	1	0.6	0.9	1	
PATCHING	5	0.3	0.6	1	0.6	0.8	1	
POTHOLES/DEBONDING	10	0.4	0.7	1	0.5	0.8	1 ✓	
CRACK SEALING DEFICIENCY	5	1	1	1	0.5	0.8	1	
RUTTING	10	0.3	0.7	1	0.6	0.8	1 ✓	
SETTLEMENT	10	0.5	0.7	1	0.5	0.8	1	
CORRUGATIONS	5	0.4	0.8	1	0.5	0.8	1	
WHEEL TRACK CRACKING	15	0.4	0.7	1	0.5	0.7	1 ✓	
BLOCK AND TRANSVERSE CRACKING	10	0.4	0.7	1	0.5	0.7	1 ✓	
LONGITUDINAL JOINT CRACKING	5	0.4	0.7	1	0.5	0.7	1	
EDGE CRACKING	5	0.4	0.7	1	0.5	0.7	1	
RANDOM CRACKING	5	0.4	0.7	1	0.5	0.7	1 ✓	

*L = LOW **O = OCCASIONAL TOTAL DEDUCT =

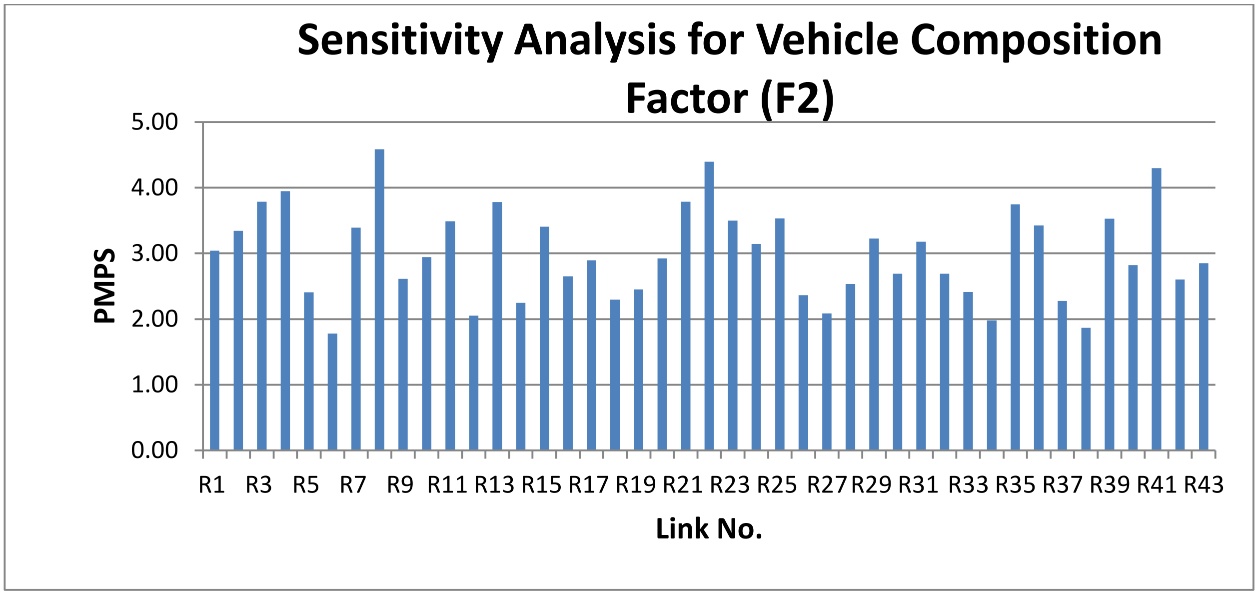
M = MEDIUM F = FREQUENT SUM OF STRUCTURAL DEDUCT (✓) =

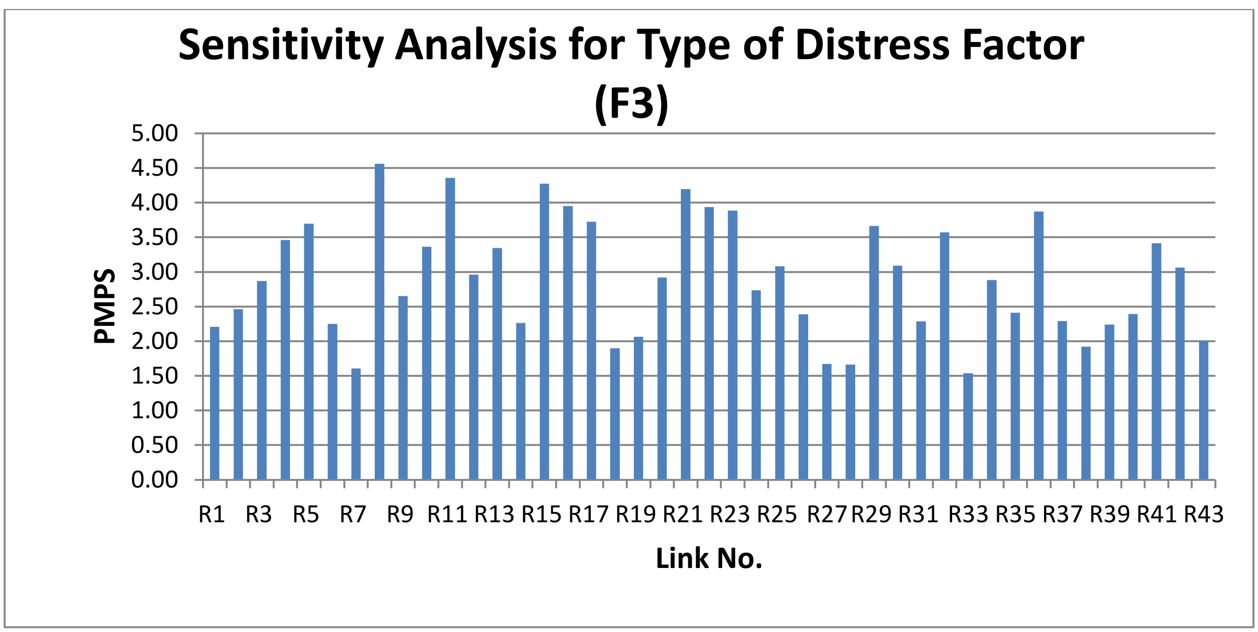
H = HIGH E = EXTENSIVE **100 - TOTAL DEDUCT = PCR =**

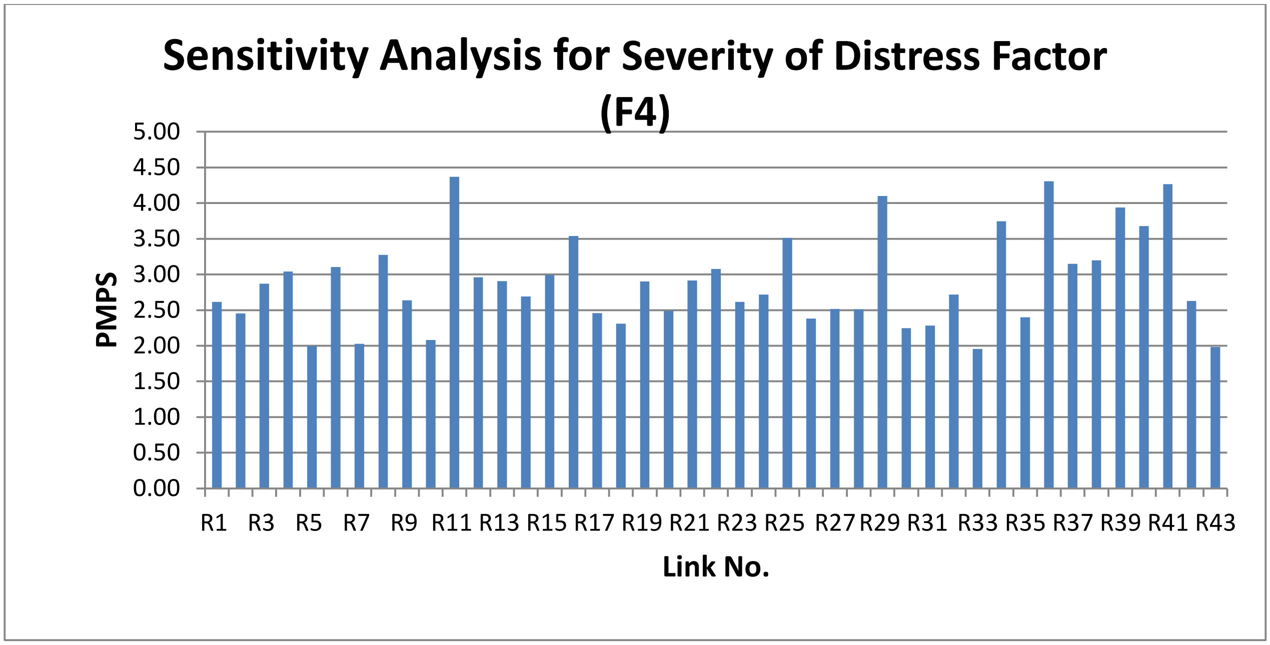
*** DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

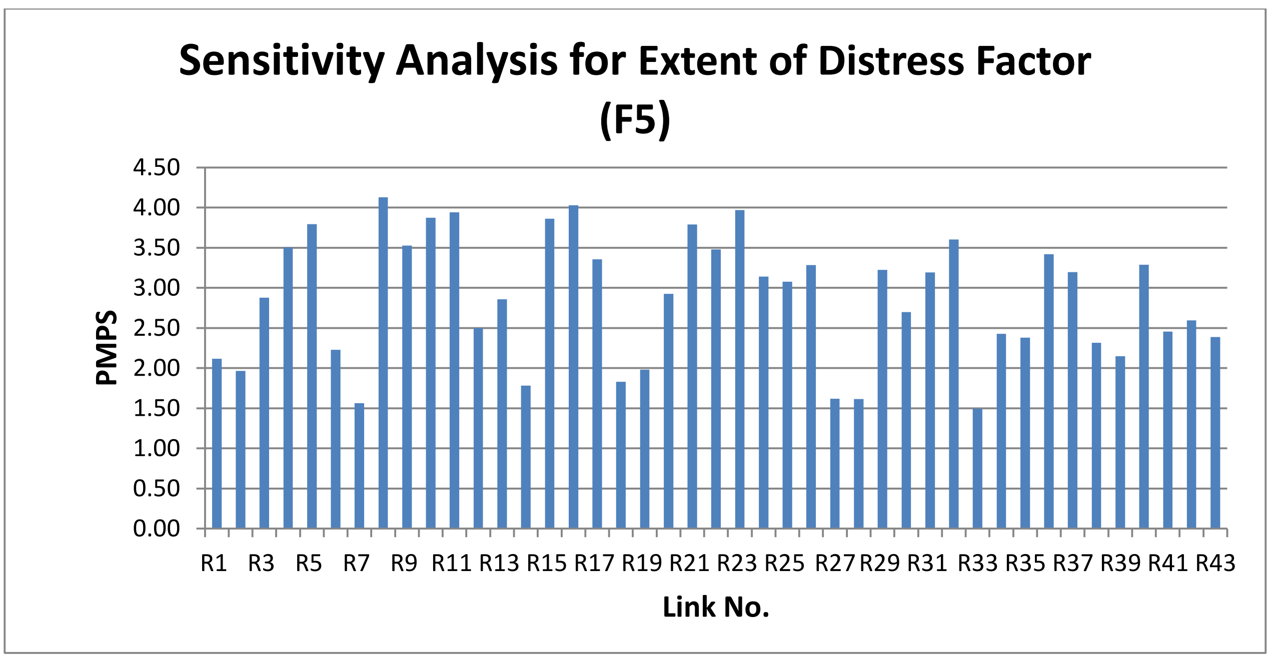
APPENDIX VII

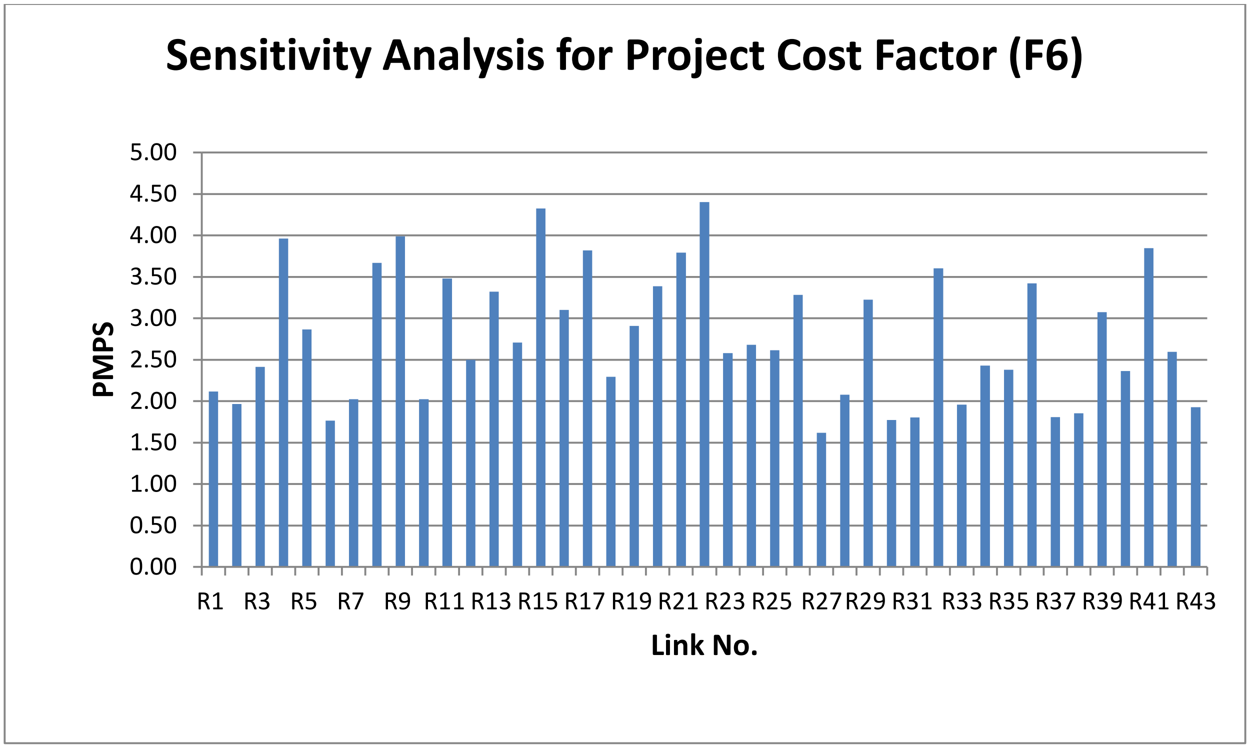
Sensitivity Analysis on Factors F2 to F9

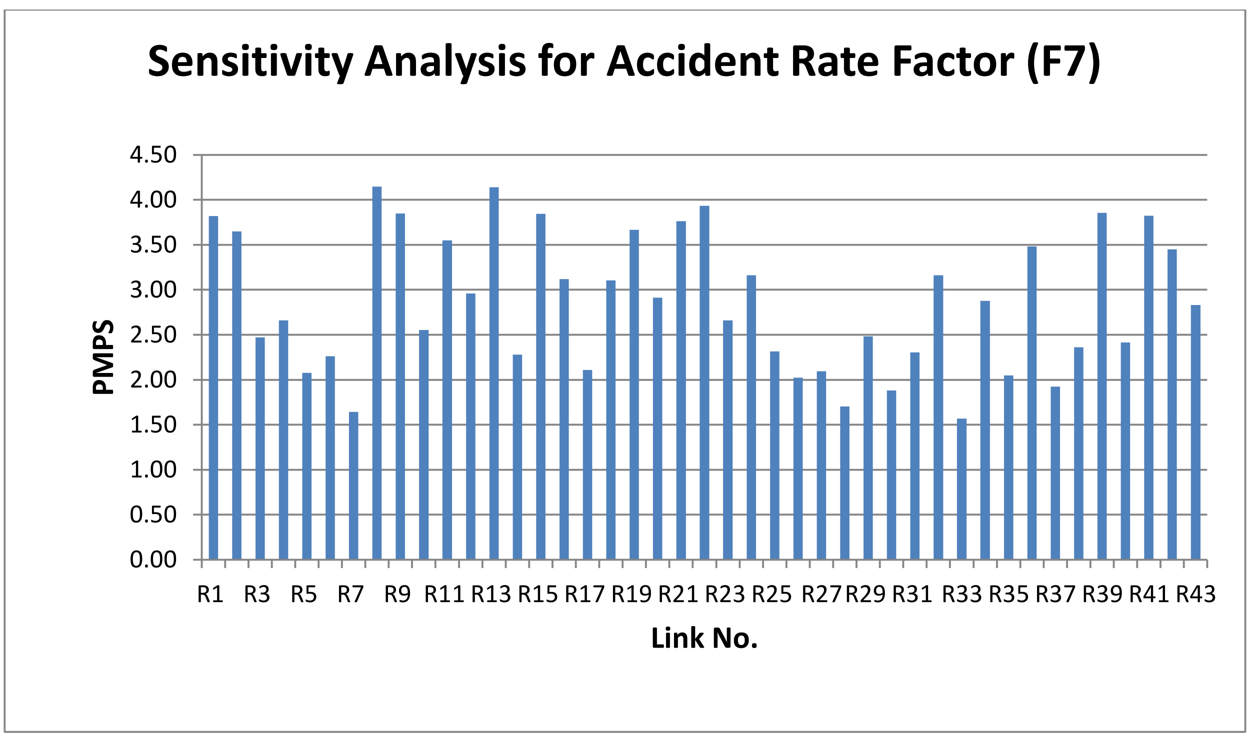


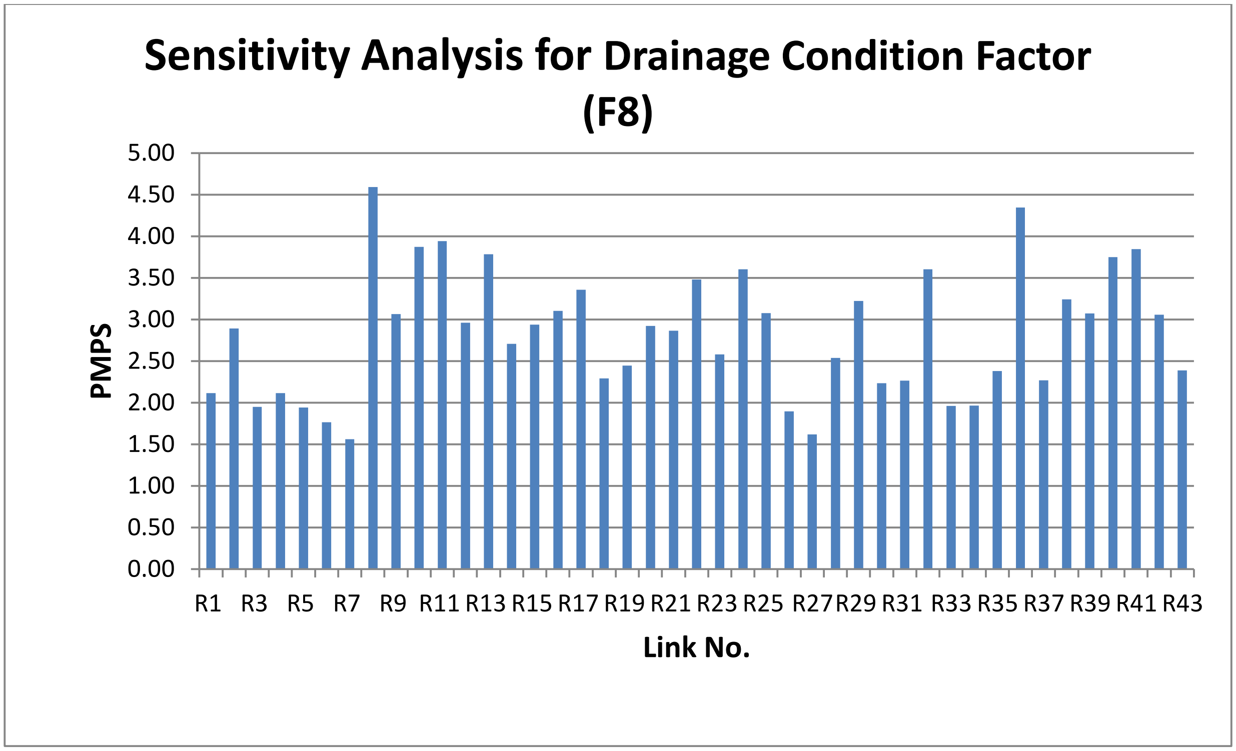


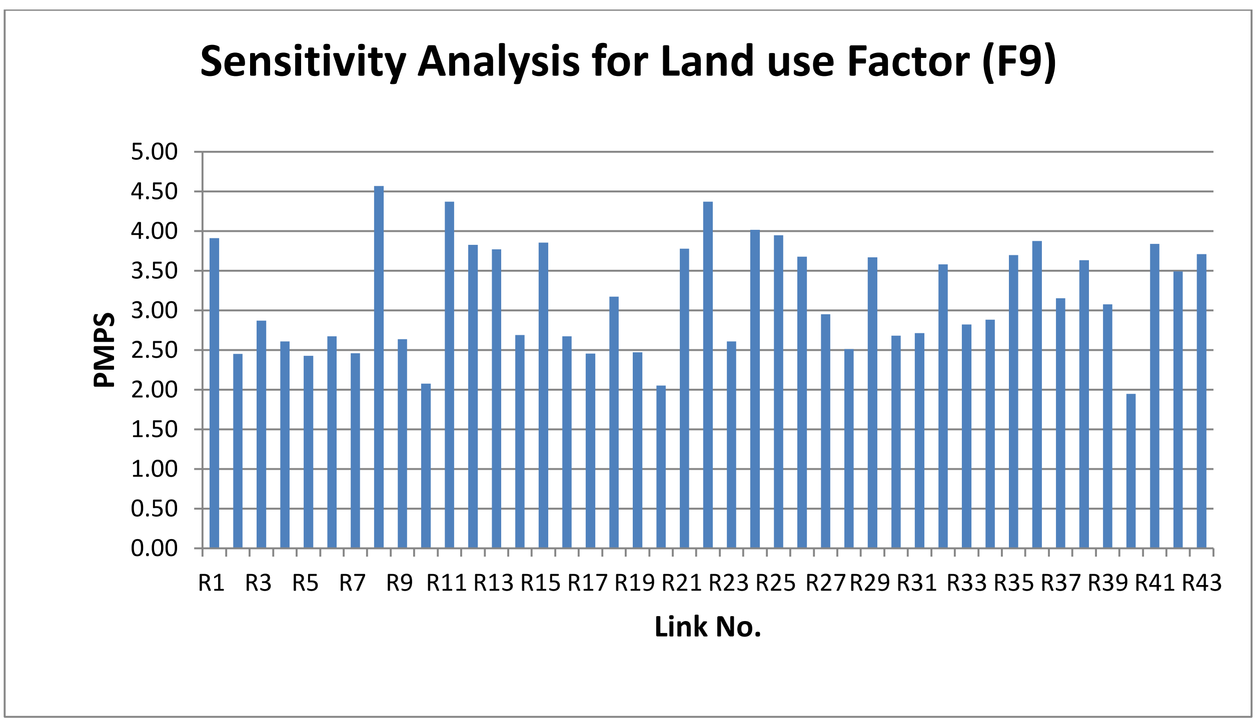

Sensitivity Analysis for Severity of Distress Factor (F4)
PMPS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.


Sensitivity Analysis for Extent of Distress Factor (F5)
PMPS
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.


Sensitivity Analysis for Project Cost Factor (F6)
PMPS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.


Sensitivity Analysis for Accident Rate Factor (F7)
PMPS
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.


Sensitivity Analysis for Drainage Condition Factor (F8)
PMPS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.


Sensitivity Analysis for Land use Factor (F9)
PMPS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R1 R3 R5 R7 R9 R11 R13 R15 R17 R19 R21 R23 R25 R27 R29 R31 R33 R35 R37 R39 R41 R43
Link No.